Modelling Community Disaster Resilience: A Participatory Approach

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DECLARATION

This is to certify that the copy of my thesis, which I have presented for consideration for my postgraduate degree: -

1. embodies the results of my own course of study and research
2. has been composed by myself
3. has been seen by my supervisor before presentation
4. has been granted the appropriate level of ethics approval

However, the author has published some of the material in peer-reviewed journal articles and are acknowledged in the thesis.

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The Author has published the following during the research, which constitutes outputs produced as part of this research.

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ABBREVIATIONS

AAR Anticipatory, Absorptive and Restorative Capacity
ABM Agent-Based Modelling
AKF Al Khidmat Foundation (NGO)
BNB Budni Nala Basin Case Study
C&W Communication and Works Department
CBO Community-Based Organization
CBSD Community Based System Dynamics
CC Climate Change
CCI Community Capacity Index
CCVA Climate Vulnerability and Capacity Assessment
CDR Community Disaster Resilience
CDRF Community Disaster Resilience Framework
CLD Causal Loop Diagrams
CoBRA Community-Based Resilience Analysis
CoPI Community of Practice and Interest
COVID Corona Viral Disease
DDMU District Disaster Management Unit
DEC Disaster Emergency Committee
DES Discrete Event Simulation
DRR Disaster Risk Reduction
EPA Environmental Protection Agency
EU European Union
FGD Focus Group Discussion
GMB Group Model Building
GNDR Global Network of Civil Society Organisations for Disaster Reduction
GOP Government of Pakistan
GUI Graphic User Interface
IDI In-Depth Interview
ILE Interactive Learning Environment
INGO International Non- Non-Governmental Organization
KP Khyber Pakhtunkhwa Province
MCEER Multidisciplinary Centre for Earthquake Engineering Research
MNA Member of National or Provincial Assembly,
NDMA National Disaster Management Authority
NGO Non- Non-Governmental Organization
NHA National Highway Authority
PDMA Provincial Disaster Management Authority
PHEOS Physical/Built, Health, Economic, Organizational and Social
PLL Peshawar Living Lab
PMD Pakistan Meteorological Department
PRISMA Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RC Resilience Capacity
SA Sensitivity Analysis
SD System Dynamics
SDG Sustainable Development Goals
SNA Social Network Analysis

SP System Performance
ST Systems Thinking
TAMD Tracking Adaptation and Measuring Development
UK United Kingdom
UN United Nations
UNDRR United Nations Office for Disaster Risk Reduction
UNISDR United Nations International Strategy for Disaster Reduction
UoP University of Peshawar
US United States of America
VC Village Council
VDMC Village Disaster Management Committee
WAPDA Water and Power Development Authority
WHO World Health Organization

ABSTRACT

Due to the increasingly complex nature of climate change impacts, decision-makers such as local government practitioners and community members need more inclusive tools to assess their communities' resilience to environmental risks and natural hazards. The implementation of the whole-of-society approach from international organisations like the United Nations Office for Disaster Risk Reduction (UNDRR), the Global Network of Civil Society Organisations for Disaster Reduction (GNDR) and the Disaster Emergency Committee (DEC) demands a more participatory and subjective approach to defining and evaluating community resilience to disasters. Each stakeholder group brings a different perspective to understanding their resilience issues, which typically cause significant debate or conflict on the policies needed to improve the community's resilience for long-term sustainable development and growth. The multi-disciplinary nature of resilience issues requires innovative techniques that can help capture multiple perspectives, the dynamic nature of community resilience at the local level, and the complexity of hazard impacts on a short- and long-term basis. This research aims to improve community resilience measurement by developing a novel Participatory Approach to Modelling Community Resilience to natural disasters associated with a simulation model that can be adapted and customised according to stakeholder specifications.

This research first analysed the key features and characteristics of 36 community disaster resilience (CDR) frameworks in the literature, which led to the clustering of six critical resilience dimensions (i.e. Physical, Health, Economic, Environmental, Social and Governance) with a library of 86 resilience indicators, composed of 360 measures. These indicators and measures were categorised into three community capacities (Anticipatory, Absorptive, and Restorative) and used as the basis for operationalising a CDR model according to the needs of the stakeholders. To overcome the objective and static nature of the current CDR frameworks, this research introduced a novel participatory approach which is comprised of two Phases: 1) Systems Thinking and Mapping to develop an understanding of community resilience with the target stakeholder groups of a disaster risk reduction intervention and determine the key dimensions of indicators (from the library) for the measurement of resilience capacities as parameters; and 2) System Design and Modelling, to use the parameters to formulate a System Dynamics (SD) model of community resilience over time, test and validate the SD

model of Community Resilience with stakeholders’ group in a case study. The case study implements the two-phased modelling approach developed in the research to model the impact of flash flooding disaster events in the Budni Nala neighbourhood in the City of Peshawar, Pakistan – a country ranked 8th in the World Climate Risk Index in 2023. The case study evaluates the Participatory Approach to Modelling Community Resilience with three stakeholder groups, Academics, Practitioners and Community members working on local resilience issues.

The first phase of the research uses Systems Thinking to customise the CDR framework according to stakeholder needs. Phase 1 uses 19 interviews to develop Causal Loop Diagrams of resilience issues to determine the dimensions to include in the model and 68 Q-Sort interviews, a methodology for ranking preferences, among the three stakeholder groups for developing a Community Capacity Index to model in the case study. The Capacities Index measures the resilience levels within the community dynamically over time as the community grows or falters. Phase 2 System Design and Modelling uses System Dynamics simulation modelling to develop the model of Community Resilience, using the dimensions and capacities identified in Phase 1, and to test and validate the model using three Focus Group Discussions with 18 participants drawn from the three stakeholder groups participating in the case study.

The SD model simulated three scenarios in the case study community to investigate the impact of disaster magnitude, relief delivery duration, and investment in adaptive capacity levels on community resilience over a one-year period. The three scenarios showed that improving communities' adaptive capacity can improve overall system resilience through different pathways: building physical infrastructure such as retention ponds, debris clearance to keep the waterways clear, and building up local capacity for preparedness and mitigation through training or increasing funds for preparedness and mitigation. This study's adaptable framework and participatory modelling approach demonstrate how greater stakeholder engagement in selecting the resilience indicators can better understand the local context of communities' risks, contribute to better intervention design, and improve mitigation and preparedness strategies.

Chapter 1 Introduction

1.1 Introduction

Since the beginning of the twenty-first century, more than two billion people have been directly impacted by recurring natural disasters, with the United Nations Office for Disaster Risk Reduction (UNDRR) indicating that total damages estimated at $ 2.5 trillion (till 2019), the majority of those affected living in developing countries (UNDRR, 2019). Due to the increasing frequency and magnitude of natural disasters occurring around the world (Ingirige et al., 2015), there is a growing need for local decision-makers, practitioners, and community members to better assess the disaster resilience of their communities from their perspectives and implement measures to reduce the impact on the economy and their citizens (Jones and Tanner, 2017, UNISDR, 2019). These stakeholders require clear methods to help them understand their risk profiles and to conduct assessments on the severity of the impact of natural disasters (Jones, 2019). Clarity on disaster risks can enable decision-makers to utilise the scarce resources available to implement disaster mitigation measures that could make their communities more resilient and sustainable over the long run (Almutairi et al., 2020).

Of all natural hazards, hydrological hazards alone are responsible for more than half of the natural disasters that have taken place over the last two decades (2000-2019), and a significant proportion of people affected by this type of disaster live in populated urban environments (Simonovic, 2012, Javelle et al., 2019). Trends like population growth, increased urbanisation, and the focus on economic development in urban areas as engines of economic growth have led to an ever-larger number of people living in and around the urban areas previously thought dangerous in terms of risk of flooding or other disasters like landslides, and coastal or tidal flooding (Smith, 2013, Almutairi et al., 2020).

Climate Change has further increased the frequency and intensity of disaster events, making the assessment and risk management of these events more challenging by adding a layer of uncertainty and complexity, requiring the development and use of additional tools to help understand them (Johnson, 2009, Clegg et al., 2019). In addition to this, disasters in urban areas are increasingly likely to have cascading impacts across the urban system with potentially devastating consequences (Dauelsberg and Outkin, 2005, Fekete, 2019). Cascading impacts across socioeconomic systems like urban and rural communities make measuring and quantifying concepts like community resilience particularly challenging and methodologically complex (Levine, 2014, Koliou et al., 2020). The complexity of impacts is further compounded by the increasing frequency of massive flood events like the recent 2022 Floods in Pakistan that directly affected more than 30 million people across the country, including significant impacts in urban areas (FCC, 2022, Harvey et al., 2022).

Building resilient communities is critical for sustaining and maintaining a healthy socioeconomic system of a nation since there is an inherent link between sustainability, development and resilience (Ramalingam, 2013). However, the sustainability of socioeconomic systems is continually challenged by increased urbanisation, natural or man-made disasters and the effects of climate change (Lannigan et al., 2014). Therefore, for the last two decades, researchers have investigated the concept of resilience to explain the impact of disasters on communities, and the ability of communities to withstand or respond to changes from those impacts (Ostadtaghizadeh et al., 2015, Serfilippi and Ramnath, 2018).

As Community Disaster Resilience (CDR) literature evolves, new research increasingly focuses on developing frameworks and tools to measure and classify community resilience (Sharifi, 2016, Cutter, 2018). Despite this growing importance, no clear procedure to define and measure CDR has emerged (Rogers, 2011, Patel et al., 2017, Jones et al., 2021a), with many different disciplinary and methodological approaches now being used in the literature (Koliou et al., 2018, Jones et al., 2021b).

There are many different perspectives among stakeholders on the understanding of resilience, which translates to varying views on measuring their community's resilience (Saja et al., 2018). Until both the scientific and the practitioner communities agree on the essential, integral focus of CDR, namely definitions, baseline attributes or dimensions, capacities and processes that emerge and develop in a community, the question of the resilience of whom and to what will remain a subject of debate (Cutter, 2016a). This research proposes an approach to define and measure community resilience from the perspective of different stakeholders and integrate those measures into a simulation model for testing potential stakeholder-defined scenarios or interventions.

1.1.1 Research Gap in Modelling Resilience

Local and national governments increasingly see building resilience as a core policy issue for sustainable growth and development at the community level (Grafton et al., 2019). Resilience programs and interventions aim to create stable, robust, resilient communities that anticipate and withstand the impacts of different hazards (UNDRR, 2022). Many scholars and policymakers have advocated the importance of assessing community resilience at the local levels (National Research Council, 2017, Cutter, 2018). Accordingly, the United Nations has made community resilience a vital component of the Sustainable Development Goals (SDGs) agenda (UNDRR, 2019). Specifically, as written in Target 1.5: "Build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters by 2030" (UN/ESCAP, 2015). Target 1.5, and others, has led to resilience becoming a core mechanism for intervention design by many international agencies working on disaster risk reduction, poverty, and sustainability issues (Serfilippi and Ramnath, 2018). The SDGs promote the overall resilience of communities, including marginal elements, to reduce the total exposure and vulnerability to extreme weather events and other social, environmental, health and economic shocks (UN/ESCAP, 2015). A recent report produced by the House of Lords Select Committee on Risk Assessment and Risk Planning in the UK (HLP, 2021) called for a whole-of-society approach that promotes an inclusive, participatory approach to solving complex community resilience issues.

Several recent reviews published on community disaster resilience frameworks have indicated that there are notable limitations such as their treatment of resilience as a static measure (Cutter, 2018, Assumma et al., 2019); their use of purely objective measures (Beauchamp et al., 2019, Jones et al., 2021b); and their inflexibility to suit local context by users (practitioner or community) (Herrera and Kopainsky, 2020, Marchal et al., 2023). Bruneau et al. (2003) stated that static resilience could be considered an attribute of a system that ignores complex inherent dynamics. It ignores the system structure and inter-relationships between system components and cannot capture interactions between system behaviour and the hazard or shock events (Bruneau and Reinhorn, 2007). Furthermore, static resilience cannot convey the dynamics of the recovery process and fails to identify when the system will recover to its normal functioning state. Moreover, it ignores the need to consider the impact of hazards in the short and long term due to climate change (Jackson, 2019).

Another critical limitation of a majority of CDR frameworks in the literature is the use of objective approaches that do not consider the community's perspectives, experiences or concerns (Clare et al., 2017). Recent emphasis by governments on the whole-of-society approach and the status of marginal populations has led to increased awareness of this shortcoming (HLP, 2021, UNDRR, 2022). Therefore, there is an increasing need for subjective methods involving stakeholders in defining the resilience indicators or measures relevant to their local context and assessing their local resilience through a participatory approach (Pagano et al., 2019). Such an inclusive approach has the potential to positively impact a community's overall resilience by contextualising local needs (Jones, 2019). Subjective approaches can lead to greater awareness of the community's resilience issues, improving the quality of interventions (Béné et al., 2019).

Accordingly, decision-makers require resilience frameworks or assessment approaches that can be customised through stakeholder participation and engagement. Resilience assessment frameworks, tools, and approaches can become more relevant if they capture the different mental models of various stakeholder groups to facilitate discussion and better consider their perspectives and requirements to reflect the local context (Clare et al., 2017, Jones, 2019). The concept of resilience can be viewed differently by various stakeholders, requiring an approach that carefully considers the questions of the resilience of whom and from what as part of the assessment process (Cutter, 2016b, Patel et al., 2017). Additionally, the focus of most CDR frameworks has predominantly been on a larger geographical or administrative unit, such as at the district, county, or metropolitan levels (Winderl, 2015, Links et al., 2017). Fewer frameworks focus on the local community level as defined by the lowest administrative unit, such as city block, election ward or village council (as per smallest administrative units in respective countries) (Irajifar et al., 2016). As most disaster risk reduction interventions have an impact at the smallest local levels, resilience frameworks designed with this scale in mind could be more relevant for local stakeholders to identify potential activities or actions that they could engage and participate in (Hovmand, 2014, Trani et al., 2019). Customisable local-level resilience frameworks represent a gap in the CDR and sustainable development literature (Clare et al., 2017, Titz et al., 2018, Jones, 2019).

Understanding and measuring CDR at the local community level is often characterised by limited technical knowledge and disagreement about the nature of resilience itself, particularly the goals required to achieve it (Reyers et al., 2015). Stakeholders may have several perspectives on understanding resilience (Abeling et al., 2018b). Diverse resilience worldviews may translate to different views on measuring community resilience, specifically for hard-to-define elements like social and human or health resilience (Saja et al., 2018). Stakeholders' perspective of community resilience includes their preferences concerning risk management and preparedness and the explicit interests and knowledge beneath these preferences (Raadgever et al., 2008). Stakeholder groups in the process discover that finding the "right solutions for the right problems" in terms of building community disaster resilience requires reaching an agreement on the goals of an assessment and, only then, the actual measures that can be used for that assessment (Reyers et al., 2015, Meerow and Newell, 2019).

Developing an overview of the different stakeholder perspectives can increase awareness of other groups' views, facilitate discussion and support critical reflection on the rationality behind stated positions (Luna-Reyes et al., 2012, Lacey, 2014a). Sharing diversity of opinions may result in a better mutual understanding and consensus between stakeholders and can be considered one of the primary benefits of using participatory modelling methods (Hovmand, 2014, Inam et al., 2015). As resilience can mean different things to stakeholders, there is an even greater need to develop and use an approach that can be adaptable and customisable to local contexts (Béné et al., 2016a, Patel et al., 2017). Customisation can help stakeholders choose what they mean by community disaster resilience – particularly to address the question of resilience to what and of whom (Cutter, 2016b). A resilience assessment based on participatory methods seeks to be more inclusive of the needs and perspectives of the community; hence the need to explore the development of resilience assessment approaches that can include subjective approaches for greater customisation and contextualisation at the community level (Jones, 2019).

Understanding resilience across multiple community systems and their environment is a priority for urban and disaster management authorities as resilience planning becomes part of policymaking at all levels (Clare et al., 2017, Dias et al., 2018). A systems approach is especially relevant for understanding resilience as there is considerable debate on the definition of CDR, indicating it is a complex concept that lies at the intersection of the social, health, economic, organisational and built/physical environments (Simonovic, 2016, Cutter, 2018, Tariq et al., 2020). To date, the resilience literature has not fully utilised the benefits of system approach to assess the resilience of communities and potential design interventions and has been found to focus on only a single aspect of the problem (Ramalingam, 2013, Jackson, 2019). According to Ramalingam (2013) and Stroh (2015), such narrow sectoral focus can sometimes lead to a misidentification of the real resilience issues or even result in unintended consequences that could le to the worsening of the problem. As the need for a more comprehensive and reliable understanding of the consequences of disaster risk reduction interventions on the impacts of natural and man-made disasters has grown, so has the interest in urban systems resilience modelling to facilitate well-informed planning and provide insights for decision-making (Irwin et al., 2016, Links et al., 2017, Almutairi et al., 2020). Most of these approaches focus on modelling physical infrastructure or economic resilience and leave dimensions like health and social resilience out or do not consider their influence and impact comprehensively enough – though this has changed due to the recent COVID-19 pandemic (Sahin et al., 2020, Alanazi et al., 2021).

This research will attempt to address some of the gaps identified in the community disaster resilience measurement and assessment literature: 1) the need for more user or stakeholder-centred approaches to resilience assessment that consider their perspectives on measuring local resilience; 2) the lack of CDR frameworks that can be adapted according to local conditions and contexts; 3) using an approach that captures the complexity of communities as systems (across multiple dimensions and capacities); and 4) an approach that considers CDR as dynamic and changing over time and not static. This research will focus on community resilience and its capacities as a critical element in understanding and planning for disaster risk reduction. It will also show how these capacities are linked across the community system and can help measure physical, health, economic and social resilience dimensions as required by the context in specific cases.

This research presents an approach using design science and systems science, called Systemic Design, which uses Systems Thinking and System Dynamics to develop a participatory community-level resilience modelling approach. The community-level modelling approach can consider the impact of a disaster event, such as a flood, on the physical, health, economic, environmental, social, and organisational dimensions and conduct a holistic analysis of a community's adaptive capacity and overall resilience. The primary motivation for using a Systemic Design approach is to employ a stakeholder or people-centred approach to understand the nature of hazard impacts across social, economic and built components of urban systems. Hovmand (2014) has shown that System Thinking (ST) and System Dynamics (SD) modelling can be used when dealing with complex, multi-stakeholder issues that require a multi-disciplinary approach. A participatory system dynamics approach can help map the relationships between these components from the point of view of experts in disaster resilience and the experience and knowledge of community members for a more subjective understanding of Community Resilience. The approach is well suited for capturing multiple perspectives due to its ability to study systems holistically as more than just a sum of its parts, contrary to other resilience frameworks and measurement approaches. Most conventional approaches focus solely on one part of the system and neglect to include feedback processes between variables while primarily using objective measures of community resilience (Sterman, 2006, Hovmand, 2014, Irwin et al., 2016).

Adopting a systemic design approach to community resilience assessment enables a more inclusive approach that captures the dynamics of community resilience over time as a pattern of behaviour in the system (Links et al., 2017). Using subjective means to capture perspectives on resilience also ensures that the assessment or measurement is grounded in local contexts and is relevant for intervention design and planning leading to greater chances of success in case of implementation (Jones, 2019). Accordingly, ST and SD can help researchers and participating stakeholder groups to work together and develop a participatory tool for community resilience assessment (Perrone et al., 2020). Using a participatory modelling approach that can be validated with participants from relevant stakeholder groups will enable the integration of local and expert knowledge and awareness of different perspectives among and within the groups. The proposed participatory SD model of CDR provides the foundation for developing decision-support tools for policymakers working on intervention design for disaster risk reduction and urban planning.

This study aims to utilise the approaches used in Systemic Design sciences to understand communities' hazard vulnerability and disaster resilience to natural disasters. It aims to explore applying a community-based participatory approach to understand hazards better and engage local stakeholders in assessing their resilience. This awareness can potentially assist intervention design and help build community resilience at the local level. The study aims to utilise elements from various works of literature and, through interviews, focus groups, and group model-building sessions with community members and experts in disaster resilience, develop a participatory modelling approach for quantifying resilience at the community level. The participatory modelling approach can estimate hazard impacts by measuring the loss in system resilience from the stakeholders' perspective, which could entail a better understanding of the critical elements that may lead to direct and indirect impacts on community systems. The participatory approach enables local stakeholder groups to define key resilience indicators and include critical parameters of community resilience, as determined by them, in a simulation model to ensure that the correct capacities are identified and addressed in future interventions.. Hence, unlike traditional CDR frameworks that mostly use objective measures of resilience, the participatory approach enables the inclusion of community perspectives, which is crucial for developing context-specific interventions.

In summary, this research aims to answer the research question "**What methods and tools are required to allow local stakeholders to understand, measure and model resilience against disasters (or shocks) and explore what-if scenarios for leverage points, that they can use for planning, advocacy and influencing policy to enhance their resilience?".**

1.2 Aims and Objectives

The aim of this research is to investigate methods and tools, or approaches, that local stakeholders can use to define, model, and measure their local resilience against climate-induced disasters (or any other shocks) and explore potential leverage points that can be used to enhance local resilience. This research intends to contribute to developing a participatory approach that uses quantitative-qualitative tools for CDR simulation modelling of resilience in urban systems. It will focus on the fundamentals of the systems approach to understanding resilience with application to urban systems after a hazard event.

This research aim will be achieved through the following research objectives:

1. To establish a library of indicators that local stakeholders can use to define and evaluate the resilience parameters of their community and its capacity to respond (anticipatory capacity), withstand (absorptive capacity), and recover (restorative capacity) from disasters or shocks.
2. To propose a participatory approach to modelling and operationalise resilience measurement for understanding resilience at the local level.
3. To investigate a participatory approach for customising resilience parameters (dimensions, capacities, and indicators) which are relevant to the local context being considered.
4. To create a computational model that can represent the dynamic nature of resilience parameters and simulate the level of resilience in the community at the local level.
5. To validate the above method and tools as an approach to understanding community-based resilience dynamics using a case study

1.2.1 Research Questions

The key questions in this research are:

RQ1: What are the indicators that can be used by local stakeholders to define and evaluate their disaster resilience?

RQ2: How can stakeholders customise disaster resilience parameters according to their preferences and the local contexts?

RQ3: How can community disaster resilience be modelled dynamically (over time) using resilience parameters?

RQ4: How can the participatory resilience assessment approach be validated?

1.3 Case Study

The research will develop the Participatory Approach to Modelling Community Resilience and evaluate it in a case study of flash flooding occurring in the Budhni Nala Basin (BNB) neighbourhood in Peshawar, Pakistan. Pakistan has been consistently ranked in the top ten countries on the Climate Risk Index since 2000 (Eckstein, 2021). In the past thirteen years, it has been severely affected by massive flood events (2010 and 2022), affecting millions of people and causing massive losses in infrastructure, agriculture and livelihoods (Waqas, 2022). The BNB is a neighbourhood in the north of Peshawar City that suffers from a higher frequency of flash flood impacts due to its geographical location, rapid urbanisation, and lack of urban planning mechanisms (Ali et al., 2022). Additionally, local community representatives have repeatedly raised concern and warned of another pending catastrophe due to recent large construction projects causing blockages in the local waterways (Khan et al., 2022). The BNB area was chosen for the case study due to the high risk of flooding, social and governance issues, interest from local communities to participate in the research and its relative proximity to local partner institutions like the University of Peshawar (UoP) and the Peshawar Living Lab (PLL). The locality is also well known to the researcher who has worked on a Water, Sanitation and Hygiene project in the area after the floods in 2010.

The case study will be used to explore and evaluate the Participatory Approach to Modelling Community Resilience in field settings. In particular, it will evaluate the use of the novel combination of Systems Thinking, Q methods and System Dynamics modelling to understand and measure resilience in a community at risk from urban flooding. Using this participatory mixed method approach enables qualitative data to parameterise the System Dynamics model used in the later stages. The application of the approach will help understand the local resilience issues faced by the community, the most vulnerable aspects, and their capacities to deal with hazards. The participatory approach seeks to engage community members, academics, and practitioners in the BNB area and determine how resilience should be defined and measured from their perspectives. The study will also look at the different policies proposed and implemented in the case study area to determine the impact (if any) on the current resilience capacities of the community. The learning and feedback during the case study will improve the design and future applications of the Participatory Approach to Modelling Community Resilience.

1.4 Research Approach

To address the research question and address the aims and objectives stated in Section 1.2, the research study will use the following methods as shown in Table 1-1.

Table 1-1 Research Objectives and Methods used in the research.

Research Objectives	Research Methods	Sample Size
Objective 1: Identify the initial library of indicators that local stakeholders can use to define and evaluate the resilience parameters of their community and its capacity to respond (anticipatory capacity), withstand (absorptive capacity), and recover (restorative capacity) from disasters or shocks	Literature review (PRISMA), Documents Analysis (Presented in Chapter 2)	36 frameworks for the Library of Indicators
Objective 2: To propose a participatory approach to modelling and operationalise resilience measurement for understanding resilience at the local levels	Literature review, document analysis, stakeholder consultation and feedback (Presented in Chapters 3, 4 and 7)	
Objective 3: To investigate a participatory approach for customising resilience parameters (dimensions, capacities, and indicators) which are relevant to the local context being considered	Semi-structured interviews, Causal Loop Diagramming (CLDs), Focus Group Discussions (FGDs), Q-methods. (Presented in Chapters 4 and 5)	CLDs (19 interviews) Q sorts (68 interviews) 2 FGD (11 participants in total)
Objective 4: To create a computational model that can compare the dynamic nature of resilience parameters and simulate the level of resilience in the community at the local level	Stakeholder consultation, Group Model Building (GMB), System Dynamics Simulation Model (Presented in Chapters 4 and 6)	
Objective 5: To validate the above method and tools as an approach to understanding community-based resilience dynamics using a case study	Causal Loop Diagramming (CLDs), Focus Group Discussions (FGDs) System Dynamics Simulation Model (Presented in Chapters 5 and 6)	Validation FGD (8 participants)

The first objective is covered in Chapter 2, Literature Review and is part of Knowledge Acquisition or Problem Identification. This chapter will conduct a literature review on CDR frameworks published from 2005 to 2020 to identify the state of the art, gaps, and potential avenues for designing a participatory modelling approach for resilience measurement. The review will be limited to articles published recently (last 15 years) and focused on local level community resilience. The literature review focuses on studies related to community-level resilience modelling, participatory approaches, and system dynamics to maintain relevance to the research objectives. The review will explore the relative lack of subjective approaches to measuring resilience in the **literature** and the justification for the Participatory Approach to Modelling Community Resilience. This stage will also lead to the development of the Library of Indicators, which can be used in the subsequent phases of the study. This part of the research led to a journal publication on the Adaptable Community Resilience Approach (Tariq et al., 2021c). Accordingly, a broader theoretical analysis of resilience is beyond the scope of this study as the focus is on practical, community-based resilience modelling and assessment methods.

Chapter 3, Research Design and Methodology (not shown in Table 1-1), will provide the research philosophy, the Systemic Design approach, and the systems methods used in the research. It will also discuss the case study that will be used for evaluating the design of the proposed approach. The second objective was to propose a design for the Participatory Approach to Modelling Community Resilience and will be detailed in Chapter 4. The Approach is divided into two Phases: 1) Systems Thinking (ST) and Mapping, a qualitative assessment of the resilience issues and the development of a community index for resilience measurement, and 2) System Design and Modelling for the development and testing of the simulation model of community resilience.

Phase 1 on ST and Mapping will be evaluated in the case study in Chapter 5. In this Phase, interviews/FGDs will be conducted (resulting in CLDs), the hazard and its impacts will be defined, and Q-Sort interviews will be conducted to develop the community capacity index to measure resilience. Subsequently, Chapter 6 will evaluate Phase 2 on the System Design and Modelling Phase and will use the outputs from Phase 1 to develop and test the system dynamics simulation model of community resilience. At this stage, several scenarios will be tested to demonstrate “what-if” policy interventions and the results will be verified with experts before sharing in a validation workshop. Throughout Chapters 5 and 6, the CLDs, the Index and the model will be shared for validation in Focus Group Discussions (FGDs) with stakeholders from the three primary stakeholder groups (academics, practitioners, and community members) in the case study. At the end of Chapter 6, the overall Participatory Approach to Modelling Community Resilience will be evaluated in a Validation Workshop FGD for further feedback and improvement. The feedback on the approach will be included in Chapter 7, which will conclude the research and will describe how each objective in the study will be achieved.

Table 1-1 also shows how many respondents participated in the study across the different stages of the research. Interviews, Focus Group Discussions and Causal Loop Diagrams were used for Systems Thinking and Mapping. Q Sort Interviews were used for Index Formulation and deriving weights for the model parameters. FGDs/Group Model Building Sessions were used in the System Design and Modelling Phase of the research to test and validate the model and were also used in the final Validation Workshop.

1.5 Contribution to Knowledge

This study will help develop a participatory approach to assess community resilience at the local level. The research will address a gap in resilience measurement literature dominated by objective measures defining and evaluating community resilience. The Participatory Approach to Modelling Community Resilience developed and used in this research uses subjective measures to develop a resilience assessment tool. It takes a holistic understanding of hazard impacts across the social, economic, and built environments, particularly emphasising the role of community resilience capacities at the local level. In the long run, this study will provide a foundation for developing a viable framework and model for use by resilience stakeholders or communities for disaster resilience planning and potentially contribute to their ability to influence policy. One of the key contributions of the research would be to develop an easy-to-learn and use participatory approach to understand CDR issues at the community level for community-based organisations or public sector organisations interested in building resilience at the local level. The study also introduces a novel approach using primary data from Q methods to derive weights for resilience parameters to model community resilience. The simulation model can be used to run scenarios and test their capacities to anticipate, cope with, and recover from hazard events and shock. The study seeks to contribute to existing resilience frameworks literature by providing an approach that allows customisation through participatory methods and operationalising resilience in a model for greater stakeholder engagement and discussion. The findings of this research can be used to develop a bottom-up, stakeholder-centred approach to measuring impact. This approach can be used for decision-making to allocate limited resources to mitigation strategies for building resilience in urban communities.

1.5.1 Challenges and Limitations

The Participatory Approach proposed in this research is designed to be flexible and adaptable to user needs, but notable challenges were faced during the study. Resource constraints and time limitations were faced due to the COVID-19 pandemic, which impacted the execution of the study concerning the participation of the stakeholder groups in the study (details in Chapter 7). Despite this, significant engagement was achieved in a much shorter time frame, and the study was completed satisfactorily.

In addition to these challenges, the following limitations must also be considered:

Case Study Specification: The Participatory Approach developed in this study has been evaluated using one case study, and this is justified in the research design as a typical case of a high-risk community. Although this is sufficient for the purposes of this thesis, the research would have benefited from an additional case study. Using the Approach in different settings will provide additional validity and may lead to further improvements. A second case study is planned for future work.

Data Availability: Data for the resilience indicators used in the study were not easily available for the case study area. This is a common problem for resilience frameworks, and system dynamics modelling enables the use of expert opinion and stakeholder inputs to determine model parameters. These parameters were then tested for sensitivity analysis in the model and compared to historical data for ground truthing before being used in scenario building. Again, this is sufficient for the purpose of this study and future studies may require a field survey in the case study area to provide additional data to address the gap.

Model Specification: The study focuses on local community resilience in urban settings, particularly in response to natural hazards, such as floods. Therefore, this research will neither result in a comprehensive detailed city level system dynamics model for disaster impacts across multiple neighbourhood levels and larger geographic areas, nor will cover non-natural hazards, or long-term economic impacts unrelated to disaster recovery, although in future work the output from this research could be expanded to cover such issues.

Lack of Gender balance in the sample: Due to the conservative nature of Pakistani society, even more so among the Pashtun people of Peshawar, there is strict gender segregation in most social settings. Therefore, it has been difficult to include more females in the sample. As the case study focused on flash flooding and its impact across the community as a whole and not on the impacts on specific sub-groups, the lack of female participants in the modelling process was mitigated somewhat. Other limitations are considered in more detail in Chapter 7.

1.6 Summary and Outline of the Research

The current research attempts to address the gap in community disaster resilience literature that uses subjective approaches to define and evaluate community disaster resilience from the point of view of key stakeholders (local government, disaster management authorities and community members). The thesis uses various methods, including literature review, in-depth interviews, focus group discussions, group model building and system dynamics modelling to achieve its stated aim and objectives. The overall structure of the thesis is shown in Figure 1.2 below.

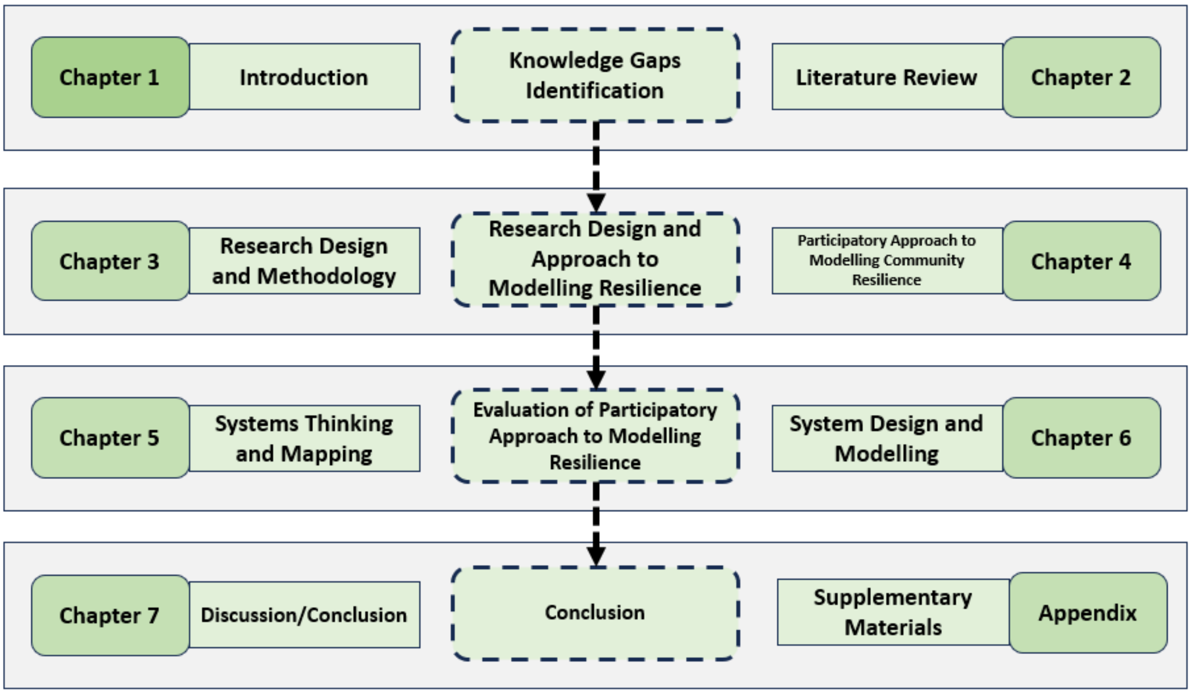


Figure 1-1 Outline of the Thesis.

This thesis consists of seven chapters. The first chapter introduces the research, while Chapter 2 reveals some of the gaps in the literature, and develops the Library of Indicators used in the literature to measure CDR. Chapter 3 provides an overview of the research design and methodology used in the thesis as well as the research setting of the case study. Chapter 4 develops the Design of the Participatory Approach to Model Community Resilience used in the research. Chapter 5 evaluates the System Thinking and Mapping Phase required for understanding the local contexts of resilience and selecting the appropriate Resilience Dimensions and Indicators for further investigation in the study. Chapter 6 evaluates the System Design and Modelling Phase of the Approach and uses the findings from the previous Chapters to develop a System Dynamics Model of Community Resilience of the Case Study Area and reports on the Validation Workshop used in the study. Finally, Chapter 7 discusses how the research objectives were achieved, followed by the conclusion and potential future work applications.

Chapter 2 Literature Review

2.1 Introduction

Measuring Community Disaster Resilience (CDR) at the local level has become increasingly important for local disaster management authorities and other agencies, as reflected in the SDG goals and the international agreements on disaster risk reduction and climate change (UNDRR, 2022). This importance can also be seen in the number of frameworks, models, scorecards, indexes and toolkits recently published in academic journal articles, theses and grey literature, such as official government or private sector reports (Serfilippi and Ramnath, 2018). These sources cover various community dimensions and use diverse methodological approaches (Saja et al., 2018). Despite this large body of literature, operationalising the concept for practical implementation is still challenging. CDR frameworks have thus far found limited success in becoming an essential part of the resilience assessment and intervention design process by the most concerned stakeholders, such as local disaster management practitioners and the community members themselves (Jones, 2019).

This chapter will review the CDR literature and the frameworks to measure it to develop an adaptable approach to modelling community resilience. The first section will examine the general concept of community disaster resilience, including its definitions, characteristics and components. The second section conducts a systematic review of current CDR frameworks, especially those that have been applied successfully to measure resilience at the community level. The review classifies the frameworks based on how CDR is defined (what dimensions or categories are used to characterise resilience) and how CDR is measured or evaluated (what measures or indicators are used in these frameworks).

2.2 Community Disaster Resilience as a Concept

Considering community disaster resilience from a participatory approach requires a robust understanding of the concept of community as it is defined in the various associated literature and how it is conceptualised for disaster resilience. This section looks at its definitions, its conceptualisation in disaster research and the relevance of this diversity for the research study. This section begins with a brief discussion on "community" and "disasters" to set the tone for reviewing the definitions and the literature on CDR frameworks in the next section.

2.2.1 Community

Considering community disaster resilience from a participatory approach requires a robust understanding of the concept of community as it is defined in the various associated literature and how it is conceptualised for disaster resilience. This section looks at its definitions, its conceptualisation in disaster research and the relevance of this diversity for the research study.

2.2.1.1 Definitions of Community

In developing participatory tools for resilience assessments, it is vital to conceptualise the concept of the community clearly to achieve both the right type of engagement and the assessment of the correct type of community as envisioned by the researchers (Hovmand, 2014). In the literature, this may reflect the resilience of whom and to what questions (Cutter, 2016b)The first step in applying the community-based approach proposed in the present study is to comprehensively define and conceptualise the term community.

A community can mean many different things to researchers, practitioners and "community" members, depending on their disciplinary backgrounds, experiences and geographical or cultural identities (Titz et al., 2018). Table 2-1 below summarises some of these concepts.

Table 2-1 Conceptual understanding of community in the literature

Conceptual understanding	Sources
Local Scale of Analysis	Norris et al. (2008), Berkes and Ross (2016), Kruse et al. (2017)
A Network of actors	Clark (2009), Barrett et al. (2011), Pauwelussen (2016)
Social Structures within a specific place	Theodori (2005), McManus et al. (2012)
Interrelations between people	Clark (2009), Beaumont and Brown (2018)
Act of Speech/Power	(Hovmand, 2013)
Networks of specific types of actors	Wenger (2000), Cox (2005)

Groups of people sharing attachment to a place	Gurney et al. (2017)
Groups of people sharing attachment to a cultural or religious belief/practice or a shared identity	Kuecker et al. (2010)
Multi-level Communities that are a combination of two or more of the above	Hunter (2018)

The table above summarises the different approaches used by researchers in trying to conceptualise community either from a geographical locality perspective, a network perspective, a shared identity perspective, or a combination of two or more of the above (Gurney et al., 2017, Kruse et al., 2017). The concept has been covered extensively in social science research and is considered a complex concept with many layers due to its broad understanding in the sociology and anthropology literature (Brint, 2001, Hunter, 2018).

In disaster management research, it is commonly understood as a geographical locality (Kruse et al., 2017). Surprisingly, since the community is a keyword in disaster research, fewer disaster management (DM) scholars have explored the concept in greater detail, at least compared to the social sciences from which the DM field can benefit (Räsänen et al., 2020). Several disaster management scholars have focused their research on networks of specific types of actors, such as a community of practice (Cox, 2005) or a network of actors working towards a common goal (Pauwelussen, 2016). Additionally, following the development of theories of social capital in disasters (Aldrich and Meyer, 2014) and social network analysis as a valued research method in disaster management (Jones and Faas, 2016), considerable emphasis has been placed on interrelationships within networks and between networks, particularly for inter-agency collaboration throughout the disaster cycle (Meyer, 2018)Hovmand (2013) also makes an important observation about defining community as a "speech" act and an act of power. The meaning of community can be extended by saying what it means and actively including (or excluding) people or organisations by stating membership (or lack thereof) clearly at the outset.

In a comprehensive review of the concept of community in social science research, Hunter (2018) has indicated that community is a multi-level concept and suggested that a community could be an object, a thing, a unit of social organisation or even a quality. This relatively open-ended conceptualisation of community allows researchers to understand community as having multiple layers linking two or more of the above understandings from the literature. It can enable stakeholders to self-define what community means to them. Researchers need to classify resilience in clear, easy-to-understand and use terms to develop a process where stakeholders can self-identify a practical understanding of the community.

More recently, Räsänen et al. (2020) have used a simple and intuitive classification system that describes three different types of communities in disaster research, as shown in Table 2-2. The classification sorts community conceptualisations into place-based, interaction-based, or community of practice and interest (Räsänen et al., 2020).

Table 2-2 Description of the types of community. Adapted from Räsänen et al. (2020)

Description of the three types of community	
Type of Community	Description
Place-based Community	Spatially defined entities, including the totality of individuals and social structures within a geographical location
Interaction-based Community	Network of interactions between people
Community of practice and interest	Network of specialised or professional actors that engage in common actions

Place-based community refers to those geographical, administrative and political boundaries that differentiate one community from another. For example, a village community, a local council or a neighbourhood includes citizens, governmental and non-governmental organisations, social and economic institutions, and local authorities. Studies using place-based community classification are more prevalent in the literature and include disaster management literature that uses index or scorecards for resilience assessments like the CDR frameworks (CDRF) covered in more detail in section 2.3 in this chapter. Such frameworks usually use spatially defined entities with administrative boundaries as proxies for the community and use multiple dimensions like social, human, economic and environmental dimensions to represent community attributes (Cimellaro et al., 2010, Thayaparan et al., 2016). Interventions or policies that improve these dimensions improve overall resilience (Cutter, 2016a). This definition will find the most use in DRR and resilience-building research and is one of the most cited concepts of community appearing in the literature (Kruse et al., 2017).

The interaction-based community type refers specifically to networks of relationships between people, regardless of geographic proximity and can usually be analysed as a social network. For example, these include formal and informal cooperative arrangements, such as diaspora members living away from the physical community or even interaction forums, civil society groups and movements that may encourage DRR or other resilience-building interventions. Research utilising interaction-based community can be seen in disaster management literature exploring the concept of social capital (Kääriäinen and Lehtonen, 2006) and its impact on DRR, response and recovery (Aldrich and Meyer, 2014). Scholars like Aldrich and Meyer (2014) use the concept to explore strong and weak social networks (described as bonding and bridging capital, respectively) and power relationships (called linking capital) and their impact on disaster preparedness and other aspects of the community's response. Power relationships between actors and their networks are difficult to conceptualise. Using the interaction-based community concept has helped deal with some of the complexity by analysing network bonds between actors in the disaster management system (Meyer, 2018). This definition can be used when a broader approach to community needs to be defined, such as collaboration and research networks, practitioner associations and international NGOs working on resilience projects (Pauwelussen, 2016).

Community of Practice and Interest (CoPI) refers to a network of specialised actors that work on a specific practice or share goals towards a common objective. For example, an organisation or group working towards DRR in an area or on a particular hazard. CoPIs include networks or groups with shared identities like faith groups, popular culture groups and sports teams (Beaumont and Brown, 2018). CoPIs can be used when exploring the perspectives or viewpoints of specific groups of stakeholders. They can be utilised in research to classify different stakeholder groups and their preferences for defining and measuring community disaster resilience (Huggins et al., 2015).

Researchers using CoPI analyse specialised networks of actors. They can be differentiated from interaction-based communities by a clearly defined purpose of the interaction, such as academic and practitioner groups working in DRR or preparedness (Huggins et al., 2015). In disaster management literature, the CoPI concept has helped look at learning within the community. For example, several studies have focused on how well the CoPI are prepared for, respond to and learn from the experience of disasters (Gimenez et al., 2017).

Systems Approach to Defining Community

Finally, Hovmand (2014) states the importance of how researchers define the community as it determines who is involved in the process, who the stakeholders are, how the issues are framed, how we understand the power dynamics, and even what language is used. For a participatory modelling approach, this distinction determines the type and level of engagement required with community stakeholders (Trani et al., 2016). For Community Resilience, which could be seen as a combination of the different types of "communities" described above (or even as one type if the research question determines it so), perhaps a broader or more holistic approach to defining it might be more appropriate (Ramalingam, 2013).

Accordingly, some researchers like Amadei (2020) have proposed a systems approach to understanding and defining what a community is. In systems science research, a system is a collection of parts that make up a whole and can be classified as a simple system containing one system or a complex system comprising many sub-systems. In terms of community, a system could be "…an assembly of interacting organisations, households, and individuals with a mutual sense of belonging and common interests…" interacting in a system designed to attain some goals (Amadei, 2020). In general, a community system has some general features, as indicated in Table 2-3, that can be used to understand the level of complexity involved.

Table 2-3 General Features of a Community as a System (Amadei, 2020)

Features	Explanation
1. Multiple Components	Consists of various components (social, economic, institutional, environmental, and others) that all interact in complex and uncertain ways.
2. Interacting units	Consist of interacting units called organisations, households, or individuals (depending on scale and unit of analysis)
3. Multiple scales	Interact with other communities at the local, regional, or global scales
4. Attributes of Complexity	Manifest all the attributes of complex dynamic systems (e.g., non-linearity, emergence, uncertainty, and synergy where the behaviour of the whole can be quite different from that of its components)
5. Initial Capacities	Possess capacity (strength), resources, assets (capital), and knowledge.
6. Collective action	Show some form of spirit, engagement, cohesion, and collective action (social capital).
7. Vulnerabilities	They have needs and are vulnerable to various adverse events ranging from everyday issues to significant disaster events, each carrying a certain level of risk for the community.

Others in the literature, like Simonovic (2011), Ramalingam (2013) and Onyeagoziri et al. (2021), also indicate the benefits of using the definition of a system as it acknowledges communities as complex adaptive systems comprising multiple sub-systems and parts that are interconnected, driven by some purpose, follow specific rules, and interact with each other and their surrounding environment. Therefore, communities are complex, open, adaptive, and dynamic social organisations with unique characteristics, needs, challenges, and potential solutions to their problems. The research must accommodate complexity and uncertainty for researchers to address community resilience issues (and other problems) successfully.

The present research intends to use a broader understanding of community to include its complexity and many elements to understand its resilience better. Thus, it requires clarity on the conceptualisation and type of community being considered. In a seminal article on the need for clarity when using the concept of community resilience, Cutter (2016b) asks the question, "the Resilience of Whom? And the Resilience of What?". Any research on community resilience must consider these questions before attempting to measure the concept. The section attempts to clarify the resilience of whom questions when resilience assessment tools are being developed. (Sturgess and Sparrey, 2016). Following this, the next section will address the question of resilience to what, as raised in the literature.

2.2.2 Disasters (and Complexity)

As mentioned in the previous section, communities are complex systems due to the multiple sub-systems that comprise a community, like natural, physical, social, and human systems. Community complexity is further compounded by the multi-dimensional nature of disasters and their impact on multiple sub-systems in the community; hence, disaster management is inherently the study of complex systems (Coppola, 2015).

Simonovic (2011) has identified this increase in complexity of disaster management across three interlinked developments that have occurred over time in the last half-century – 1) an increase in domain complexity due to rapid urbanization, diversity of stakeholders and uncertainty from climate change; 2) increased computation power available to researchers investigating disasters; and 3) increased complexity of modelling tools that are now easily available for use by researchers to apply to disaster management issues – as shown in Figure 2-1. For example, new simulation software requiring no programming experience on the user's part has made using these complex tools easier. Researchers can now use modelling tools such as AnyLogic, STELLA and Vensim for conducting analysis using Social Network Analysis (SNA), Systems Thinking & System Dynamics (ST & SD), Discrete Event Simulation (DES), and Agent-Based Modelling (ABM) to better understand, measure and analyse the increasing complexity of disasters (Sharifi, 2016).

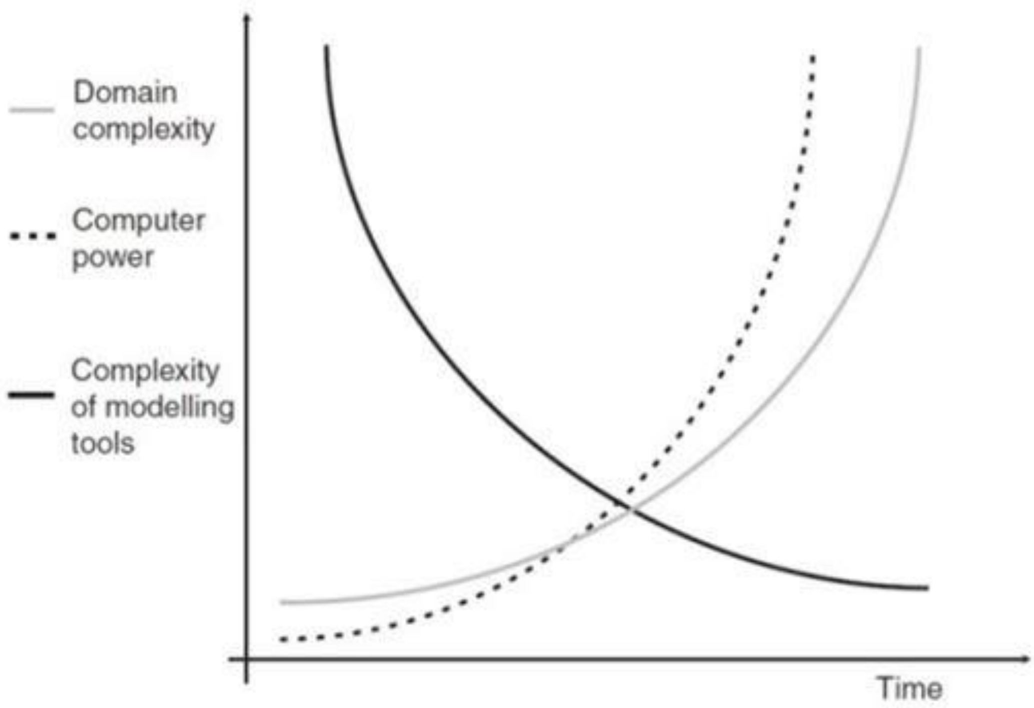


Figure 2-1 Increasing complexity in the field of disaster management (Simonovic 2011, p. 22)

Disasters are becoming increasingly complex due to the different human, social and technical systems becoming more and more interlinked together in urban systems (Aumann, 2007). Smith (2015) has illustrated in Figure 2-2 how the interconnectivity between physical, human, and technical systems can be understood and modelled as a DNA strand where feedback, inter-dependencies and cascading effects can be seen across community systems. Accordingly, disaster impacts on a community can vary and have different outcomes at different times and places due to the complex interactions between individuals, government agencies and private organizations. For example, these complex interactions could range from differing levels of communication among these actors to the existence or absence of social bonds and networks or the extent of awareness of each other's roles and functions (Therrien et al., 2019).

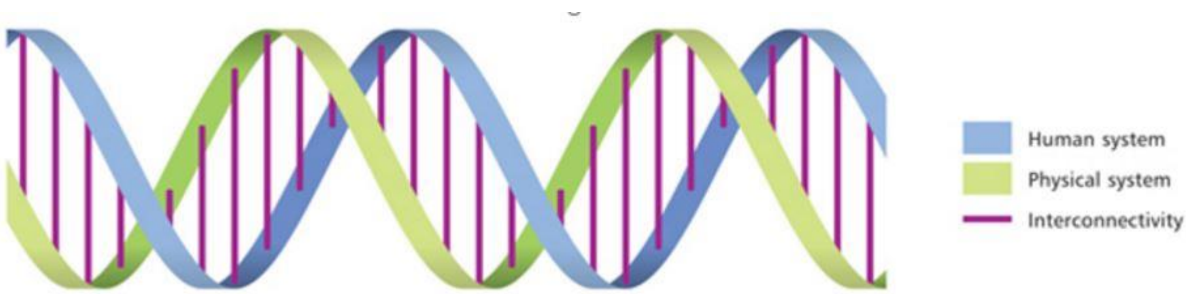


Figure 2-2 DNA strand model of complexity and disaster causation showing interconnectivity between the Human and Physical systems (Smith, 2015, p.14)

To measure and understand the impacts of disasters on a community, we need a concept like community resilience that can bring together the different strands of complexity of human and physical systems and help us interpret the core features that make communities resilient. Disaster management has embraced the concept of resilience, as demonstrated by the literature published over the last two decades. A subsection of it will be reviewed in the next section.

2.2.3 Resilience

Resilience has been a central concept in disaster management for the last decade and has found increasing popularity in journal articles, reports and dialogues by academics, practitioners and even community members. Despite this widespread use, there is still little consensus on its precise definition and measurement. The operationalisation of the term remains challenging due to methodological and conceptual approaches and perspectives of different stakeholders like academics, practitioners and community members themselves (Saja et al., 2018). This section looks at the historical evolution of the term itself in the various disciplines as it has developed, focusing on disaster management academic and grey literature and the core elements of resilience as revealed in that literature. It starts with discussing the definitions and core aspects of resilience and how resilience has been operationalised in the literature. Then, the section focuses on Community Disaster Resilience Frameworks (CDRF) selected by a systematic literature review. The review looks at these frameworks' methodological approaches, their core dimensions or categories covered, and the level of subjective and objective methods used to evaluate community resilience. After consolidating the review, the gaps will be identified and how the approach used in this study can address some of those gaps.

2.2.3.1 Definitions

Although there is some debate on the origin of the term resilience in its modern form, there is agreement on its linguistic roots. Resilience originally stems from the Latin term *resiliere*, to bounce, and *resilio* for jumping or bouncing back (Klein et al., 2003). Alexander (2013), in his seminal work on "Resilience and disaster risk reduction; an etymological journey", he traced the term as far back as writings of philosophers of Classic times (circa. 1st century AD) like Seneca the Elder, Pliny the Elder, Ovid, Cicero and Livy where the term was used to describe rebounding or jumping back. In its modern form, resilience was perhaps first used in the 17th Century in the writings of Sir Francis Bacon, one of the pioneers of the modern scientific method, who used it to describe the strength of echoes in his compendium of essays on natural history, the *Sylva Sylvarum* in 1625. Subsequently, it continued to be used, albeit sparingly, by Scottish natural philosophers, where the term was used to describe the property of rebounding and elasticity and, curiously, to go back on one's words – a rare negative connotation of the term (Alexander, 2013).

The term then appears consistently in the field of mechanics being used by William Rankine (1820-72), an eminent Scottish engineer, for the strength and ductile properties of steel beams. Interestingly, for disaster management, the term found use early on in describing the fortitude of populations to recover from adversity and was used by American naval officers to describe the citizens of the city of Shinoda, Japan, as they saw them recover from the impacts of two devastating earthquakes in 1854 (Perry and Tomes, 1857, Alexander, 2013).

From mechanics, some scholars say it was applied to psychology and psychiatry, featuring mainly in the works of Norman Garmezy, Emmy Werner and Ruth Smith on their groundbreaking work on risk, resilience, coping and stress in child development (Waller, 2001). Others, like Folke et al. (2002), attribute its emergence from mechanics to the systems approach to ecology introduced by Holling (1973), who is credited for using the term in its modern sense in his seminal work "Resilience and Stability of ecological systems". However, Lindseth (2011) suggests it was used in ecology for several years before Holling made it more prominent.

In the disaster management context, Timmerman (1981) first introduced the term in his work, “Vulnerability, Resilience, and the Collapse of Societies”, to link the impact of climate change on hazard and risk mitigation relating it with the term used by Holling earlier. For community resilience to disasters, John Twigg provided a comprehensive framework for understanding resilience that has been influential among the current generation of disaster management scholars. Twigg's definition of community resilience and its characteristics can be found in his seminal work "Characteristics of a Disaster-Resilient Community: A Guidance Note" which emphasises the multidimensional nature of resilience and the importance of proactive and reactive capacities (Twigg, 2009). Twigg's definition of resilience aligns with the notion that disaster resilience pertains to a community's ability to withstand the impacts of catastrophic events while maintaining essential functions. Moreover, Twigg emphasizes that a resilient community not only sustains its regular operations during disasters but also has the capacity to recover and bounce back post-event (Twigg, 2009). Twigg underscores the importance of communities being able to absorb shocks, adapt to changes, and ultimately retain their core functions and identity (Chisty et al., 2021). Twigg's perspective on resilience resonates with the idea that resilience involves coping with unforeseen challenges, learning from them, and rebounding effectively. Twigg’s guidance note, and his subsequent publications have influenced the discourse on disaster resilience and more inclusive community-based approaches to disaster risk reduction over the last decade.

Building on this conceptualisation of resilience, Manyena (2009) emphasizes a forward-looking approach, highlighting resilience as a process that involves not only bouncing back but also bouncing forward following a disaster. This perspective underscores the active role of individuals and communities in not just recovering from adversities but also adapting, learning, and progressing beyond the initial impact (Manyena et al., 2011). He emphasizes that resilience is not just about bouncing back to a pre-disaster state but also about transforming to a better state, integrating the concept of vulnerability and adopting a holistic, systems perspective.

Accordingly, the resilience concept has continued to evolve since then, appearing across many disciplines ranging from ecology and environmental & hazard sciences to sociology, public health, economics, urban planning and geography (Sheffi, 2015). Due to the complex nature of natural disasters and their impacts, the concept has been defined and conceptualized in many ways, making it inherently multi-disciplinary in scope and nature (Ostadtaghizadeh et al., 2015).

In this research, we consider resilience as referring specifically to Community Disaster Resilience (CDR) as applied in disaster management for preparedness, planning and mitigation, as well as response and recovery at the local community level. Keeping this application of CDR in mind, Table 2-4 provides an overview of key definitions of resilience from academic and grey literature. The table also looks for keywords in the definitions, underlining them to understand the critical components of CDR as conceptualized by the researchers, academics and practitioners who developed them in the literature.

Table 2-4 Key Components of Community Disaster Resilience Definitions

No.	Reference + year	Definition
1	Timmerman (1981)	Resilience is the measure of a system's or part of a system's capacity to <u>absorb</u> and <u>recover</u> from a hazardous event.
2	Wildavsky (1988)	Resilience is the capacity to <u>cope</u> with unanticipated dangers after they have become manifested. It is also learning to <u>bounce back</u>.
3	Comfort et al. (1999)	The capacity <u>to adapt</u> existing resources and skills to new systems and operating conditions.
4	Mileti (1999)	The ability <u>to withstand</u> an extreme natural event without suffering devastating losses, damage, diminished productivity, or quality of life without a large amount of assistance from outside the community.
5	Adger (2000)	The ability of communities <u>to withstand</u> external shocks to their social infrastructure
6	Paton, Smith, and Violanti (2000)	The capability <u>to bounce back</u> and to use physical and economic resources effectively <u>to aid recovery</u> following exposure to hazards.

7	Carpenter et al. (2001)	The amount of disturbance a system can absorb and still remain within the same state or domain of attraction; the degree to which the system is capable of self-organisation; the ability to build and increase the capacity for learning and adaptation.
8	Paton and Johnston (2001)	Resilience describes an active process of self - organizing, learned resourcefulness and growth - the ability to function psychologically at a level far greater than expected, given the individual's capabilities and previous experiences.
9	Waller (2001)	Resilience is the capacity to survive, adapt and recover from a natural disaster. Resilience relies on understanding the nature of possible natural disasters and taking steps to reduce risk before an event, as well as providing for quick recovery when a natural disaster occurs. These activities necessitate institutionalized planning and response networks to minimize diminished productivity, devastating losses and decreased quality of life in the event of a disaster.
10	Bruneau et al. (2003)	The ability of social units to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes.
11	Bruneau et al. 2003, McDaniels et al. 2008	Robustness (the extent of system function that is maintained) /Redundancy (system properties that allow for alternate options, choices, and substitutions under stress) /Resourcefulness (the capacity to mobilize needed resources and services in emergencies)/ Rapidity (the time required to return to full system operations and productivity)
12	Cardona (2003)	The capacity of the damaged ecosystem or community to absorb negative impacts and recover from these
13	Godschalk (2003)	A resilient city is a sustainable network of physical systems and human
14	Pelling (2003)	Resilience is the ability of an actor to cope with or adapt to hazard stress.
15	Ahmed (2004)	The development of material, physical, socio-political, socio-cultural, and psychological resources that promote safety of residents and buffer adversity
16	Coles and Buckle (2004)	A community's capacities, skills, and knowledge that allow it to participate fully in recovery from disasters
17	Adger et al. (2005)	The capacity of linked social-ecological systems to absorb recurrent disturbances, such as hurricanes or floods, so as to retain essential structures, processes, and feedbacks

18	Allenby and Fink (2005)	The capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must
19	Burton (2005), UKCIP (2003)	The ability of a system to recover from the effect of an extreme load that may have caused harm.
20	UNISDR 2005	Resilience is the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of function and structure. This is determined by the degree to which the social system is capable of organizing itself to increase this capacity for learning from past disasters for better future protection and improve risk reduction measures.
21	Folke (2006)	(1) the amount of disturbance a system can absorb and still remain within the same state or domain of attraction, (2) the degree to which the system is capable of self-organization (versus lack of organization, or organization forced by external factors), and (3) the degree to which the system can build and increase the capacity for learning and adaptation
22	Twigg (2009)	Resilience is defined as the capacity of a community to withstand, adapt to, and recover from disasters and adverse events. His framework emphasizes a community-centered approach, highlighting the importance of multi-dimensional resilience (including physical, social, economic, and environmental aspects), proactive and reactive capabilities, and inclusive participation in resilience-building processes.
23	Maguire and Hagan (2007)	Social resilience is the capacity of a social entity to bounce back or respond positively to adversity. Social resilience has three major properties, resistance, recovery and creativity.
24	Paton (2007)	The capacity of a community, its members and the systems that facilitate its normal activities to adapt in ways that maintain functional relationships in the presence of significant disturbances
25	Pfefferbaum, Reissman, and Klomp (2007)	The ability of community members to take meaningful, deliberate, collective action to remedy the impact of a problem, including the ability to interpret the environment, intervene, and move on
26	Haimes et al. (2008)	The ability of the system to withstand a major disruption within acceptable degradation parameters and to recover within an acceptable time and composite costs and risks.
27	Norris et al. (2008)	A process linking a set of adaptive capacities to a positive trajectory of functioning and adaptation after a disturbance
28	Manyena (2009)	Resilience is defined as a dynamic and evolving process involving continuous adaptation and transformation in response to changing risks

		and vulnerabilities. Emphasizes that resilience is not just about bouncing back to a pre-disaster state but also about transforming to a better state, integrating the concept of vulnerability and adopting a holistic, systems perspective.
29	Wilbanks (2009)	The capacity to anticipate problems, opportunities, and potentials for surprises; reduce vulnerabilities related to development paths, socioeconomic conditions, and sensitivities to possible threats; respond effectively, fairly, and legitimately in the event of an emergency, and recover rapidly, better, safer, and fairer
30	UNISDR 2009	The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure
31	Cutter et al. (2010a)	A set of capacities that can be fostered through interventions and policies, which in turn help build and enhance a community's ability to respond and recover from disasters
32	IPCC 2012, UNISDR 2009	Ability to anticipate, absorb, accommodate or recover from hazards in timely and efficient manner through preservation, restoration or improvement of structure and functions
33	McBain et al. 2010	Ability of an asset, or system of assets, to continue to provide essential services when threatened by an unusual event and its speed of recovery and ability to return to normal operation after the threat has receded.
34	The U.S. White House (Obama 2011)	The ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies
35	Committee on Increasing National Resilience to Hazards and Disasters (2012)	The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events
36	Hallet 2013	Ability to prevent, withstand, recover from and learn from the impacts of extreme weather hazards
37	UNDP (2014)	Resilience is a tendency to maintain integrity when subject to disturbance
38	EPA 2015	Capacity to anticipate, prepare for, respond to and recover from the effects of hazards with minimum damage to the social-wellbeing, the economy and environment

39	Tariq and Pathirage (2017)	Capacity to resist, absorb, accommodate to and recover from the effects of hazards in timely and efficient manner through preservation and restoration of structure and functions

Elements of resilience in the definitions

A partial textual analysis of the keywords used in these definitions (as shown in Figure 2-3) illustrates the importance of words like systems, capacities, and abilities of communities to recover, absorb, withstand, and adapt to hazards. The word cloud gives a visual representation of the most frequently used words to describe resilience and is indicative of the major themes and concepts covered by the definitions in Tables 2-4.

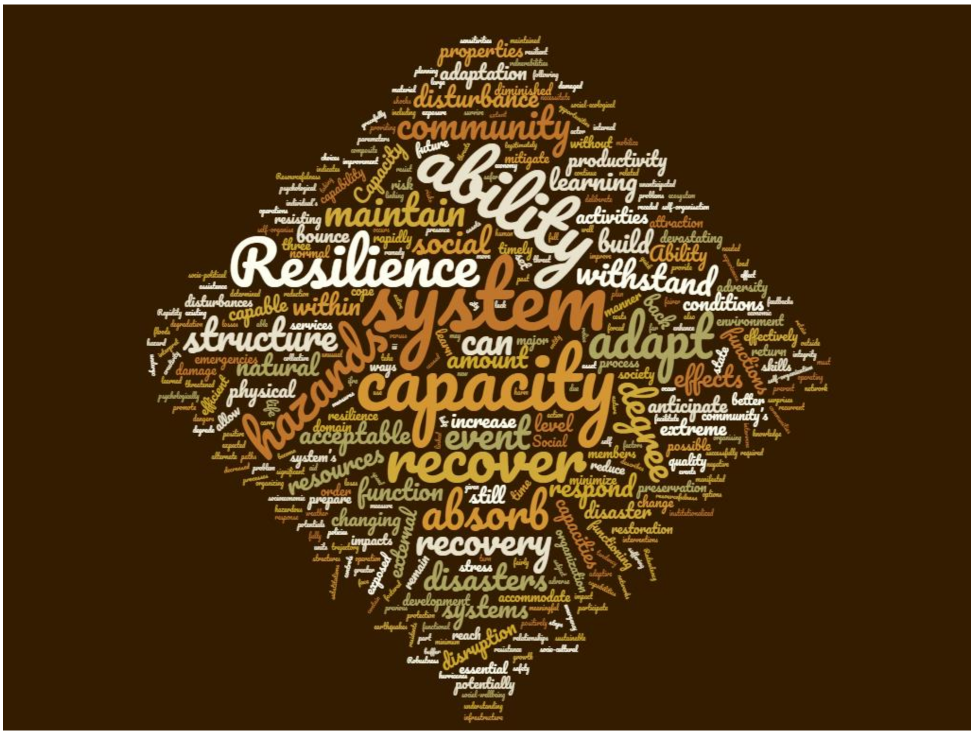


Figure 2-3 Word cloud of 39 resilience definitions.

The thirty-nine definitions were then subjected to a thematic analysis for a more detailed textual analysis of the wording used and the context from the original literature, the keywords in the definition text were arranged into themes, and similar themes were combined into the key elements of community resilience, which are important for measuring and understanding community resilience at the local levels. Table 2-5 below summarises the analysis into seventeen elements. These seventeen elements can be used to understand the major themes in the resilience definitions literature collected in Table 2-4 and reflect the research background and focus of the authors proposing the definitions. This list is not exhaustive and can be expanded as more research is included or published. It is essential to understand that any definition of resilience will be similarly dependent on the need, context and purpose of the research and researchers considering it. Hence, any research into community resilience must understand what elements of the discussion it is attempting to capture, as the language used can mean several things for different stakeholder groups, as is often the case when working on resilience issues in communities (Huggins et al., 2015).

Table 2-5 Three main themes (or capacities) emerge from the definitions.

No.	Sub-elements	Theme	Link to Capacity
1	Preparedness	The ability of a system to anticipate and reduce the impact of hazards, climate variability and extremes through preparedness and planning (Bahadur et al., 2015).	Anticipatory
2	Communication		
3	Governance and Leadership		
4	The Role of Local Knowledge		
5	Collaborative and engaged communities		
6	Efficiency		
7	Redundancy and durability	The ability of a system to buffer, bear and endure	Absorptive
8	Robustness and strength		
9	Diversity and density		
10	Health		
11	Mental outlook		
12	Interdependence and feedback sensitivity		
13	Bounce back		

14	Adaptability and variability	The ability of a system to be repaired quickly and easily, the ability to learn and adapt	Restorative
15	Economic investment		
16	Resources		
17	Community networks and relationships		

Although terms with precise meanings like robustness, resistance, withstand, absorb and recover (as well as others) are used in the definitions, it is essential to realise that these are distinct processes that can vary from hazard to hazard, place to place and country to country (Constas et al., 2014). Therefore, one of the main challenges for resilience quantification is the operationalisation of these processes, particularly when capturing the hazard and cultural and national diversity in the global context (Saja et al., 2018). In addition to developing a robust operational definition, it is vital to identify the variables and processes that influence or predict resilience and the variability of resilience within different communities (Serfilippi and Ramnath, 2018). However, operationalising the resilience definition in this manner presents its own set of challenges. It can range from methodological issues (i.e., measuring "soft" variables like social and human relationships) to the role of power and influence in building resilience (i.e. equitable representation in resilience assessments), lack of direct measures of hazards being used and the temporal dynamics of resilience over time (Levine, 2014, Saja et al., 2018, Jones et al., 2021b).

Some articles have defined community disaster resilience as a system's capacity to rebound or return to equilibrium following an external disturbance (Cimellaro et al., 2010, Peck and Simonovic, 2013). How these capacities are defined and operationalised in the literature ranges from relatively simple direct measures of disaster impact to more complicated indices representing aspects of a community's capacity (Irwin et al., 2016). Hence, to better understand and measure these processes, a more subjective approach, where stakeholders play a more participatory role in defining resilience capacities and how to measure them, can help operationalise CDR (Jones and Tanner, 2017). This research adopts the approach used in the literature that links community resilience to community capacities and has defined these as the three capacities (anticipatory, absorptive and restorative) that best represent the processes mentioned in the UNISDR definition (Thayaparan et al., 2016, Tariq et al., 2021b). The seventeen elements from the reviewed definitions shown in Table 2.4 are characterised according to these three capacities to better define them*:*

"*Anticipatory capacity* is defined as the ability of a system to anticipate and reduce the impact of climate variability and extremes through preparedness and planning (Bahadur et al., 2015). This capacity is considered a proactive action before a foreseen event to avoid disturbance, either by preventing or reducing exposure or by minimising vulnerability to specific hazards (Kellett and Peters, 2014).

Accordingly, *Absorptive capacity* is considered as the ability of a system to buffer, bear and endure the impacts of climate extremes in the short term and avoid collapse (death, debilitation and destruction of livelihoods) (Wisner et al., 2004, Folke et al., 2010, Béné et al., 2012). This capacity also represents people, organisations and systems' ability to face and manage adverse conditions, emergencies or disasters using available skills and resources (UNISDR, 2009).

In the case of *Restorative capacity,* the study defines it as the ability of a system to be repaired quickly and efficiently (Biringer et al., 2013). This capacity is also linked to the terms adaptive and transformative, where communities respond by learning and using their knowledge and experience to "build back better" over the long run (Constas et al., 2014)."

This research has chosen the above three capacities as those which are most suited to characterise the community resilience assessment process. The three capacities outlined above have been used to address some of the fundamental limitations and challenges researchers face in developing community resilience measures as specified in the literature (Levine, 2014, Beccari, 2016a). Researchers can address some of these challenges by using community capacity assessments to measure community resilience and make a more robust, valid and "fit-for-purpose" resilience measurement tool. Stakeholders can design fit-for-purpose tools to measure processes they need to measure rather than from the perspective of external actors, like researchers. For example, by allowing a more significant role for community members and other key stakeholders in defining how these capacities are measured, stakeholders can feel engaged in the process, ensuring vital issues are included in the assessment (Jones, 2019). To be used effectively for decision-making, community capacity assessments must also correspond to a community's appropriate context that best describes the resilience issue affecting it, e.g., the social, economic, and physical elements of the built environment or other aspects of the community.

2.3 Consolidating Community Disaster Resilience: Review of Frameworks

One of the stated goals of this research is to present an inclusive and adaptable framework to assist community resilience stakeholders (residents, local government officers, practitioners, and researchers) in measuring CDR at the local level. For this purpose, we review resilience frameworks that have been applied successfully to measure resilience at the local community level to develop our adaptable CDR framework. This section examines and classifies the frameworks based on how CDR is defined, what dimensions or categories are used to characterise CDR, how CDR is measured or evaluated, and what measures or indicators are used in these frameworks. The section also contributes towards developing a customisable CDR framework by synthesising a library of indicators across the most cited CDR dimensions to propose a resilience measurement framework that is adaptable and more "fit-for-purpose," that are according to the needs of stakeholders in community resilience assessments at the local level.

2.3.1 Consolidated Definition and Perspectives on CDR

As covered in Section 2.2.1 on community, several definitions for community exist; in this study, the community is defined as "*A group of people with diverse characteristics who are linked by social ties, share common perspectives, and engage in joint action in geographical locations or setting*" (Ostadtaghizadeh et al., 2015). This definition focuses on the capacity of a community to work together and engage in disaster risk reduction activities by pooling knowledge, experience, and actions towards the common goal of a resilient community in geographical-based populations like wards, villages, neighbourhoods, towns, and districts.

As covered in Section 2.2.3 in our review of the literature on resilience definitions, we have listed thirty-seven definitions of community resilience and identified three fundamental capacities – Anticipatory capacity for reducing future vulnerabilities, Absorptive Capacity for reducing impacts or consequences, and Restorative capacity for reducing recovery time and bouncing back better (Constas et al., 2014, Koliou et al., 2018).

The origin of the word resilience has been covered in detail above, where it had been shown to indicate how much a material can bend and then bounce back before it breaks (Bodin and Wiman, 2004) and how it came into use in its present form in ecological resilience in the work of Holling (1973) (Folke et al., 2002). Subsequently, researchers in disaster management (and other fields like development studies and sustainability) extended and adapted the concepts to community resilience in facing adverse shocks and stresses such as hazards (Folke, 2006, Alexander, 2013). From the literature in disciplines like environmental and natural sciences, additional concepts such as non-linear dynamics, thresholds, and multiple adaptation outcomes, also entered into use by social scientists looking at vulnerability and other complex phenomena like sustainable development, disaster recovery and conflict zones in developing countries (Ramalingam et al., 2008, Ramalingam, 2013). Although vulnerability is still an essential concept for disaster management, it has been eclipsed by resilience as a more proactive concept that better describes the whole of the community in its capacities, abilities and other characteristics, as shown in the definitions reviewed above (Dalziell and McManus, 2004, Beccari, 2016b). Hence, vulnerability is a sub-component of resilience, which describes a system's susceptibility to a shock or hazard event (Coppola, 2015, Cutter, 2018). For some disaster management researchers, the resilience concept has addressed some of the shortcomings of the vulnerability approach to hazard impacts and broadened the analysis to include dynamics of social processes and adaption pathways, while for others, many of the criticisms used to describe vulnerability research like lacking meaning without context, vagueness, multiple meanings and, even by some scholars as a colonial or racial term apply to resilience as well (Levine, 2014, Ford et al., 2018).

Critics of using vulnerability as a core indicator in community assessments argue that it is a vague concept with many definitions, methodologies and approaches being developed independently by different disciplines, focusing on static values (at one point in time) of various dimensions and often excluding relevant processes from the analysis (Cutter, 2003). Virokannas et al. (2020) cautioned about the danger of using vaguely defined concepts like vulnerability to stigmatise, label, marginalise and objectify communities and deny them their agency. They state that researchers working with at-risk communities will do better if they acknowledge that these communities can act of their own accord and are fully capable of expressing themselves concerning issues of their vulnerabilities and risks (Virokannas et al., 2020). With some of these concerns in mind, the present research requires a robust definition of resilience that can be used as a starting place for co-creating a context-specific definition based on stakeholder needs.

After reviewing the definitions used in the literature, two definitions stand out for this research. The two definitions have been selected because they have considerably influenced resilience researchers around the World. The first one from the National Academy of Sciences in the United States: *"The ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events"* (National Research Council, 2012) and the second one form the United Nations International Strategy for Disaster Reduction (UNISDR), which has defined community resilience as: *"the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions*" (UNISDR, 2013). These definitions capture the three capacities (Anticipative, Absorptive and Restorative) and the other broader elements of resilience identified above in the previous section. The definitions are comprehensive, have achieved consensus among many academics, governments, and international organisations, and are well-recognised among the stakeholders participating in this study. Both definitions also form a good starting point for stakeholders to discuss their conception of community disaster resilience and define it in their own terms, if required.

Although resist, absorb and recover are used in both definitions, it is essential to realise that these processes can vary from hazard to hazard, place to place and country to country (Norris et al., 2008, National Research Council, 2015). Therefore, one of the main challenges of measuring resilience is operationalising these processes, particularly when capturing the hazard or cultural and national diversity globally (National Research Council, 2017). In addition to developing a robust operational definition, it is vital to identify the measures and processes that influence or predict resilience and the variation of resilience within different communities (Serfilippi and Ramnath, 2018).

Norris et al. (2008) proposed that definitions of resilience can be operationalised differently depending on the level of analysis and the goals of the resilience assessment process and can be understood as a system of community capacities that include shocks and stresses, adaptation, wellness, and resource dynamics. Subsequently, building on the previous work of Norris et al. (2008), Sherrieb et al. (2010) stated that community resilience can be measured as a set of adaptive capacities that changed over time and not as a single outcome, as is considered in many frameworks, but rather several possible outcomes. Hence, CDR is a complex multi-dimensional phenomenon with diverse perspectives and multiple interdependencies, making it hard to define and conceptualise (Cutter et al., 2010b, Levine, 2014). This methodological difficulty is especially apparent when resilience is considered a single static value and not a dynamic value that changes over time to reflect evolution or degradation, as the case may be (Cutter, 2018). This difficulty also extends to resilience in hard-to-define and measure "soft" or "intangible" variables, such as social and human dimensions, that have a clear impact on CDR (Saja et al., 2018). Bene et al. (2019) differentiate between tangible and intangible factors that may impact community resilience; tangible factors are those that can be objectively measured, like financial, institutional, or technical factors, whilst intangible factors are those that are hard to measure and can vary because they depend primarily on aspirations, expectations, and motivations of citizens in the community.

Resilience research can benefit from the literature in parallel fields of climate change adaptation and well-being research in development, which have used innovative tools to capture intangibles such as risk perception, self-efficacy and aspirations of individuals in communities (Eitzinger et al., 2018). Capturing stakeholder worldviews and mental models requires increased participation of communities using participatory tools that may enhance engagement and representation of diverse groups in the assessment of resilience, as well as encouraging conversations about resilience among diverse groups (Herrera and Kopainsky, 2020). This engagement process may lead to the development, co-creation and use of resilience assessment tools by fit-for-purpose stakeholders who measure what they want and need rather than what researchers think is required (Tariq et al., 2021b).

The methodological challenges of considering resilience as a process over time, the nature of gathering data in tangible and intangible variables, the ability to engage and provide context for diverse stakeholders and to provide fit-for-purpose resilience assessment tools for stakeholders have resulted in limited guidance on what dimensions and characteristics to measure (resilience of what?), for what purpose (resilience to what?) and community context (resilience of who?) (Thayaparan et al., 2016, Abeling et al., 2018a).

One way to address some of these methodological considerations is by applying a systems approach to the community resilience context and using more participatory tools that help in answering these questions – tools that allow for the inclusion of the perspectives and mental models of the community whose resilience is being assessed (Hovmand, 2014). Therefore, using participatory modelling techniques developed in systems thinking to understand and develop resilience assessment tools may allow resilience frameworks the flexibility to use complementary tools for measuring tangibles through objective measurement and intangibles utilising a combination of objective and subjective methods and hence require more attention from researchers on community resilience (Jones, 2019, Mishra et al., 2019).

Resilience Measurement Approaches: Subjective Vs Objective

Generally, CDR frameworks that measure resilience at the community level can be sorted into two broad categories: objective and subjective approaches (Béné et al., 2016a). Objective approaches refer to those features of resilience measurement that are independent of the subject's judgement; for example, in this case, it refers to approaches that use characteristics of resilience that are defined externally and not by members of the community themselves (Maxwell et al., 2015, Béné et al., 2016b). Most resilience frameworks use objective measures to assess tangibles such as income, assets, and other relatively easier-to-quantify variables (Jones and Samman, 2016). The indicators for these objective measures are more developed as measurement tools, such as household survey questionnaires and have been used extensively in the literature, in many contexts, and provide relevant, validated data sets (Cutter, 2016a).

Objective approaches can also be considered "positivist" in their outlook, preferring data collection using objective measures that can be relatively easy to collect and apply in other settings to measure the same type of variables (Keck and Sakdapolrak, 2013). Hence, its popularity is due to its relative ease of development and deployment in different contexts and settings (Maxwell et al., 2015). Subjective approaches, on the other hand, tend to a more "interpretive" (or "constructivist" if considering a more critical approach) outlook as subjective measures are designed to capture the relative viewpoints and understanding of different stakeholder groups (Endress, 2015). Hence, if appropriately designed, subjective approaches may provide a deeper level of understanding as the indicators themselves are not free from interpretation, and their selection may generate valuable insights for resilience intervention design and implementation (Hamborg et al., 2020).

Recently, more subjective approaches to measuring resilience have found acceptance among resilience researchers, where these approaches seek to actively include the perspectives and judgements of the subjects themselves to understand their circumstances (Maxwell et al., 2015). Clare et al. (2017) further go on to state that subjective-based approaches may also challenge the idea that experts may be the best source for the evaluation of a community's resilience issues and that they do not necessarily have a better understanding of factors contributing to community resilience than the community members themselves.

A subjective resilience assessment captures an individual's cognitive self-assessment regarding their household, community, or social system's capacities to the underlying risk and relies heavily on perceptions, judgements, and preferences. For example, self-assessment of what resilience is (defining it), what resilience consists of (dimensions), and other factors that impact resilience can clarify the context of a community's response to current or future shocks and stresses (Jones and Tanner, 2017). These perspectives and judgements often examine intangible variables like social cohesion, trust, and other social dimensions (Saja et al., 2018). Although intangibles may be challenging to measure as they tend to be subjective, they are no less important to capture than tangibles, especially in vulnerable communities, because they may provide a deeper insight and understanding into underlying issues of resilience by giving context and representation to marginal voices (Béné et al., 2019). Additionally, bottom-up approaches where community members participate in resilience assessments and provide input to the measurement process may minimize or remove biases like external framing that may lead to errors in resilience intervention design and implementation (Beauchamp et al., 2019).

It is important to note that subjective measures and objective measures are not mutually exclusive as there are resilience frameworks that can be classified as objective but have some elements in their assessment process that are subjective and vice versa (Maxwell et al., 2015). Jones (2019) has proposed a classification system where resilience measurement frameworks can be placed on a continuum between objective and subjective approaches based on two factors; "…firstly, how is resilience defined? Objective approaches use external definitions of resilience (typically by the evaluator); subjective approaches allow the subject(s) to define resilience. Secondly, how resilience is evaluated? Objective approaches rely on external observation; subjective approaches use a subject's judgments and self-evaluation of their resilience" (Jones, 2019). Figure 2.4 illustrates the Subjective-Objective continuum and reveals some of each quadrant's relative strengths and weaknesses Jones (2019).

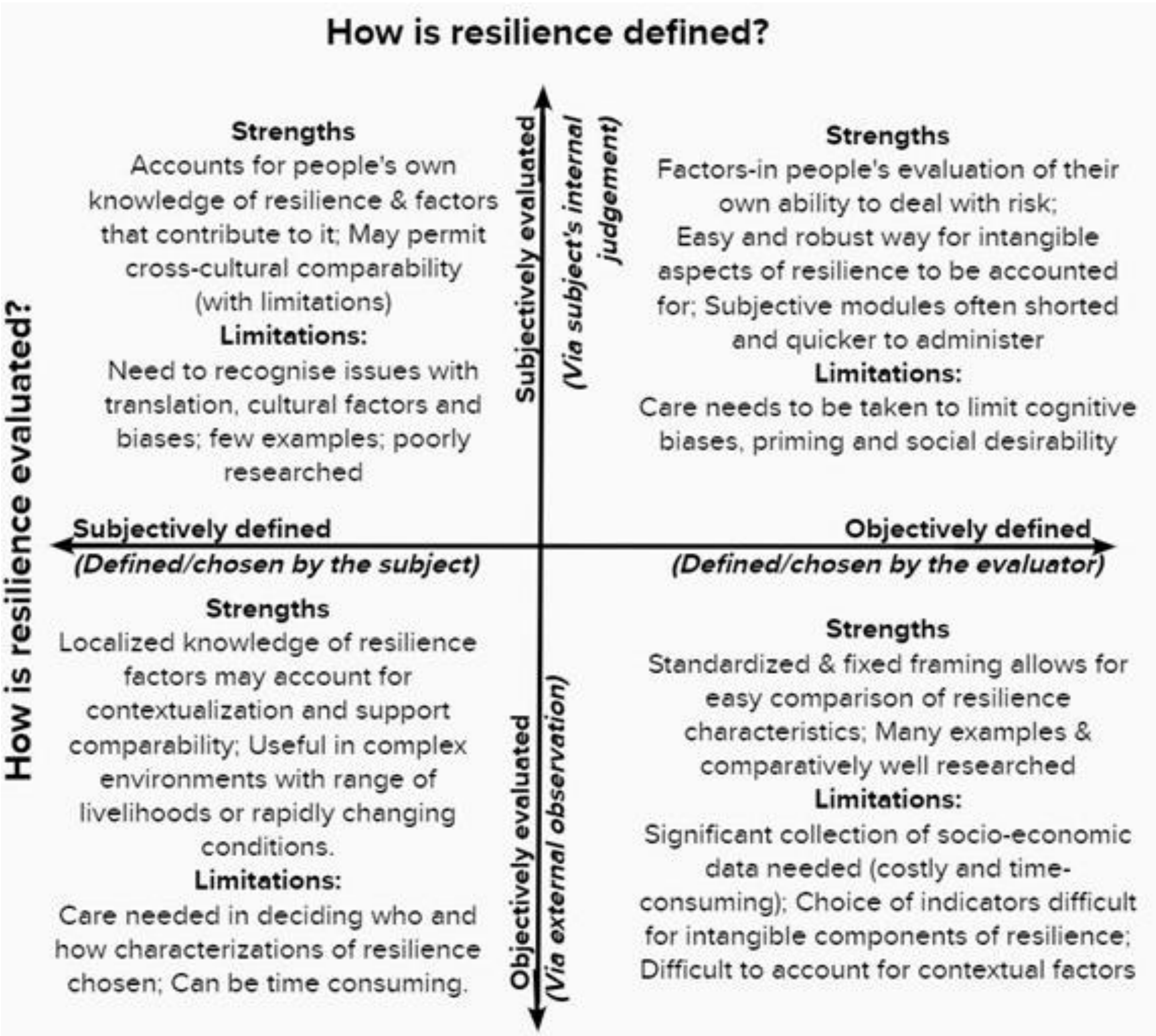


Figure 2-4 Subjective-Objective continuum with strengths and limitations (Jones, 2019, p. 9) .

Due to the challenge of operationalising community resilience processes and capacities, there is a need to review the current literature for more inclusive and comprehensive frameworks. The review can help identify critical characteristics, dimensions, features, and approaches used across existing CDR frameworks. The study results can then be used to develop an adaptable CDR approach that can be applied to a specific location, hazard, or case context – allowing interpretation and customisation by key stakeholders from across the community spectrum.

2.3.2 CDR Frameworks Review

A systematic literature review of current community resilience frameworks was conducted to assess their applicability in the community resilience context, especially those frameworks applied in the community context at the local level in varied settings, such as those in developed and developing countries. This study used the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA, 2009) method to structure the community resilience literature review at the first analysis stage. The PRISMA method is a widely used literature review methodology with four steps: identification, screening & eligibility, and inclusion (Moher et al., 2015).

This initial search was conducted using a combination of databases used in social science research, namely the Scopus database, ISI Web of Science and Google Scholar for peer-reviewed literature between 2005 and 2020, focusing on Title, Abstract, and Keywords. These electronic databases were chosen for their extensive selection of peer-reviewed journals, particularly in fields related to disaster resilience. Google Scholar was also included for its comprehensive database of journal articles by author and subject matter across many disciplines. The specific criteria for inclusion and exclusion are shown in Table 2-6**.** Preference was given to those frameworks which clearly stated a definition of resilience within the text that mentioned community as the core system under consideration. Additionally, care was taken to include only those frameworks used to measure a community's resilience with results or an outcome indicating that it had been operationalised at the local level.

Table 2-6 Inclusion/exclusion criteria

Inclusion Criteria	**Exclusion criteria**
Articles which a clear definition of CDR	Articles which did not clearly define CDR
	Articles that only list resilience as a co-benefit of another project, program or intervention
Articles that have operationalized the framework, model, tool, or index (in a developing world context)	Articles that specified the resilience of a specific material or product
	Articles that focused on mental or psychological resilience only
Articles published between 2005 and 2020	Articles on organizational or institutional resilience
	Articles on Wider Regional or national level resilience

The initial search strategy across all databases yielded 3,842 documents, necessitating a revision of the keywords. A refined search using the keywords "communit*" AND "disast*" AND "resilien*" AND "frame*" (followed by another search with "tool*" and "model*") was conducted to capture all the relevant peer-reviewed publications to reduce the documents to 1,039 articles further. The researcher then began to apply the steps of the PRISMA approach to refine the search further and include only subject disciplines related to disaster management (i.e. social sciences, environmental sciences and multi-disciplinary research) and exclude duplicates. The step resulted in 516 relevant research documents being chosen for closer eligibility check by exporting the titles, abstracts and keywords into an Excel database for closer scrutiny. As a result, 275 articles were shortlisted for abstract review and analysis to determine the final selection of 49 articles on community resilience frameworks applied at the local level in different settings.

The research closely reviewed 49 articles by studying their full texts. Of these, 36 were selected for inclusion, while 13 were excluded. Exclusions occurred either because a complete framework, model, or index was not included, or because the articles were duplicates, representing the same framework implemented in different settings. Each of these thirty-six articles was separately evaluated and analysed. Articles were examined for their approaches to defining resilience and the capacities or dimensions they used in those definitions. The frameworks were also analysed on the method used for evaluation, the methodology used for data collection, and the types of data required. The details of how this was done are shown in **Figure 2-5.**

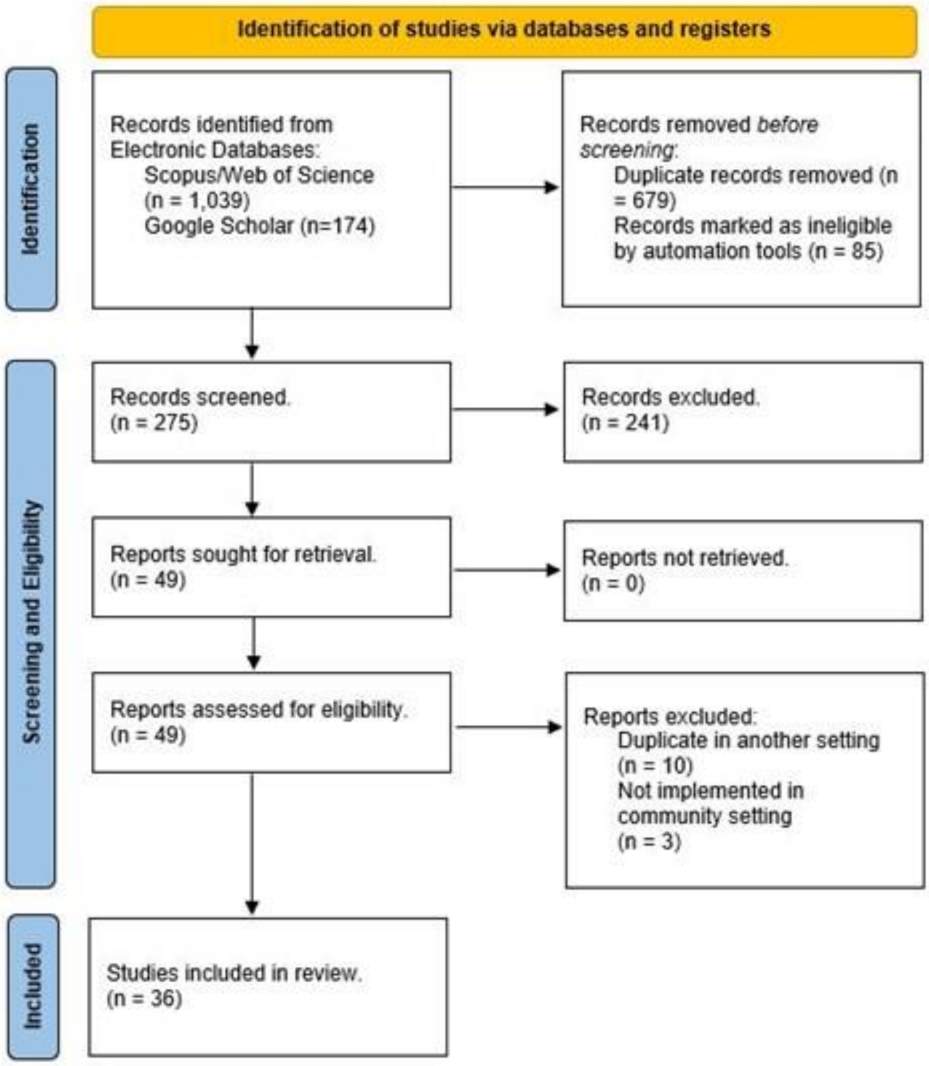


Figure 2-5: Stages in PRISMA review as carried out in the study.

All the selected frameworks are shown in Table 2-7. A critical analysis of the text of each article allowed the research team to determine which of two approaches, either subjective or objective, was used to define resilience and evaluate it. Keywords describing the dimensions used in determining the most common themes covered in these frameworks are shown in Table 2-8 Keywords used for Dimensions by Frameworks**.** The dimensions and capacities used in each framework indicate how those frameworks operationalise resilience.

Results/Findings

The selected thirty-six frameworks are listed in Table 2.7 in alphabetical order. Table 2-7 reviews the current practices and approaches used in these frameworks and lists the hazard type covered by each framework. Most of the frameworks (n=26/36, 72%) had an all-hazards approach, whilst four frameworks have been developed for climate change hazards and another four for flooding and coastal hazards. The remainder were focused on droughts, famine, and food security. The analysis of these 36 frameworks showed that community resilience was conceptualised differently based on each framework's approach, context, and research focus.

Resilience measurement approaches

Table 2-7 also indicates the framework type, classifying it as a scorecard, index, model or toolkit. Scorecards are used to evaluate performance or progress towards a goal and are often implemented as checklists. Each index summarises observations and measures by aggregating multiple indicators into a single value. In contrast, a model is a simplified representation of processes using mathematical formulas to estimate relationships and interactions in the real world. Finally, toolkits guide the resilience assessment using two or more types listed above, i.e. a combination of scorecards, indexes or models (Sharifi, 2016). The table also indicates the data required for its implementation and its approach to defining and evaluating resilience.

Table 2-7: Selected Frameworks for review by type (n=36).

Framework/tool	Reference/Year	Format /Type	Hazard covered	Data Source	Quantitative or Qualitative	How is resilience defined?	How is resilience evaluated?
Alkire -Forster resilience index (AFRI)	Hughes and Bushell (2013)	Index	Drought	Secondary	Quantitative	Objective	Objective
B16	Béné et al. (2016b)	Model	All	Both	Both	Objective	Subjective
Baseline Resilience Index for Communities (BRIC)	Cutter et al. (2010a), Siebeneck et al. (2015)	Index	All	Secondary	Quantitative	Objective	Objective
Climate Change Agriculture and Food Security (CCAFS15)	Hills (2015)	Toolkit	All	Both	Both	Objective	Objective
Coastal Cities Adaptive Resilience (CCAR)	Peck and Simonovic (2013)	Toolkit	All	Both	Both	Objective	Objective
Coastal Community Resilience Framework and Assessment (CCR)	Courtney et al. (2008)	index	Coastal	Primary	Both	Objective	Subjective

Conjoint Community Resilience Assessment Measure (CCRAM)	**Cohen et al. (2013)**	**Index/toolkit**	**All**	**Both**	**Qualitative/ both**	**Objective**	**Subjective**
Climate Disaster Resilience Index (CDRI)	**Prashar et al. (2012)**	**Index**	**Climate**	**Secondary**	**Both**	**Objective**	**Objective**
Community Disaster Resilience Index (CDRI2)	**Mayunga (2007)**	**Index**	**All**	**Both**	**Both**	**Objective**	**Objective**
Community Resilience Index Korea (CDRI-K)	**Yoon et al. (2016)**	**Index**	**All**	**Secondary**	**Quantitative**	**Objective**	**Objective**
Community Disaster Resilience Scorecard and Toolkit (CDRST)	**Arbon et al. (2016)**	**Toolkit**	**All**	**Primary**	**Qualitative**	**Objective**	**Subjective**
Community Based Resilience Analysis (CoBRA)	**UNDP (2014)**	**Toolkit**	**All**	**Both**	**Both**	**Subjective**	**Subjective**
COPEWELL	**Links et al. (2017)**	**Model**	**All**	**Both**	**Both**	**Objective**	**Subjective**
Community Resilience to	**Alshehri et al. (2015)**	**Toolkit**	**All**	**Primary**	**Both**	**Objective**	**Subjective**

Disasters Saudi Arabia (CRDSA)							
Community Resilience Index (CRI)	Ainuddin and Routray (2012)	Index	Earthquake	Primary	Quantitative	Objective	Subjective
Community Resilience Index (CRI2)	Norris et al. (2008), Sharreib et al. (2010)	Index	All	Secondary	Quantitative	Objective	Objective
Community Resilience Toolkit (CRT)	Schwind (2009)	Toolkit	All	Primary	Qualitative	Objective	Subjective
Climate vulnerability and capacity assessment (CVCA)	CARE (2009)	Toolkit	All	Primary	Qualitative	Subjective	Subjective
DRLA/UEH evaluation resilience framework	Sylvestre et al. (2012)	Toolkit	All	Both	Both	Objective	Objective
FAO14	Alinovi et al. (2010)	Index	Food security	Secondary	Quantitative	Objective	Objective
JS16	Jones and Samman (2016)	Model	All	Secondary	Quantitative	Objective	Subjective

L15	**Lockwood et al. (2015)**	**Index**	**All**	**Primary**	**Qualitative**	**Objective**	**Subjective**
Localized Disaster Resilience Index (LDRI)	**Orencio and Fujii (2013)**	**Index**	**All**	**Primary**	**Both**	**Objective**	**Subjective**
Livelihood change over time (LCOT)	**Vaitla et al. (2012)**	**Index**	**All**	**Primary**	**Quantitative**	**Objective**	**Objective**
MM07	**Marshall and Marshall (2007)**	**Model**	**Climate**	**Primary**	**Quantitative**	**Objective**	**Subjective**
NJ13	**Nguyen and James (2013)**	**Index**	**Floods**	**Primary**	**Qualitative**	**Objective**	**Subjective**
PEOPLES	**Cimellaro et al. (2010)**	**Toolkit**	**All**	**Both**	**Both**	**Objective**	**Objective**
PRIME	**Smith et al. (2015)**	**Index**	**All**	**Both**	**Both**	**Objective**	**Objective**
ResilSim	**Irwin et al. (2016)**	**Model**	**All**	**Both**	**Both**	**Objective**	**Subjective**
ResilUS	**Miles and Chang (2011)**	**Model**	**All**	**Secondary**	**Quantitative**	**Objective**	**Objective**
Resilience Inference Model (RIM)	**Lam et al. (2016)**	**Model**	**Coastal Hazards**	**Secondary**	**Quantitative**	**Objective**	**Objective**

Resilience index measurement and analysis (RIMA)	**FAO (2016)**	**Index**	**All**	**Primary**	**Quantitative**	**Objective**	**Objective**
Self-evaluation and holistic assessment of climate resilience of farmers and pastoralists (SHARP)	**Choptiany et al. (2017)**	**Model**	**Climate**	**Primary**	**Quantitative**	**Objective**	**Subjective**
Tracking adaptation and measuring development (TAMD)	**Brooks et al. (2013)**	**Toolkit**	**Climate**	**Primary**	**Both**	**Subjective**	**Objective**
WB15	**Alfani et al. (2015)**	**Model**	**All**	**Secondary**	**Quantitative**	**Objective**	**Objective**
Weather and climate-resilience indexes (WCRIs)	**Kimetrica (2015)**	**Model**	**Food**	**Primary**	**Quantitative**	**Objective**	**Objective**
UNISDR14	**UNISDR (2012), Gencer (2017)**	**Toolkit**	**All**	**Both**	**Both**	**Objective**	**Subjective**

The selected frameworks either rely on existing secondary data sets or collected primary data or on both types combined. Secondary data sets use census data, historical records and statistics provided by national or local authorities, and in some specific cases, data collected by non-governmental agencies and non-profit organisations. Primary data was collected through household or individual surveys, interviews, or focus groups. In the review, many frameworks (12/36, 33%) have used primary and secondary sources in their resilience assessments. Nine frameworks (25%) have used only secondary data sources, and the majority (n=16/36, 44%) have used only primary data. Of the thirty-six articles in the evaluation, only three (n=3/36, 8%) have used the subjective approach to define resilience from the community members' perspective. The rest used an objective approach where the authors defined resilience externally, as shown in Table 2-7.

Figure 2-4 previously illustrated the subjective-objective continuum across which CDR frameworks lie (Jones, 2019). **Figure 2-6** shows where the frameworks reviewed in this study are placed on that subjective-objective continuum. Most frameworks (n=33/36, 92%) lie to the right of the continuum, where they are classified as objectively defined. With regards to evaluation, there is a greater even spread with many of the frameworks (n=15/36, 41%) using participatory methods that allow for the direct input of key stakeholders like community members. **Figure 2-6** reveals that objective approaches are the norm in resilience frameworks. As such, they inform the understanding of the processes of community disaster resilience among practitioners and researchers. It is important to note here that both approaches are valid and useful for the purpose they were designed for and have their respective benefits, costs, and limitations, as shown in **Figure 2-4**.

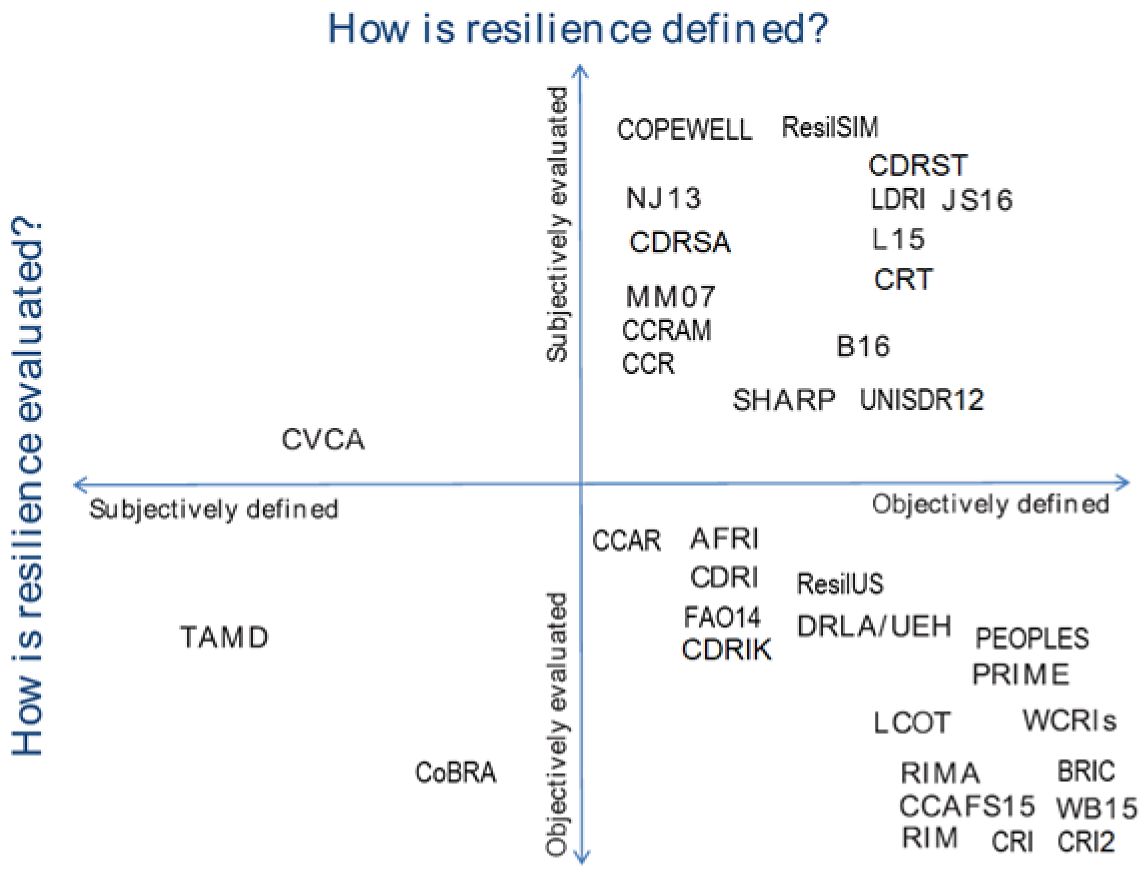


Figure 2-6 Selected frameworks in the subjective-objective continuum (adapted for this study from Jones, 2019, p.9)

Purely objective approaches are the most common type in the selected frameworks (n=17/36, 47%), where both the definition and measurement of resilience are done using objective assessment tools. Objective tools and approaches are more standardized and are easier to use for comparisons between different communities (Clare et al., 2017). These approaches are relatively well-researched and are covered more extensively in the literature, with many covered in this review (47%) falling under this bracket. One of the significant drawbacks of this type of assessment is the requirement of socioeconomic data that can only be collected by extensive data collection processes at a high cost and are more commonly found in the developed world than in the developing world context (National Research Council, 2015, Jones et al., 2018). Additionally, in these purely objective frameworks, it is hard to quantify intangible resilience dimensions like social and human factors that are important for measuring resilience (Saja et al., 2018). Also, another limitation of these frameworks is that it is difficult to contextualise or customise the resilience assessment to the needs of stakeholders. Hence, these frameworks may not be suitable for implementation in diverse, ever-changing communities with continually evolving needs like those at risk from increasing climate change hazards (Jones et al., 2018).

Of the frameworks that used a combined or hybrid approach (n=17/36, 47%), all but three employed an objective method to define resilience and are considered outliers among the CDR frameworks reviewed. These three exceptions, the Climate Vulnerability and Capacity Assessment (CCVA) (CARE, 2009), Tracking Adaptation and Measuring Development (TAMD) (Brooks et al., 2013) and the Community Based Resilience Analysis (CoBRA) (UNDP, 2014), have used a participatory community-based approach to define community resilience. Clare et al. (2017) suggest that these participatory-based subjective approaches have the advantage of including people's self-evaluations about risk and vulnerability and considering the community's knowledge base regarding resilience. Further, subjective approaches use a more robust method to include intangible factors of resilience (such as social issues) and were relatively quicker and cheaper to collect data for (Saja et al., 2018, Béné et al., 2019). On the other hand, due to the nature of the qualitative methods, more care and attention are needed to avoid cognitive biases, social desirability and priming (Jones, 2019).

Significantly, two of the three outlier cases, the TAMD framework (Brooks et al., 2013) and the CoBRA framework (UNDP, 2014), have used a subjective approach to defining resilience and an objective approach to evaluating and measuring resilience, signifying the relative rarity of frameworks utilising this approach. Both these frameworks have utilised innovative approaches where CDR was defined by subjective means and then measured using standard objective measures. This approach allowed for the inclusion of localised knowledge of resilience factors and used more validated and standardised objective resilience indicators (Brooks et al., 2013). This combination enables CDR frameworks to be contextualised to the needs and requirements of a community’s stakeholders – a critically desirable outcome for a more inclusive Disaster Risk Reduction (DRR) policy and programming (Clare et al., 2017). Jones (2019) reports that the utility of the TAMD approach is better suited to capture the uncertainties in complex environments and fast-changing situations in communities in disaster management and risk reduction contexts. The major limitation of this approach is that it is relatively time-consuming, and the process may be affected by the representation of fewer stakeholders than is ideal for the assessment, which can adversely impact who is represented and how resilience is categorised (Béné et al., 2019). This approach also generates value due to its ability to customise and adapt resilience measurement tools according to their respective stakeholders' needs, resulting in more "fit-for-purpose" resilience assessments (Tariq et al., 2020).

2.4 Categories or Dimensions of Resilience

The frameworks show a considerable diversity of categories being utilised, indicating the multi-disciplinary nature of CDR and how different research teams have used different theoretical approaches to measure the community resilience concept. A textual analysis of the keywords used as categories in these frameworks is shown in Table 2-8. Most of the frameworks (n=22/36, 61%) cover some aspect of the economic dimension, emphasising the role of livelihoods, financial capital, and assets on vulnerability in resilience frameworks, followed closely by social dimension indicators (at 58%) and by human/health indicators (at 55%). This analysis also showed that despite an emphasis on natural disasters, fewer (33%) of these frameworks included indicators and measures of the environment to assess community resilience.

Table 2-8 Keywords used for Dimensions by Frameworks

Dimension	No of frameworks using dimension (n=36)	% of frameworks	Framework References
Economic	22	61	CCR, BRIC, PEOPLES, CDRI2, CCAR, B16a, CCAFS, CVCA, DRLA, LCOT, PRIME, FAO, COBRA, LDRI, ResilSim, ResilUS, COPEWELL, CDRSA, CDRST, CRT, CRI2, CDRIK
Social	21	58	CDRI, BRIC, PEOPLES, CDRI2, CRI, CCAR, B16a, CVCA, DRLA, PRIME, FAO, COBRA, LDRI, ResilSim, ResilUS, COPEWELL, CDRSA, CDRST, CRT, CRI2, CDRIK
Human/Health	20	55	AFRI, PEOPLES, CDRI2, CCAR, CVCA, JS16, LCOT, PRIME, RIMA, WCRI, FAO, COBRA, LDRI, ResilSim, ResilUS, COPEWELL, CDRSA, CDRST, CRT, CDRIK

Physical	17	47	CVCA, CCR, CDRI, BRIC, PEOPLES, CDRi2, CRI, CCAR, CVCA, FAO, COBRA, LDRI, ResilSim, ResilUS, COPEWELL, CDRSA, CDRST, RIM
Governance	15	42	CDRI, PEOPLES, CDRI2, CRI, CCAR, CCAFS, CVCA, FAO, COBRA, LDRI, ResilSim, ResilUS, COPEWELL, CDRSA, CDRIK
Environmental	12	33	CDRI, CCR, BRIC, PEOPLES, CDRI2, CRI, CCAR, FAO, COBRA, LDRI, CDRSA, CDRIK
Food Security	8	22	JS16, LCOT, PRIME, RIMA, WCRI, FAO, LDRI, SHARP
Poverty	6	17	JS16, LCOT, PRIME, RIMA, WCRI, COBRA
Quality of life	4	11	AFRI, B16a, FAO, CDRST
Access to services	3	8	JS16, RIMA, FAO
Security	1	3	DRLA
Coping Behaviour	1	3	DRLA

As shown in Table 2-8, the frameworks included in the systematic review covered twelve broad categories or "dimensions" of community resilience. These categories were developed according to the research questions addressed by the investigators developing and using the frameworks in the original articles. In this research, where a participatory approach to measuring community resilience is proposed, twelve different categories can be challenging to explain and use to engage community stakeholders in field settings. This is especially true for those categories with similar meanings that can be grouped as they cover comparable aspects or dimensions of community resilience. These categories and their indicators used to measure them require further analysis so similar categories of resilience can be combined into fewer ones that are more manageable and less confusing to use with community stakeholders.

Further analysis of the dimensions, indicators and measures used in these frameworks to measure and assess CDR resulted in selecting five of the thirty-six for closer scrutiny. These frameworks were chosen because they covered a broad range of dimensions shown in Table

2-8 and the comprehensiveness of the indicators across the dimensions. The indicators used in these frameworks covered the more general dimensions of Physical, Human/Health, Economic, Environmental, Social and Governance resilience. Table 2-9 shows how comprehensively these dimensions were covered by listing the indicators and measures used to operationalise the CDR frameworks. The dimensions and indicators shown in Table 2-9 are an example of the type of indicators used in major CDR frameworks in the literature – particularly those that use an objective approach to evaluate and measure resilience. The indicators in Table 2-9 show some similarities between the frameworks and the diversity needed when conducting CDR assessments at the community level. A matrix table of indicators, like Table 2-9, combined similar indicators and developed the library of indicators used in this study. The process of combining and sorting the categories into fewer resilience dimensions and developing the Library of Indicators is explained in detail in Chapter 4.

Table 2-9 Selected frameworks with dimensions and indicators. (green=covered extensively, yellow=partially covered, red=not covered)

No.	Dimension	Category	Indicators	CDRI	BRIC	CDRI2	CCAR	CCVA
1	Economic	Household	Income	green	green	green	green	green
			Employment	green	green	green	green	green
			Households’ assets	green	green	green	green	green
			Access to financial services	green	green	green	green	green
			Savings and insurance	green	green	green	green	green
			Budget and subsidy	green	red	green	red	red
			Home ownership	green	green	green	green	green
		Other	Race/ethnicity income equality	green	green	green	red	red
			Non-dependence on primary/tourism sectors	green	green	green	red	red
			Gender income equality	green	green	green	red	red
			Insurance coverage	green	green	green	red	red
			Size of Gross Domestic Product (GDP) per capita	green	green	green	red	red
			Business size	red	red	red	green	red
			Large retail-regional/national geographic distribution	yellow	red	yellow	green	red
			Funds available for reconstruction after disaster	yellow	red	yellow	green	red
			Level and diversity of economic resources	yellow	red	yellow	green	red
2	S o		Education and awareness	green	green	green	green	yellow

			Community preparedness during a disaster					
			Risk awareness and training					
			Risk perceptions					
			Social capital					
		Demography	Personal faith and attitudes					
			Trust in authorities					
			Previous experience					
			Social networks					
			Faith organizations					
			National language non-speaking (percentage)					
3	**Health**	Population Health	Food security					
			Family health education and training programs					
			Identification/definition of special needs					
			Access to mental health care and psychological support programs					
			Access to clean water and adequate sanitation					
		Health Facilities	Availability of trained health workers					
			Medical resources such as the availability of hospital beds					
			Infection control					
			Access to health assistance					
			Immunization programs					
			Effective biosecurity and biosafety systems					
			Disease surveillance and Medical intelligence gathering					
4	**Physical**	Residential, Commercial and Industrial buildings	Housing and land use					
			Community assets					
			Sturdier housing types					
			Temporary housing availability					
			Industrial re-supply potential					
		Utilities/ Lifeline Systems	Electric supply					
			Water supply					
			Transportation					
			Sanitation					
			Integration of services					
			Warning system and evacuation					
			Evacuation routes					

		Early Warning Systems	Lessons learnt from previous disasters					
5	Governance	Multi-agency collaboration	Disaster plans and policies including mitigation and evacuation emergency management plans					
			Effectiveness of internal institutions					
			External institutions and networks					
			Institutional collaboration and coordination					
			Mitigation spending					
		Leadership and Knowledge Management	Flood insurance coverage					
			Knowledge dissemination and management					
			Disaster aid experience					
			Local disaster training					
			Unity of the leadership after the disaster					
		Private-Public partnerships	Integrating populations with special needs into emergency planning and exercises					
			Participation of community members (volunteerism) including women and children					
			Industrial plant accident planning					
			Clear partnership modalities defined and cooperation between concerned entities including private sector					
6	Environment	Hazard	Hazard intensity					
			Hazard frequency					
			Number of different hazards at risk					
		Natural Assets	Land use in natural terms					
			Natural flood buffers					
			Ecosystem services					
			Natural resource use policy and management					
		Biodiversity	Local food suppliers					
			Environmental policies					
			Biodiversity Index					

The variety of the categories and the indicators used to measure them indicate considerable diversity of opinions and perspectives on how to define and evaluate community resilience. One of the key objectives of this research is to use a participatory approach to capturing some of this diversity of views, opinions, and perspectives within and between groups of stakeholders, requiring the application of participatory methods to capture this diversity.

2.5 Participatory Approaches

The systematic review identified only three CDR frameworks that use subjective approaches to define community resilience (CoBRA, CVCA and TAMD) and only one that uses both a subjective approach to define community resilience and to evaluate it (CVCA). This section will look at what tools or techniques are used in those three frameworks from the systematic review and conduct a short overview of other subjective approaches that can be used in this research.

Community-Based Resilience Analysis (CoBRA)

The CoBRA framework mainly utilises interviews and focus group discussions to define the community resilience concept. It uses the qualitative data generated from the process to identify the main categories or indicators that can help evaluate the target community's resilience level (UNDP, 2014). In the FGDs, several Participatory Rural Appraisal (PRA) tools and techniques are also used for group activities like brainstorming and bean score ranking for prioritising Community Resilience Characteristics (MacOpiyo, 2018). Unlike the other resilience frameworks that rely solely on objective data and quantitative metrics, CoBRA strongly emphasises community perspectives, experiences, and local knowledge. Using interviews and FGDs acknowledges that community resilience is deeply rooted in the perceptions and needs of the community members themselves. Through qualitative data analysis, CoBRA identifies the key factors and assets contributing to or hindering community resilience. These factors often encompass social, economic, environmental, and cultural dimensions.

Climate Vulnerability and Capacity Assessment (CVCA)

The Climate Vulnerability and Capacity Assessment (CVCA) framework developed by CARE in 2009 is a participatory and community-centred approach for assessing and measuring community resilience to climate change and other environmental stressors. The CVCA framework focuses on understanding a community's vulnerabilities, adaptive capacities, and resilience from the community members' perspective. It emphasizes local knowledge, perceptions, and experiences. To collect data, the framework employs qualitative research methods, including focus group discussions, community workshops, participatory mapping, and interviews. These methods encourage community members to share their experiences and insights about climate impacts and vulnerabilities. Among the frameworks reviewed, CVCA also uses a subjective approach to evaluate resilience using stakeholder-defined measures as it engages them in defining what resilience is and how it can be measured. CVCA can be used by communities for goal setting and identifying key performance indicators for themselves that can be monitored and evaluated in case of meeting or falling short of those goals/objectives. One key feature of this framework is that it is designed to develop action plans during the assessment that the community can use.

Tracking Adaptation and Measuring Development (TAMD)

The Tracking Adaptation and Measuring Development (TAMD) framework, developed by Brooks et al. in 2013, is a comprehensive approach for measuring and assessing community resilience in climate change adaptation and development. This framework captures the complex interactions between adaptation efforts, development outcomes, and resilience-building processes. TAMD uses three types of indicators: 1) Development Indicators, representing the various dimensions of development, such as income, education, health, and infrastructure; 2) Adaptation Indicators, which assess the effectiveness of climate change adaptation strategies and actions, including measures related to disaster risk reduction, resource management, and capacity building; and 3) Resilience Indicators, capture the community's ability to adapt to climate change while maintaining or improving development outcomes. TAMD involves collecting quantitative and qualitative data to track development, adaptation, and resilience indicators changes over time. These data can be collected through surveys, interviews, focus groups, and existing sources. TAMD recognizes that adaptation and resilience-building approaches should be context-specific, considering each community's unique challenges, vulnerabilities, and opportunities. This includes the subjective experiences and views of community members. TAMD encourages the active involvement of community members, local authorities, NGOs, and other stakeholders in the data collection, analysis, and decision-making processes, including sharing their subjective views and experiences. A vital feature of this framework is that it promotes an adaptive management approach, where communities and decision-makers continually assess and adjust adaptation strategies based on quantitative data and community perspectives.

Reviewing the three frameworks that use subjective approaches in our systematic review indicates that interviews, focus group discussions (FGDs), participatory mapping, group workshops and PRA techniques for ranking (like matrix ranking and bean counting) were used and can provide a sound basis of capturing local opinions, perspectives, and experiences. Causal Loop Diagramming (CLD) is a form of participatory mapping that uses interviews and FGDs to enable stakeholders to directly draw maps of the central causal relationships in a system.

Participatory Mapping

To capture stakeholders' perspectives and mental models, researchers can use **Systems Thinking (ST)** to achieve situational awareness about the system and its components and how systems influence one another within a more extensive system (Maani and Cavana, 2007). ST can be considered a qualitative method for making sense of the complexity of real-world problems by considering them as a whole instead of splitting them into smaller parts (Kim and Anderson, 2007). ST can help answer the What, Why, When, Where and How? of problem issues and help explore and develop models for achieving system change (Sweeney and Meadows, 2010). It can be used to identify the elements or components of a system as well as to define its boundaries (Sherwood, 2011). ST uses tools like Causal Loop Diagrams, Behaviour Time Graphs, Rich Pictures and other tools to visually illustrate cause-and-effect relationships in a system using the language of systems analysis (Stroh, 2015). Once knowledge about the system, its components, and their interactions are noted, a modelling approach can be selected for its specification to derive further insights (if required).

Additionally, participatory approaches may provide participating stakeholders with some ownership of the modelling process, which can improve the acceptance of model outcomes and results (Clare et al., 2017). Research has shown that the use of more participatory methods for research into policy issues can increase the level of understanding and improve the engagement of local stakeholders (and their groups), ensuring the success of any interventions designed in this manner (Béné et al., 2019, Compagnucci et al., 2021). Systems science has been used effectively to understand complex phenomena ranging from public health, climate change, urban planning, education, sustainable development and poverty (DUIT, 2016, Rehman et al., 2019, Jackson and Sambo, 2020). These approaches have helped decision-makers in various disciplines to address real-world challenges more effectively (GOScience, 2022).

CLDs have been used extensively for participatory mapping in many applications ranging from operational research, organisational learning, supply chain management, public health, and many more (Sterman, 2000). Vennix (1996) developed a 4-step process (Figure 2-7) for drawing CLDs with participants during an interview or FGD using basic materials like sticky notes, chart paper and markers adapted for this study. First, the participant(s) were asked to place the problem variable in the middle of the sheet. Second, they were asked to add cause variables on the left side of the problem variable in order of flow sequence (i.e., direct or first-order causes first, then second or third-order ones). Next, these variables were joined through causal links with arrows and polarities assigned to each link (i.e., positive if moving in the same direction or negative if moving in the opposite direction). Thirdly, direct, and indirect consequence variables are added to the right side of the problem variable in sequence as before (i.e., immediate or first-order causes first and subsequent ones). Finally, for the fourth step, the consequence variables are connected to the cause variables to identify potential feedback loops.

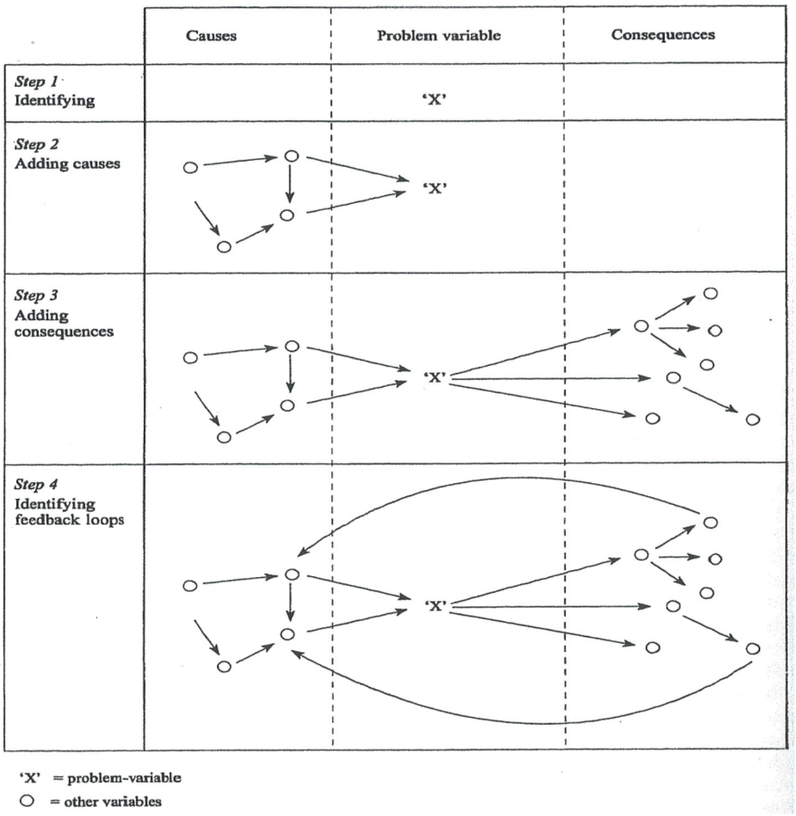


Figure 2-7. 4 step process of drawing a CLD. (Vennix, 1996, p.120)

The interviews and FGDs can be used to develop CLDs of the participants' problem issues to illustrate the main points clearly and quickly. CLDs effectively describe participants' mental models and perspectives about a problem issue or variable (Sterman, 2006, Williams and Hummelbrunner, 2010). CLDs can facilitate a better understanding of complex problems that different groups may perceive differently and have been used effectively in public health, water management, education and many other fields (Sherwood, 2011, Yearworth and White, 2013). CLDs can be used to visually capture cause-and-effect relationships between variables and provide a language for describing the dynamics and interconnections between them in the system (Kiani et al., 2009, Yearworth and White, 2013). Other advantages of using CLDs are: 1) they require little skill to make and can be made directly with stakeholders after a brief introduction; 2) they can be made quickly depending on the time given by the respondent or group (15 to 45 minutes are usually sufficient); and 3) because of the graphical aspect of the diagrams, they are relatively easy to understand for stakeholders and hence helpful for closer engagement in fostering a sense of "ownership" of the CLD map generated (Inam et al., 2015). According to Voinov et al. (2016), CLDs can be used to qualitatively model a system from the perspective of a local stakeholder and enable researchers to identify variables in a system and visualise their relationships over time. The diagrams can help analyse the relational patterns, the current state, and the dynamic changes that might occur in a system according to a participant's belief or perspective (Jackson, 2017). Along with CLDs, Behaviour over Time Graphs (BoTGs) are also used to enable stakeholders to visually depict how a variable will move in the future, thus defining the hopes and fears of participants regarding the variable (Perrone et al., 2020).

In CLDs, variables are connected by arrows drawn in the direction of the cause to the effect. They can be labelled with a plus sign to indicate variables acting in the same direction or a negative sign to show the variables are inversely related (Meadows, 2008). Figure 1 below illustrates the commonly used terminologies according to the standard conventions in systems thinking for CLDs. This approach is based on the feedback loop, a closed sequence of causes and effects that trace a relationship through one or more variables and form a loop (Gharajedaghi, 2012). CLDs are constructed from two types of feedback loops: reinforcing and balancing loops (Lacey, 2014b). Reinforcing, also called positive, loops are those where the sequence of variables forming a loop results in responses to each other in the same direction, whereas balancing, also called negative, loops are those where the variables respond in the opposite direction to each other (Jackson, 2017). Drawing CLDs with stakeholders through interviews can allow researchers to identify underlying patterns of behaviour by tracing feedback loops to provide deeper insight into how a system works (GOScience, 2022).

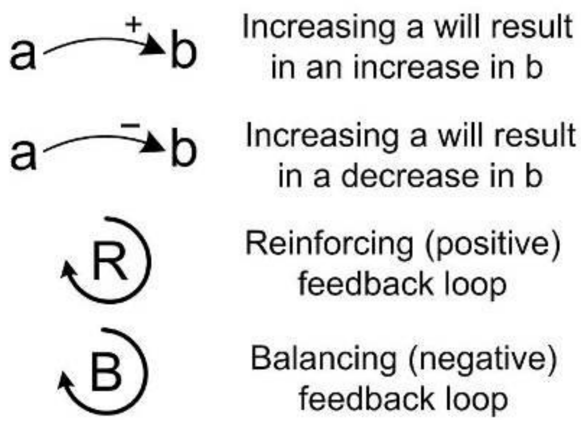


Figure 2-8 Terminology of Casual Loop Diagrams

An essential function of CLDs is identifying reinforcing and balancing loops in a system (Maani and Cavana, 2007). These two types of loops together form the basis of the behaviour observed in a system (Kim and Anderson, 2007). According to Kim and Anderson (2007), Reinforcing and Balancing Loops are the basic building blocks determining a system's behaviour. A reinforcing loop results in rapid growth or collapse by driving change in one direction with increasing change in the same direction each time you go around the loop. In contrast, a balancing loop produces a goal-seeking behaviour where the process keeps the system steady around a particular goal. Figure 1 shows the birth rate leading to an increase in a population as an easy-to-explain (and understand) example of a reinforcing loop. Figure 2-9 shows an example of a balancing loop by illustrating how the death rate reduces a population over time. If the rates are the same, then the population will remain the same. Drawing feedback loops can help participants visually understand the dynamics in a system and can be used to represent direct and indirect impacts that may arise from variables interacting across the system. By combining insights from interviews and focus group discussions, researchers can develop rich and accurate causal loop diagrams that capture the system's complexity under study. These diagrams can serve as the foundation for system dynamics modelling and analysis.

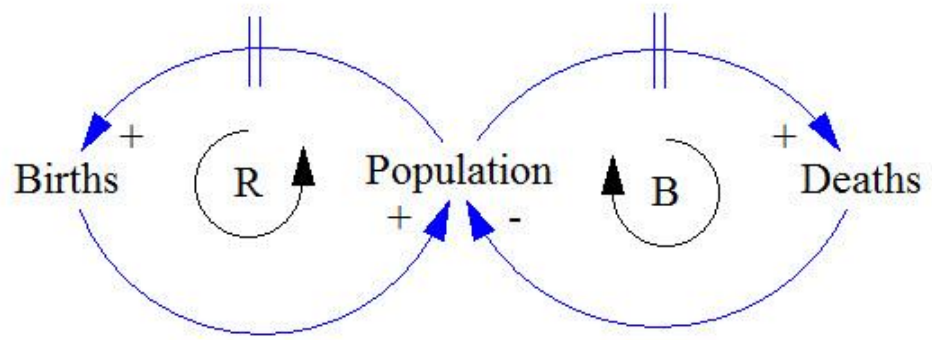


Figure 2-9 – Example of CLDs showing (a) reinforcing feedback and (b) balancing feedback (Ford, 2010).

Supplementing the CLDs, the reviewed CDR frameworks also used ranking techniques like matrix ranking and bean counter ranking methods taken from PRA techniques. Additionally, other tools can also be used for applying a more subjective approach to ranking and selecting between options that are considered to be more quantitative in their application and that generate statistically significant ranking and weighting procedures along with the standard descriptive statistics found with the matrix ranking and bean counting methods used.

Participatory Ranking

Several innovative mixed methods approaches using qualitative and quantitative tools for ranking and selecting resilience characteristics have been used in the disaster management literature. In this study, three such techniques are compared for use. In a recent review of techniques for capturing views and judgments for decision-making, Mukherjee et al. (2018) list the three most frequently used ones in disaster management: the Delphi technique, Analytical Hierarchy Process (AHP) and Q methods. All three methods capture participants' subjective input differently: Q methodology uses rankings, Delphi gathers expert opinions, and AHP involves pairwise comparisons. Delphi and AHP are better suited for group interaction, while Q methodology focuses on individual sorting.

Furthermore, AHP and Delphi are decision-orientated, while Q methodology focuses on understanding perspectives. Delphi aims for consensus, AHP for decision-making, and Q methodology for capturing diverse viewpoints. Both Q methodology and AHP are more resource intensive, requiring time and effort from the researcher to prepare materials beforehand.

The Delphi technique gathers input from experts to reach a consensus on a particular issue, can be used remotely, and ensures anonymity of the participants (Skulmoski et al., 2007). According to Skulmoski et al. (2007), it is mainly used to achieve consensus among experts on a topic and has been applied mainly in forecasting and decision-making studies. AHP is a structured decision-making technique for comparing and prioritizing alternatives (de FSM Russo and Camanho, 2015). It uses a structured approach to consider multiple criteria and alternatives while capturing subjective judgment (Darko et al., 2019). It has been used in studies examining decision-making involving multiple criteria, such as project selection or resource allocation (Al-Harbi, 2001). Other methods that can be used are interviews, FGDs, or surveys. Still, they are generally not as effective at understating the subjective perspectives, nor do they provide an analysis of the patterns in the data that require deeper insight between groups of stakeholders (Tariq et al., 2022).

Delphi techniques are suitable for achieving expert consensus, but it can be challenging to find the right group of experts for the given topic while also not being influenced by the biases and assumptions of those experts. It also lacks any opportunity for participant interaction and does not provide the depth of contextual understanding for their choices as the Q methodology does. AHP is a versatile tool and can also be used for indicator selection as it provides a structured approach to incorporate subjective judgements in the decision-making process. However, it is limited when considering many options for selection as it relies on pairwise comparisons.

Q methodology combines qualitative and quantitative approaches to study subjectivity, perspectives, and opinions (Brown, 1996). It was developed in psychology and has since been used in other disciplines, like sociology, political science, market research and public health (Valenta and Wigger, 1997). Q methodology is particularly useful when understanding subjective experiences, studying diverse viewpoints, and identifying patterns within these perspectives (Ramlo, 2016). After considering the different features of all three approaches and the specific needs of this research, Q methodology, or Q methods for short, was chosen for this study. This study uses it to rank (and weight) the resilience indicators used in the artefact/model.

Q methodology is a mixed methods approach that combines the richness of qualitative data and the statistical rigour of factor analysis (Watts and Stenner, 2012). According to Brown and Rhoades (2019), a Q methodology study typically has the following steps: 1) Statement generation, where a set of statements or items representing a range of viewpoints, opinions, or attitudes on the subject or topic of interest is developed; 2) Q-sort - where the set of statements are sorted by the participants into a pre-determined distribution according to their personal agreement or disagreement and qualitative information on their views is also gathered; 3) Data Collection - participants' choices in the q sort essentially represent their subjective perspectives on the topic and are entered into a q sort data matrix (one for each participant); 4) Data analysis - the data matrix is converted into a correlation matrix, and factor analysis is applied to identify patterns of similarity among the participants' Q sorts; 5) Interpretation - researchers can then interpret the factors by analysing the statements that are highly correlated which helps in understanding the underlying themes, viewpoints, and perspectives represented by each factor, 6) Triangulation - qualitative data collected through interviews and open-ended questionnaires can help validate and provide a more comprehensive understanding of participants' perspectives (Brown and Perkins, 2019, Brown and Rhoades, 2019).

The approach can help researchers understand the different viewpoints within and between participant groups concerning the research question by exploring the meanings, beliefs, and values associated with each perspective (Watts and Stenner, 2012). Q methodology is a participant-centred approach, and its use of mixed methods allows researchers to potentially capture the richness of subjective viewpoints of participants in a relatively non-intrusive and intuitive manner (Lundberg et al., 2020). Another advantage of the method is that it is relatively easy to train researchers and core modelling team members to use and deploy for data collection. However, data analysis of Q-sort data requires some expertise (Churruca et al., 2021). Additionally, the design of the research is time intensive as it requires a comprehensive literature review to generate the statements in the first stage, then the selection of statements that best reflect the research question and conducting pilot studies to finalise the statements before the data collection stage (Millar et al., 2022). The statements also need to be carefully translated into local languages so the meaning and intent of the statements are not lost.

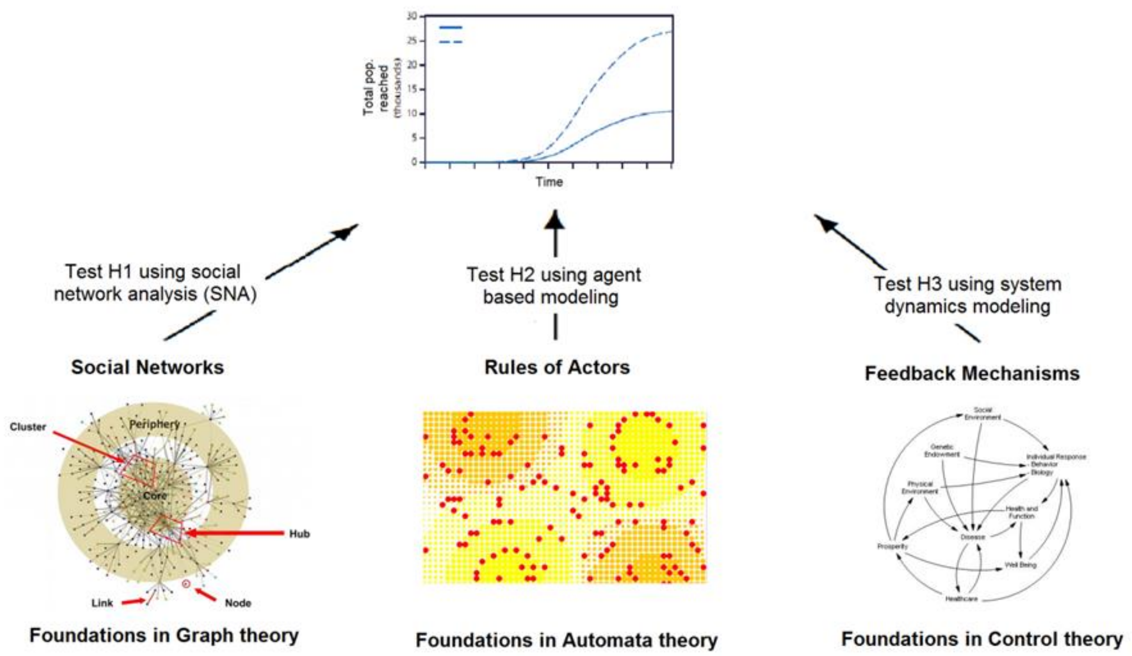
Q methodology is an excellent example of a participatory tool to study subjectivity and diverse perspectives on a topic (Brown and Rhoades, 2019). It can help researchers go beyond traditional quantitative and qualitative methods to uncover the complexity of human viewpoints on a particular topic and has been used in disaster management effectively in several contexts and settings (Raadgever et al., 2008, Huggins et al., 2015, Tariq et al., 2022). Chapter 5 will detail Q methodology, Q Sort interviews and their use in the case study to select indicators.

2.6 SD Modelling in Disaster Management

In addition to using participatory and more subjective approaches to defining and evaluating resilience, one of the critical limitations in many of the frameworks reviewed was considering the community holistically as a system and dynamically over time. Five of the frameworks reviewed (COPEWELL, ResilSim, ResilUS, CCAR, and PEOPLES) used a systems science approach, and three (COPEWELL, ResilSim and CCAR) use system dynamics to develop a model of community resilience over time. This section will review what systems science is and how it can be used to understand and model complex phenomena like community resilience.

Systems science is a set of methods investigating complex issues like climate change impacts, rapid urbanisation and sustainable development issues. It covers a range of methods and tools from several disciplines, such as engineering, social sciences, biology, physics, and others (Sterman, 2000). These approaches permit scientists to capture the complexities of difficult-to-solve issues and problems in a manageable form by providing a holistic approach while still capturing the problem's relevant features, allowing these methods to address both the system's elements and the bigger picture (Anderson et al., 2005). Neglecting the larger context and failing to capture the true complexity of the system may lead to spurious or inaccurate problem assessments, silo-thinking, unintended consequences and systemic failures, especially in the case of hard-to-understand and solve issues, called wicked problems (Jackson, 2017). One of the critical features of system science is understanding how different system components interact, resulting in emergent behaviour otherwise not observable when studied in isolation (Ramalingam et al., 2008). Ben Ramalingam argues that complex systems can be better understood using systems science methods to capture the nonlinear relationships generating feedback and emergent behaviour in a system to understand better and explore ways to address particularly difficult-to-solve issues called wicked problems (Ramalingam, 2013). A systems approach allows us to make sense of nonlinear dynamics when a slight change in one part of the system can lead to a significant and unpredictable change in another part (Ghosh, 2015). Systems science uses both qualitative systems thinking and more quantitative computer-assisted simulation modelling to help analyse these complex relationships and how different parts of the model might interact under other circumstances in group model-building sessions for testing “what if?” scenarios (Czaika and Selin, 2017, Langellier et al., 2019).

As mentioned above, systems science approaches can help researchers better understand the interconnectedness and interdependence of elements within a system, the feedback between them, and the emergent behaviour arising from these interactions (Maani and Cavana, 2007). System science methods can identify underlying patterns and relationships, generate predictive insights and help with problem-solving and decision-making (Gharajedaghi, 2012). Crucially, systems science is inherently transdisciplinary and encourages collaboration between researchers (and stakeholders) from diverse fields that may not otherwise be possible when covered by a single discipline (Stroh, 2015). In addition to those benefits, systems science approaches allow greater use of participatory tools for data collection and analysis, resulting in models based on direct information or the involvement of stakeholders (Voinov et al., 2016). Participatory modelling can help ground the model in real-world problems by capturing participants' perspectives in the modelling process (Baig, 2017). Including the perspectives and opinions of stakeholders can enable researchers to co-develop models and ensure a certain amount of validity in the topics and issues being covered (Basco-Carrera et al., 2017). Modelling approaches like Social Network Analysis (SNA), Agent-Based Modelling (ABM) and System Dynamics (SD) can then be used for more detailed insights (there are others, but for this study, only these three are considered).



(a) Social Network Analysis (b) Agent-Based Modelling (c) System Dynamics

Figure 2-10 Social Network Analysis, Agent-Based Modelling and System Dynamics (Williams and Hummelbrunner, 2010)

SNA, ABM and SD are the three most popular systems science methods used in the literature on disaster management and are summarised in Figure 2-10 above. The three methods may have some common features from complexity science but use different approaches to understand messy and wicked problems. For example, for research into separate actors and their behaviours in a system, SNA or ABM would be better suited than SD. SNA focuses on actors and the social networks in which they are embedded. If the research requires an investigation of individual rules that the actors follow in interaction with systems, then ABM would be better suited (Williams and Hummelbrunner, 2010). Alternatively, if feedback mechanisms between system elements are the focus, SD would be used to analyse this problem (Luke and Stamatakis, 2012). Table 2-10 summarises the salient features of each method (Luke and Stamatakis 2012).

Table 2-10 Overview of Three System Science Methods (Luke and Stamatakis, 2012)

Systems Property	SD	SNA	ABM
Model breadth	X		
Feedback loops	X		X
Dynamic systems in real time	X		X
Interactions of individual actors		X	X
Interactions between multiple levels	X		X
Complex relational structures		X	
Heterogeneous actors	X	X	X

All three methods allow the involvement and engagement of heterogeneous actors in the research, enabling researchers to capture diverse and dynamic views on how wicked problems or complex issues evolve in their environments or systems (Coetzee et al., 2016). Understanding dynamics, or how situations change over time, is crucial for community resilience to avoid simplifying resilience as a "snapshot" or a static point of time as communities constantly evolve (or devolve) and change is ever-present in the system (Cutter, 2018, Datola et al., 2019). Another critical factor in community resilience research is the interaction between multiple levels as decisions and inputs from higher levels (i.e., external support systems like funding or relief provision) can impact the system's lower or local levels (Feofilovs et al., 2020). Finally, feedback between the elements within a community system, such as the social, economic, environmental and physical infrastructures, constantly interact with and are somewhat interdependent (Asif et al., 2023). In the context of our research, SD was chosen due to its ability to capture local stakeholder perspectives and the feedback mechanisms among the different community dimensions and capacities that occur when designing disaster risk reduction interventions for preparedness and mitigation.

System Dynamics is an interdisciplinary approach to understanding and modelling complex systems (Sterman, 2000). It has been applied to various domains, including economics, environmental management, public health, urban planning, energy policy, and many more (Maani and Cavana, 2007). Its ability to capture the dynamics of complex systems and inform strategic decision-making has made it a valuable tool for addressing real-world challenges in various fields (Cimellaro et al., 2010). It is a computer-based research method that utilises software to mathematically model the dynamic behaviour of complex systems (Williams and Hummelbrunner, 2010). SD applies simulation modelling methodology to help strategy development and decision-making (Ford, 2010). Both ST and SD study the behaviour of a system, which is a function of its structure (Gharajedaghi, 2012). If an intervention, for example, a DRR program in the community, wishes to change behaviour, the designers should carefully scrutinise the system's structure to understand it better (Hovmand, 2014).

System Dynamics recognises that the relationships between variables can be nonlinear, meaning that changes in one variable do not necessarily result in proportional changes in another (Sterman, 2006). Nonlinear relationships contribute to the system's complexity (Ghosh, 2015). Ghosh (2015) shows that SD can help understand nonlinear processes in complex phenomena like policy resistance, unintended consequences, and counter-intuitive behaviour in social systems. SD is a participatory modelling approach that captures stakeholder perspectives using group model building (GMB) that takes this engagement to a higher level (Voinov et al., 2016).

Understanding dynamics, or how situations change over time, is crucial for community resilience to avoid simplifying resilience as a "snapshot" or a static point of time as communities constantly evolve (or devolve) and change is ever-present in the system (Cutter, 2018, Datola et al., 2019). Another critical factor in community resilience research is the interaction between multiple levels as decisions and inputs from higher levels (i.e., external support systems like funding or relief provision) can impact the system's lower or local levels (Feofilovs et al., 2020). Finally, feedback between the elements within a community system, such as the social, economic, environmental and physical infrastructures, constantly interact with and are somewhat interdependent (Asif et al., 2023). In the context of our research, SD was chosen due to its ability to capture local stakeholder perspectives and the feedback mechanisms among the different community systems that occur when designing disaster risk reduction interventions for preparedness and mitigation.

In our systematic review, three frameworks (COPEWELL, ResilSim and CCAR) used SD modelling to develop a holistic model with multiple interconnected dimensions that show resilience over time. This section will now provide an overview of the SD modelling approaches used in the three frameworks.

COPEWELL (Composite of Post-Event Well-being) by Links et al. (2017):

COPEWELL primarily focuses on assessing community resilience in the context of disaster events and evaluating the community's well-being in the aftermath. System Dynamics modelling simulates and measures the dynamic interactions between community systems, disaster events, and resilience-building strategies. COPEWELL assesses community vulnerabilities, capacities, emergency response, infrastructure, community functioning, organizational networks, population characteristics, economic recovery, well-being, education, learning, leadership, and governance. COPEWELL is often applied in disaster preparedness and response planning to enhance the efficiency and effectiveness of emergency response systems. The COPEWELL framework uses the County level in the US as a unit of analysis, aggregating resilience at that level due to data availability.

ResilSim by Irwin et al. (2016):

ResilSim primarily targets the simulation and measurement of the resilience of critical infrastructure systems. It employs System Dynamics modelling to analyze how infrastructure systems perform under stressors and shocks, focusing on physical and operational aspects. Considering their interdependencies, ResilSim models critical infrastructure elements like transportation, energy, water supply, and telecommunication. ResilSim is typically used to evaluate the resilience of infrastructure systems to various disruptions, including natural disasters, cyberattacks, and other disturbances. The ResilSim framework uses the city level as its unit of analysis. It can be disaggregated to provide insight into the network-level or neighbourhood-level analysis of critical infrastructure systems for modelling the physical resilience of the built environment and its impact on communities.

Coastal Cities Adaptive Resilience (CCAR) by Peck and Simonovic (2013):

CCAR concentrates on climate change resilience in coastal cities, mainly urban environments. It combines System Dynamics modelling with other tools to examine the complex interactions between urban systems, climate change, and resilience strategies. CCAR models urban systems, including infrastructure, transportation, land use, social factors, climate change impacts, and adaptation strategies. CCAR is used for assessing and enhancing the resilience of coastal cities to climate change, sea-level rise, extreme weather events, and other environmental challenges. The CCAR framework also uses a city-level unit of analysis but can be adapted to other levels and dimensions as needed. For example, modelling the health dimension of a city separately in case of pandemics (Lannigan et al., 2014).

Critical Considerations for Comparison:

These frameworks differ in their specific focus, whether it's disaster response (COPEWELL), infrastructure resilience (ResilSim), or urban resilience to climate change (CCAR). The frameworks encompass various components or dimensions in their System Dynamics models, ranging from community well-being and infrastructure to urban systems and climate change impacts. Each framework has distinct applications, with COPEWELL targeting disaster preparedness and response, ResilSim focusing on critical infrastructure resilience, and CCAR addressing climate adaptation in urban coastal areas. The complexity of the models varies, with some frameworks being more comprehensive and data-intensive than others. These frameworks involve interdisciplinary collaboration to consider various factors influencing resilience. Some frameworks (COPEWELL and CCAR) emphasize stakeholder engagement in the assessment process but are mostly limited to experts only. The choice of approach within the frameworks aligns with the specific goals and context of the resilience assessment they are designed for. In this research, the SS approach to modelling Community Resilience will be applied for use with communities at the local level.

2.6 Summary/Conclusion

This section reviewed current community disaster resilience frameworks and the methods and approaches used to define and evaluate community disaster resilience. Frameworks were assessed on whether they used subjective or objective approaches to define and measure resilience, what data collection methods they used, what data they depended on for assessments and what dimensions were included in the measurement process. Subsequently, the study revealed gaps in the CDR literature across the subjective-objective continuum. The review also suggested that more participatory modelling approaches like Systems Thinking (ST) and its more formal application, System Dynamics (SD), can be helpful tools in resilience measurement. ST and SD can be used together with perspective-capturing methods, like

Causal Loop Diagrams (CLDs), Q methods and Group model-building sessions (GMBs), to form resilience assessment tools that can be contextualized and adapted to users or stakeholder needs.

Chapter 3 Research Design and Methodology

3.0 Overview

This chapter introduces the research design and methodology adopted in this study. The appropriate choice of research methodologies can give a solid foundation for the structure of a study and can ensure the correct approach to data collection and analysis to achieve the overall objectives of the study (Anderson et al., 2005). This chapter presents the nested approach for determining the Research Philosophy, Approach and Techniques used in the research, as shown in Figure 3-1(Kagioglou et al., 2000). The chapter then details the case study and the participants used in the research for validation, followed by the validation process. Finally, a summary of the overall research methodology is provided.

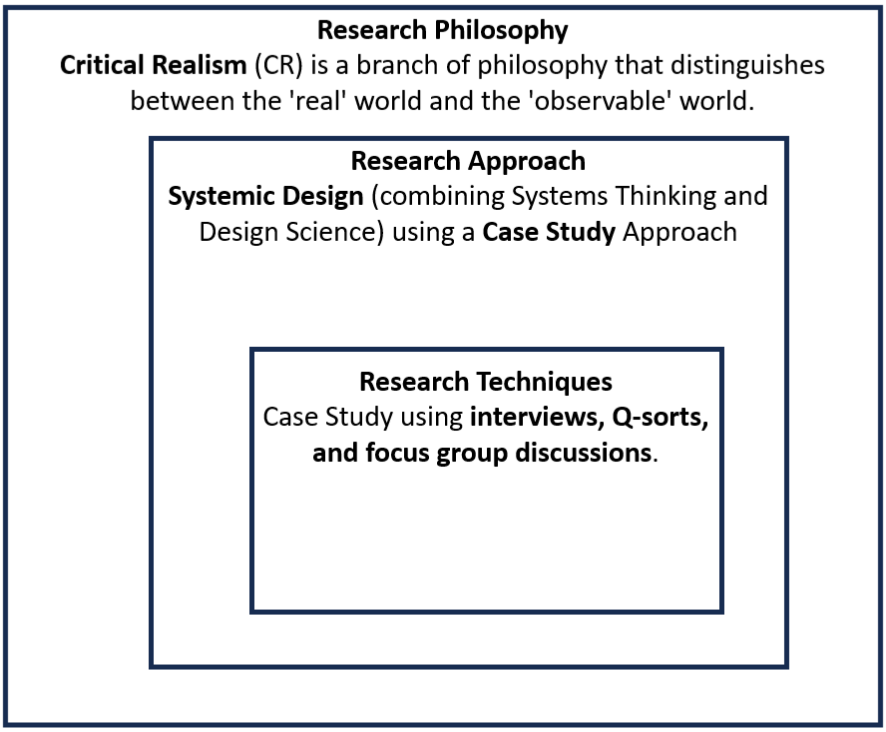


Figure 3-1 Nested Methodology Approach. Adapted from Kagioglou et al. (2000, p. 144).

3.1 Research Philosophy

To select the correct research design and methods, the researcher must understand the theoretical and philosophical positioning of the investigation (Saunders et al., 2016). The stated aim and purpose of this research is to develop a community-based participatory modelling approach to operationalise resilience measurement at the local level from the perspective of community stakeholders themselves. The phenomenon being investigated occurs in the real world, involving local government members, practitioners, academics and community members. It crucially depends on how they perceive and understand the world. One of the key objectives of this research is to develop an artefact that can measure resilience from stakeholders' perspectives. In this research, an artefact refers to a construct created to solve a specific problem or address a particular need within a given context. This artefact needs to be validated by those same stakeholders. The methods selected show a design science, participatory and subjective approach, whereby multiple perspectives about the phenomenon under investigation exist simultaneously, and a systems approach for considering the complexity and dynamics in a community system.

Although the research methods' literature suggests that there are no rigid boundaries for research paradigms (Saunders et al., 2016) but rather a continuum (Archer, 2016), for this research, the Critical Realism paradigm is considered the most appropriate philosophy. Critical Realism is selected due to the inclusion of subjectivity in developing the measurement tools and their application and validation in the real world (Jackson, 2019). According to critical realists, the "real" world exists independently from human perceptions, theories and constructs and cannot be "observed" (Mingers, 2014). As humans understand it, the world is constructed from their experiences and perspectives of the "observable" around them (Archer, 2016). Thus, according to Archer (2016), for critical realism researchers, unobservable structures cause observable events, and social phenomena can only be understood if people understand the structures (or systems) that generate them.

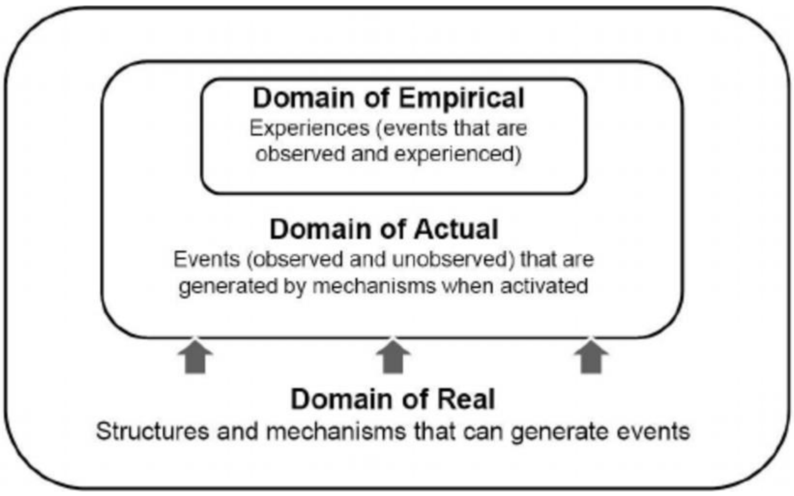


Figure 3-2 The Real, the Actual and the Empirical. Adapted from Mingers (2014, p. 12).

Mingers (2014) states that critical realists' reality is intransitive (independent of human thought) and hierarchically ordered between the real, the actual and the empirical, as shown in Figure 3-2. According to Bhaskar and Hartwig (2016), critical realists take an unexplained or partially explained phenomenon that has been observed (for example, in previous studies or research) and then propose a hypothetical mechanism that, if it existed, could explain that phenomenon at each stage, moving from one of the inner hierarchies to the outer in a process using abduction. Critical realism's main concern is the explanation in terms of the independent underlying mechanisms, which are generally unobservable in contrast to the empiricist approach, which limits itself to only the observable. Some critical realists emphasise the concept of Dialectical Critical Realism which considers the role of human agency and social structures in shaping social reality (Bhaskar and Hartwig, 2016). Dialectical Critical Realism explicitly states that social phenomena are influenced by individual actions and the broader socioeconomic structures that exist on the ground in a community or society (Roberts, 2014, Archer, 2016).

Keeping in mind the complexity of the disaster resilience concept and how debate still exists in the literature on its definition and composition – a critical realism approach in this study allows for developing an artefact that represents the concept of resilience from stakeholder perspectives. Using subjective means to define community resilience at the local level can provide a deeper understanding of the underlying determinants (observable and unobservable) of a community's resilience. Additionally, the complex and dynamic nature of community resilience requires using tools from systems science to complement the design science approach. These considerations are summarised in Table 3-1 Paradigms and their philosophical assumptions used in the research. As the last column in Table 3-1 shows, the study will use the design and systems science set of methodologies and employ a mixed-method approach using the methods available in the systems science or system dynamics to develop the participatory approach to modelling community resilience.

Table 3-1 Paradigms and their philosophical assumptions used in the research. Adapted from Jackson (2019).

Scientific paradigm	Ontology	Epistemology	Methodology
Post positivism Realism	Critical Realism Social structures do not exist independently of the activities they govern. They exist only in their effects. Social structures are localised and only hold true in particular cultures or for a finite period of time Reality is real but only imperfectly understandable	Modified objectivist findings are probably true; objectivity is worth striving for. Social systems are inherently interactive and open. Importance of a theory's explanatory rather than predictive power Meanings cannot be properly measured and compared, only understood and described	Design Science and Systems Science (Systemic Design) Mixed methods/triangulation Qualitative/Quantitative Case studies/systems thinking and system dynamics modelling

3.2 Research Approach

Research philosophy refers to the overall framework or worldview used to guide the creation, development, and evaluation of knowledge in the research process (Saunders et al., 2016). According to Saunders et al. (2016), the research approach or the methodology outlines the general steps, methods and procedures that should be followed to address the research questions and objectives. Since this research involves the creation of artefacts or solutions with stakeholders to address real-world problems, approaches such as the Design Science Research (DSR) methodology can help achieve the research aims and objectives of this research.

Design Science is a problem-solving approach that involves developing and evaluating solutions to address specific challenges or improve existing systems (Jones, 2014). It follows a structured process of problem definition, solution design, implementation, and evaluation

(Schwaninger, 2018). The Design Science approach can be beneficial in understanding stakeholder needs and requirements by providing a structured and systematic framework to tackle intricate and multifaceted real-world problems from the perspective of users (Blomkamp, 2022).

In design science, the term "artefact" is used to emphasize the tangible and purposeful nature of the outputs created through the design process. These artefacts are not merely theoretical constructs but are practical solutions that are designed, developed, and tested to address specific problems or needs (Venable et al., 2017). They are called artefacts due to the following reasons: 1) they are tangible and concrete and can be applied or implemented in a real-world context; 2) they are created with a specific purpose in mind and are designed to solve a particular problem, 3) their creation involves iterative cycles of design, testing and refinement, and 4) artefacts embody new knowledge and innovations derived from rigorous research by contributing to both practical applications and theoretical advancements in the field (Knutas et al., 2019). Therefore, the term "artefact" in design science underscores the practical, purposeful, and research-driven nature of the outputs generated through the design process.

In the context of DSR, an artefact is created through stakeholder engagement and involvement (Hevner et al., 2004). Artefacts are central to DSR because they represent the practical solutions or innovations that researchers aim to create through their work (Baskerville et al., 2009). These artefacts can take various forms, depending on the nature of the problem and the research goals. Crucially, DSR is user-centred, ensuring that the artefact created is relevant to user needs, creating a sense of ownership and leading to a greater chance of acceptance (Jones, 2014). DSR relies on question-driven research and uses a participatory approach, making it an appropriate approach for understanding stakeholders' perspectives in a system (Dresch et al., 2015). In this research, a community is considered a complex system that is dynamic and changes over time, requiring techniques that can also help capture this complexity. Systems Science techniques, like systems thinking and system dynamics simulation modelling, produce artefacts as an outcome and can complement the DSR approach used in this research (Blomkamp, 2022).

3.2.1 Design Science and Systems Science

Design science and systems science are complementary approaches that can be used to address complex problems, create innovative solutions, and improve the understanding of complex systems (Baskerville et al., 2009). Baskerville et al. (2009) have shown that both approaches can be used effectively in enhancing research into human organisations and processes such as the design of social policy or interventions. Equally important in this research is understanding the community context for measuring resilience. System Science approaches adopt a holistic view of problems by considering a broader context in which concepts such as resilience, hazards, and the community's capacity to deal with hazards such as floods, storms and other events are considered. This perspective can help researchers identify appropriate factors and constraints, leading to more contextually relevant and practical artefacts.

Additionally, Systems Science methods such as System Dynamics can explore feedback and dynamic relationships within systems (Sterman, 2000). Researchers can leverage this knowledge to create artefacts incorporating feedback mechanisms, adaptability, and resilience, making them better suited to real-world systems (Sterman, 2006). Finally, the iterative and adaptive nature of systems thinking aligns with design science's iterative design process (Venable et al., 2017). Therefore, System Science principles can guide DSR researchers in refining and improving their artefacts over time to ensure they align with the dynamic nature of the systems with which they interact. By integrating principles from both approaches, this research aims to address challenges in understanding and measuring community resilience more effectively and to develop a practical and theoretically grounded artefact.

The DSR approach and System Science methods (such as System Dynamics simulation modelling) are also similar in their application, and some of the steps they take for Problem Identification, Artefact or Model Formulation and Validation are almost identical (Hevner et al., 2004, Maani and Cavana, 2007). DSR has been primarily used in information sciences to create artefacts such as software applications, products, and process frameworks. In contrast, Systems Science is used for developing models of social, technical, and environmental systems (Dresch et al., 2015, Ghosh, 2015). Although their origins are different, they have many processes in common. They are similar in having user or stakeholder-centred approaches to creating artefacts or models that test or propose solutions to identified problems.

Some researchers have labelled this hybrid approach combining Systems Science and Design Thinking for policy modelling as Systemic Design (Jones, 2014). Systemic Design is an approach that can use both principles to help nurture and support putting systems and design thinking into practice in organisations working on social change (Ryan, 2014). Systemic Design, in practice, encourages learning and innovative thinking in those organisations (and through them in communities) working on developing interventions for any sustainable improvement in a community (Blomkamp, 2022). According to Blomkamp (2022) the approach seeks to build on the complementary strengths of each, where systems science approaches enable researchers to understand the complexity of the systems, while the design science approach can help jointly develop action plans for achieving desired outcomes at the community level, while both include the involvement of participants in understanding local issues and contexts. Crucially, the Systemic Design approach also allows for reflexive thinking that leads to active learning among users and participants which enables adaptive management of complex and difficult-to-define problems such as community resilience suffering from frequent hazard events (Battistoni et al., 2019, Moons et al., 2023).

Systemic Design and participatory modelling incorporate elements of auto-ethnography, offering a unique, insider perspective on the issues under study. In this research, the researcher is not just an academic observer but an integral part of the community and the academic community of experts addressing resilience issues relevant to a given local context. Moreover, the researcher has practical experience working with a non-governmental organization that implemented a Water and Sanitation program in the case study area following the 2010 floods. As a potential member of all the identified stakeholder groups (ie. academics, practitioners and the community), the understanding the researcher's positionality in the research is crucial.

Positionality is a key aspect of research, requiring the acknowledgement and critical examination of the researcher's social, cultural, and personal background (Pitard, 2017). These factors influence his/her perspectives, biases, and interactions within the research process. It is crucial to be transparent about one's identity, experiences, and potential power dynamics to ensure a more ethical and reflective approach to conducting research. This level of transparency not only helps mitigate bias but also reassures the audience about the study's integrity, fostering a more inclusive and authentic engagement with research participants (Luitel and Dahal, 2021).

According to Hovmand (2014), positionality plays a central role in participatory modelling, shaping the researcher's perspectives, biases, and interactions with community members. Researchers' social, cultural, and personal backgrounds influence how they design and facilitate modelling exercises, select participants, and frame research questions (Hovmand, 2014). The awareness of positionality is not just a tool for addressing power imbalances, but also a means to ensure equitable participation and authentic representation of diverse community voices (Phillips et al., 2022). By engaging in reflexive practices and acknowledging their own biases, researchers can mitigate the impact of their positionality, fostering a collaborative environment where community insights drive the co-creation of knowledge. This reflexivity is crucial for generating meaningful, contextually relevant findings that enhance community resilience.

In this research, positionality necessitates honest and transparent reflection throughout the process. This reflexivity helps researchers identify potential biases and mitigate their influence on the research process. Practically, the researcher's positionality can influence the dynamics of participatory modelling sessions, impacting how participants engage with the process. For example, participants may feel more comfortable sharing their experiences and insights if they perceive the researcher as relatable or trustworthy based on shared identities or backgrounds. Thus, appreciation of these elements in auto-ethnography enhances the understanding of the phenomenon being studied from a deeply personal viewpoint and links it to broader social and cultural contexts.

3.2.2 Systemic Design Approach

The systemic design approach is a problem-solving and design science-based methodology that focuses on addressing complex, interconnected issues by considering the entire system in which a problem exists. It is particularly useful when dealing with multifaceted challenges that involve social, environmental, economic, and technological factors (Jones and Van Ael, 2022)Using a systemic design science methodology in research requires a stepwise procedure to investigate the research problem using the appropriate techniques to achieve the stated objectives. Figure 3-3 below is a five-stage systemic design methodology for artefact creation, testing and validation.

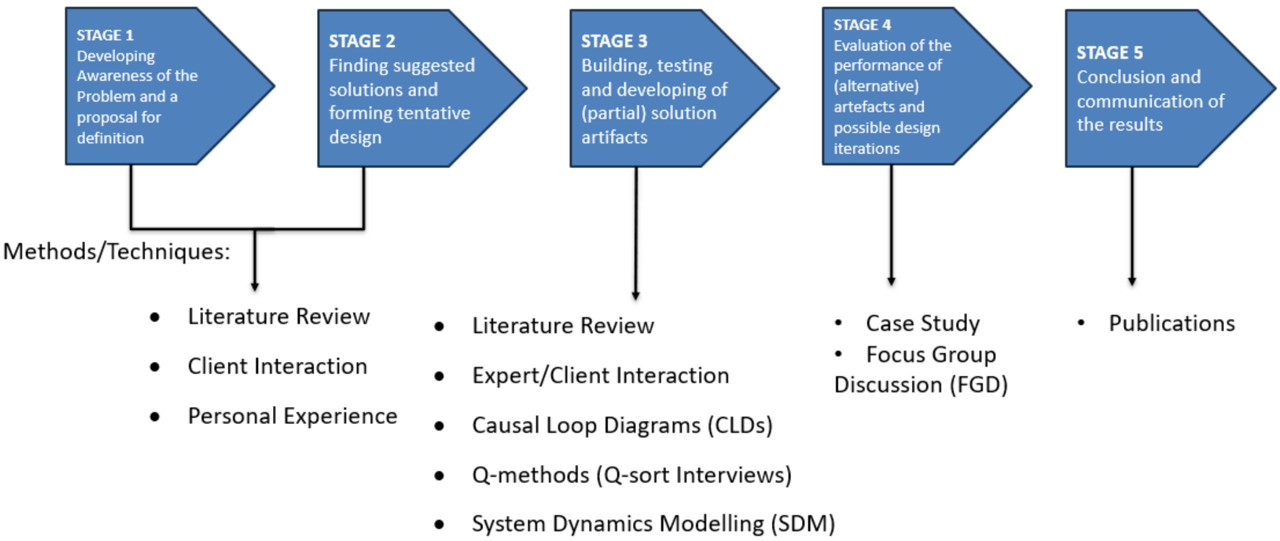


Figure 3-3. Stages in Systemic Design Methodology and the methods/techniques used (Lukka, 2003, p. 86)

Stage1: Developing Awareness of the Problem and a Proposal for Definition:

The first step in the process requires researchers to identify a real-world problem or need that requires a solution (Jones, 2014). According to Jones (2014), researchers can gather information, review existing literature, and engage with stakeholders to understand the problem's context and significance. The goal is to define the problem precisely and propose a research plan that outlines the objectives and expected outcomes of the study (Fernandez et al., 2013). One key aspect of Systemic Design research is using personal experience to inform the design or development of an artefact (Ryan, 2014). Personal experience of the context is used to ground the research in terms of previous interactions with the stakeholders, the problem issues, and/or the geographical context of the setting (Battistoni et al., 2019). Systemic Design enables the researcher to empathise with the stakeholders' needs, gain contextual insight, and reflect on their interactions and positionality within the research context (Jones and Van Ael, 2022). By integrating personal reflections into the design process, designers can create solutions better suited to communities' complex, interconnected challenges, ultimately contributing to more resilient and sustainable outcomes. A key benefit of using the Systemic Design approach is the potential for long-term cooperation between academic researchers and practitioners working on real-world problems (Lukka, 2003, Jones, 2014). Accordingly, it is vital to have a working relationship with experts and practitioners from disaster management organisations.

This research uses a comprehensive literature review to form an awareness of the problem alongside discussions with experts working in disaster management and community resilience. The researcher's interactions with practitioners and experts have indicated that there is a desire for an easy-to-use and applied participatory approach to measuring CDR. The literature also confirms the relative lack of participatory CDR frameworks that dynamically model community resilience over time.

Stage 2: Finding Suggested Solutions and Forming a Tentative Design:

Once the problem is well-defined, researchers review relevant literature and existing solutions to gain insights into potential approaches and design ideas (Ryan, 2014). A systematic review can help explore existing research, best practices and case studies relating to the problem and identify successful solutions and approaches employed in similar contexts. Based on insights gained from the literature review, expert consultations and, if possible, brainstorming or conducting ideation sessions with the end user group, researchers can begin to develop a conceptual framework or tentative design for the artefact that will address the problem (Battistoni et al., 2019). This artefact design is informed by theories, models, and best practices in the field (Blomkamp, 2022). It is essential to consider any constraints or resource limitations on the design process at this stage and propose a feasible and practical solution. In this study, several participatory mapping and modelling methods from Systemic Design are considered for CDR assessment and proposed for inclusion in a prototype resilience assessment approach.

Stage 3: Building, Testing, and Developing Solution Artefacts:

In this step, researchers create the actual artefacts or prototypes based on the tentative design which involves implementing software systems, developing models, or constructing physical prototypes depending on the artefact (Lukka, 2003). According to Vaishnavi (2007), the process often involves iterative development, whereby researchers build and refine the artefact through multiple cycles of design, implementation, and testing. Once a working prototype is developed, it can be tested in a pilot study to ensure functionality. When the artefact is ready for deployment or use, preparations can be made for field testing in a case study. For this study, a stepwise participatory approach was developed based on a combination of participatory methods for mapping and modelling community resilience.

Stage 4: Evaluation of the Performance of Artefacts:

After constructing the artefacts, researchers can evaluate their performance and effectiveness (Kuechler and Vaishnavi, 2012). According to Kuechler and Vaishnavi (2012), the goal is to assess how well the artefact addresses the defined problem and to identify any shortcomings or areas for improvement. This evaluation can take various forms, including usability testing, performance benchmarking, user surveys, expert reviews, and case studies (Fernandez et al., 2013). This research uses a case study to test the artefact in a field setting. A detailed explanation of the case study is presented in Section 3.3. As part of the case study, the Participatory Approach to Modelling Community Resilience developed in this research was evaluated in a focus group discussion (FGD) with participants from the three major stakeholder groups: academics, practitioners, and community members. Feedback from FGDs was then incorporated into the artefact to improve it further.

Stage 5: Conclusion and Communication of the Results:

In the final step, researchers draw conclusions based on the evaluation results by assessing the impact of the artefact on addressing the problem and whether it meets the defined objectives (Baskerville et al., 2009). For academic research, the priority will be to highlight any contribution to existing theory or practice and provide recommendations for future research. These recommendations can include further refinements to the participatory approach, potential applications, or areas for future research and development. The findings can also be communicated through research papers, reports, or other forms of dissemination that will enhance the value of the study.

3.3 Research Techniques

Research techniques, also known as research methods, are specific procedures, tools, or instruments used to collect, analyse, and interpret data or information during a research study (Kagioglou et al., 2000). The study will implement the stages shown in Table 3-2, first to develop the Participatory Approach to Measuring Community Resilience and then to validate the approach using a case study. The research process detailed here is an iterative process where learning can be reflected in improving the initial conceptual artefact in this research, namely the approach.

Table 3-2 Stages of Systemic Design Approach with methods used at each stage.

Stages in the Systemic Design Methodology	Methods/Technique Used	Chapters in Study
Stage 1: Developing awareness of the problem and a proposal for definition	• Literature Review • Client Interaction • Personal Experience	Chapter 1 Introduction Chapter 2 Literature Review Chapter 3 Research Methodology
Stage 2: Finding Solutions and forming a tentative design		Chapter 4 Participatory Approach to Measuring CDR
Stage 3: Building, testing, and developing of solution artefacts	• Literature Review • Expert/Client Interaction • System Dynamics Modelling (SDM)	
Stage 4: Evaluation of the performance of the artefacts and possible design iterations	Case Study • In-depth Interviews (IDIs) • Focus Group Discussion (FGD) • Causal Loop Diagrams (CLDs) • Q methods • System Dynamics Modelling (SDM)	Chapter 5 Systems Thinking and Mapping Chapter 6 System Design and Modelling

Stage 5: Conclusion and communication of results	• Publications	Chapter 7 Discussion and Conclusion

3.3.1 Case Study Approach for Artefact Validation

The Systemic Design Approach requires the use of a Case study in Step 4 to evaluate the artefact. Using case studies as a research method in design science research can provide valuable insights into the design, development, and validation of artefacts. Case studies allow researchers to investigate the effectiveness of an artefact in a specific context (Blomkamp, 2022). Thomas (2015) presents a step-by-step procedure to justify using a case study method, as shown in Table 3-3.

.

Table 3-3 Steps for Conducting Case Studies (Thomas, 2015)

Subject	Purpose	Approach	Process	
	Intrinsic	Testing a theory	Single	Retrospective
Outlier	Instrumental	Building a theory		Snapshot
Key	Evaluative	Drawing a picture		Diachronic
Local	Explanatory	Experimental	Multiple	Nested
	Exploratory	Interpretive		Parallel
				Sequential

The choice of subject (as with the rest of the steps) depends on the research questions being explored in the study. In this thesis, the research seeks to develop and validate a participatory approach for measuring community disaster resilience for local communities. The subject of the study to validate the approach would be an urban community historically vulnerable to a hazard type. The next step requires the researcher to define the purpose of the study, whether it is: (1) an Intrinsic study, where the purpose of the inquiry is of interest in itself; (2) Instrumental, where it is a means to an end; (3) Evaluative, to see how well intervention or change has performed; (4) Explanatory, for a deeper understanding of the phenomenon, or (5) Exploratory, where little is known, and the purpose is to know more about the nature of the problem. The research aims to develop, test and validate a participatory approach for modelling resilience, which can be considered explanatory (i.e., to understand how that community defines resilience and wants to measure it) and exploratory (i.e., to understand how participatory tools can define and measure resilience).

The third step requires selecting an approach. This research could be either by testing or building a theory, drawing a picture, an experiment or an interpretive approach. The analysis in this research can be considered as an application of the interpretive approach, as the study can closely observe how the different stakeholders operate in their local contexts. This research aims to develop an approach to assist community resilience stakeholders (such as local government officers, disaster management authority staff and community members) in defining and understanding community resilience. The approach developed and validated in this research could enable researchers and decision-makers to understand better how resilience can be conceptualised and operationalised at the local community levels by those stakeholders most relevant to the process.

Accordingly, from an interpretive approach, the study requires the selection of a single case study. Given the time frame and resource constraints, it is considered prudent to conduct a single case study in this research to build an understanding of how subjective participatory approaches can help stakeholders define and evaluate community resilience from their perspective and how valuable such approaches can be to improve the process of measuring and tracking community resilience over time.

Consequently, a vulnerable urban community in Peshawar City in Pakistan was chosen because it is a typical example of an urban neighbourhood in a high-hazard risk category that has historically been prone to regular flash flooding (more details in the next section). The case study area has also seen rapid developmental changes over the last two decades, resulting in an increase in the built environment, rapid population influx and other urban pressures.

POPULATION 2017	
Total Population	207,774,520
Urban Population	75,584,989 (36.3%)
Population Density Per Km^2	166.3
ECONOMIC INDICATORS	
Gross Domestic Product in Current $US	305 billion
GDP Per Capita ($US)	1547
GDP Growth (Annual %)	5.28%
HUMAN DEVELOPMENT	
Human Development Index	0.562
HDI Rank	150
Income Level Category	Lower-Middle income

Climate Risk Index
–
Rank 8 / Very High Risk*

INFORM Risk Index
–
Rank 19 / High Risk**

* Climate Risk Index of 2019 analyses the extent to which countries have been affected by weather-related losses between 1998-2017 (GermanWatch, 2019)

** INFORM risk index is a global tool which measures the risk of humanitarian crises and disasters based on 50 indicators assessing hazards, vulnerability and capacity (resources available to mitigate the impact) (INFORM, 2019)

Figure 3-4. Climate risk profile of Pakistan (Eckstein, 2021, p. 15)

3.3.2 Research Setting

In the global context, developing countries disproportionately face the impacts of climate change and extreme weather events (UNDRR, 2022). Despite being responsible for less than 1% of global greenhouse emissions, Pakistan is one of the hardest-hit countries from the perspective of climate-related natural disasters, as shown in Figure 3-4 (Eckstein, 2021). The country is prone to various natural disasters due to its location, topography, and climatic conditions (Waqas, 2022). The recent 2022 floods caused an estimated $40 billion loss and affected 33 million people, making it one of the worst disasters of the century in Pakistan (Qamer et al., 2023). Frequent high-intensity disasters significantly impact the country and its population, affecting economic growth, development and health outcomes, making achieving the UN Sustainable Development Goals difficult and resulting in slow progress and low outcomes on the Human Development Index, as shown in Figure 3-4 (Eckstein et al., 2019). With a population of 207 million, almost 75 million of which live in urban areas, Pakistan has been consistently ranked highly on the Climate Risk Index – ranking 8th in the world for most affected by climate-related disasters between 1998 and 2019 (Eckstein, 2021).

Table 3-4 Top 10 disasters in terms of people affected in Pakistan (SAARC, 2018, Harvey et al., 2022)

Disaster	Date	People Effected
Flood	**July 2022**	**30,000,000+**
Flood	28-Jul-2010	20,202,327
Flood	9-Feb-2005	7,000,450
Flood	8-Sep-1992	6,655,450
Flood	15-Jul-1992	6,184,418
Flood	2-Aug-1976	5,566,000
Earthquakes	8-Oct-2005	5,128,000
Flood	Aug-1973	4,800,000
Flood	Jul-1978	2,246,000
Drought	Nov-1999	2,200,000
Storm	26-Jun-2007	1,650,000

As shown in Table 3-4 above, floods are Pakistan's most significant and recurring natural disaster, affecting millions of people and causing substantial damage to infrastructure, agriculture, and livelihoods (SAARC, 2018). The country's geographical location, monsoon weather patterns, and topography contribute to the vulnerability of many regions to flooding (NDMA, 2018). Table 3-4 also shows that most floods occur when Pakistan experiences its annual monsoon season, typically from July to September. While crucial for agriculture, the monsoon rains can also lead to excessive and intense rainfall, causing rivers and streams to swell beyond their capacity, which may result in riverine and pluvial flooding (PDMA-KP, 2018).

3.3.3 Study Area

The community chosen for the case study is one of the high flood-risk neighbourhoods of Peshawar City in Khyber Pakhtunkhwa province (SAARC, 2018). The case study area is close to the University of Peshawar, the local research partner for this research, where the Peshawar Living Lab (PLL) was established in 2021 for closer engagement with local stakeholders and communities on disaster risk reduction and urban planning. After consultation with members of the PLL, the Budni Nala Basin (BNB) area was chosen as the study site due to its risk and vulnerability profile as well as its accessibility and proximity to the University of Peshawar. Additionally, there was a relatively high level of interest and involvement from local stakeholder groups in PLL activities, as well as the availability of local organisations willing to collaborate.

Peshawar City and the Budni Nala Basin (BNB) Case Study Area

This research uses the participatory approach developed in the study to investigate the impact of urban flash flooding in the Budni Nala Basin (BNB) area of Peshawar City, the largest city in Khyber Pakhtunkhwa Province (KPK) of Pakistan. Peshawar City is in the Peshawar valley, surrounded by the River Bara to the south and the River Budni in the north (a subsidiary of the Kabul River) and on the west by the Khyber Agency, a federally administered tribal area located in mountainous or hilly terrain leading to the border with Afghanistan. The BNB area runs from the North West to North East part of the City. Frequent urban flooding events have occurred in the area, most notably in 2002, 2008*, 2010*, 2012, 2014, 2015*, 2018, and 2022* (*major events) (Khan et al., 2022). The floods in 2022 had a relatively lower impact on the case study area than on the rest of the country due to the geographic location and role of the Kabul and Indus Rivers in those floods.

The City District of Peshawar comprises four Town (or Tehsil in Urdu) committees, subdivided into ninety-three Village Councils (VCs), and the BNB case study area consists of fourteen VCs located in the northern part of the city, as shown in Figure 3-5. According to the latest Census in 2017, Peshawar has a population of 4,331,959 people, and the fourteen VCs of BNB have a population of 410,032 (GoP, 2017). As mentioned above, Peshawar lies between two rivers, Kabul and Bara, which flow from the northeast and southeast of the city, respectively. Many canal drains and riverways flow in the city's northern part, rendering the area susceptible to floods, particularly in the annual monsoon season (July-August) (Hamidi et al., 2020). Peshawar is vulnerable to hydro-meteorological hazards because of its geographical location regarding water sources, unplanned city expansion and the lack of a coherent town planning framework (Tayyab et al., 2021). Figure 3-6 below indicates the VCs' exposure level in the BNB area to flooding from the Waterway. According to the last Census conducted in 2017 by the Census Bureau, Government of Pakistan, Sardar Garhi is one of the most densely populated neighbourhoods in the area. (GoP, 2017) According to Tayyab et al. (2021), due to the population influx into the area and the lack of planning, the exposure of people and buildings to flash floods has increased dramatically, making it difficult to assess the resilience of the local communities in BNB.

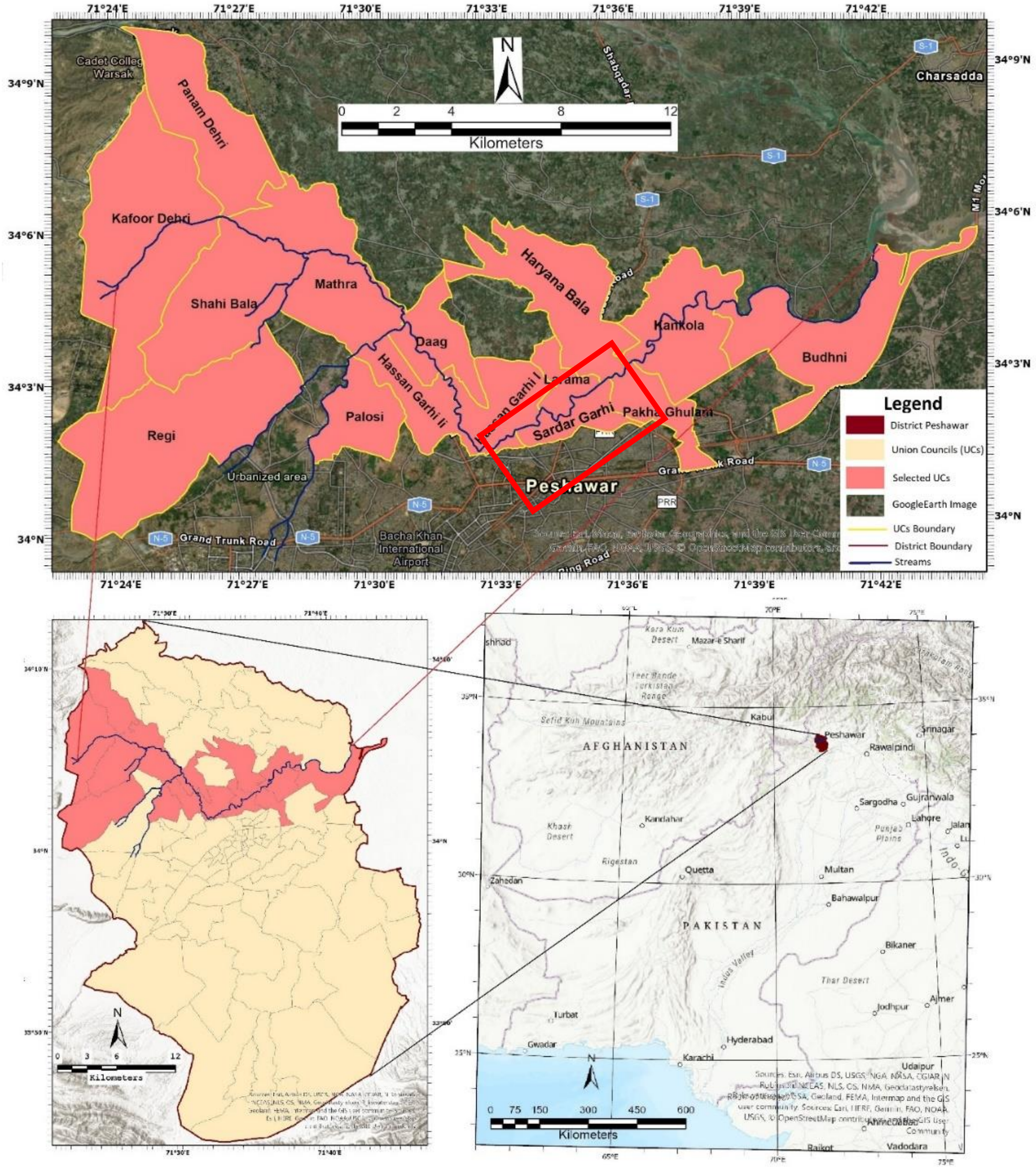


Figure 3-5. Map of the Study Area outlined in red.

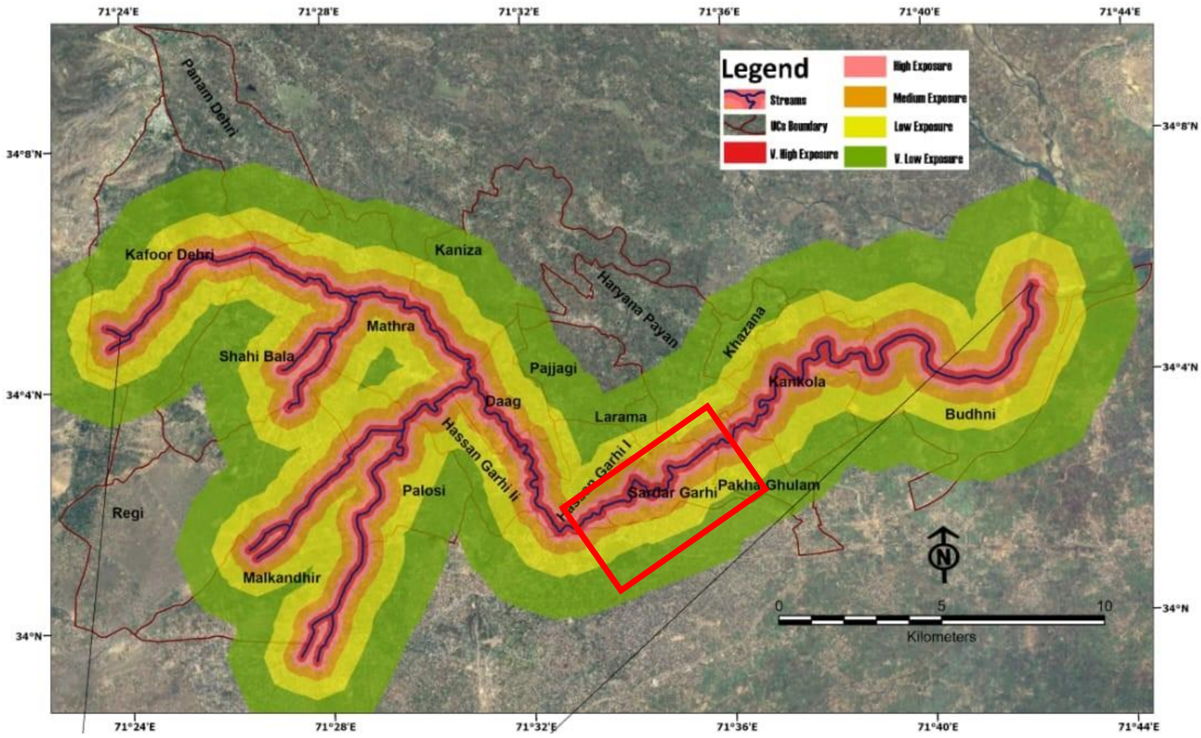


Figure 3-6. Flood Exposure Map of Study Area outlined in red (Ali et al., 2022, p.37)

3.3.4 Primary Stakeholders

To frame the systemic design approach, the research requires the involvement of a local stakeholder to participate in the study. The University of Peshawar (UoP), the local academic partner in the research, was asked to find any local organisations that might fit the research well. The stakeholder organisation needed to facilitate the investigation by providing access to the case study area and validating the approach used in the study. The local academic research partners at the University of Peshawar suggested organisations based in the area (which had previously participated in activities at the Peshawar Living Lab) which would be suitable for participation. For this purpose, the local chapter of a Non-Governmental Organization (NGO) operating in the area, called the Al Khidmat Foundation (AKF), was approached for participation in the study.

AKF is a local NGO dedicated to humanitarian and social development work. Established in 1990, Al Khidmat has grown into a network of volunteers and professionals committed to serving the needs of the local communities where it is based. The NGO has local chapters in the most high-risk Districts in the city and is staffed by community members from the local areas (employees and volunteers). Peshawar and the BNB case study area are considered relatively deprived, low-income and high-risk areas of the city and the AKF local chapter was set up to primarily address the shortfall in public services such as health and education among the marginal populations of the case study area. They run free schools (two primary and one secondary) and regularly operate health clinics with volunteer doctors and nurses in the area. During the last Flood Incident of 2022 (and in previous events since 2005) they provided food distribution to the affected areas and conducted free medical camps in the case study location. When contacted, the local chapter of the AKF agreed to participate and expressed interest in the research. They shared some of their concerns about the lack of resources, facilities and the future impacts of floods in the area. The AKF leadership were interested in any learning they could gain from participating as an organisation working on community issues.

In addition to the AKF, the primary stakeholders also included members of the Peshawar Living Lab (PLL), a coalition of experts, practitioners and community members who are all working on urban planning and risk-sensitive urban design as part of a larger research project being led by the University of Peshawar. The PLL was able to provide access to the experts and practitioners who were familiar with the case study area or were knowledgeable about the hazard. Recruitment of participants for the case study was initiated through the PLL, and letters (or emails for some academics and practitioners) requesting participation were sent through two channels: The University of Peshawar for academics and practitioners and the AKF for community members. Each participant was drawn from a list of participants who attended or participated in an event at the PLL at the University of Peshawar. Academics who participated were drawn from those academics who had either worked in disaster management or on the social and economic impacts of disasters in Peshawar City. Practitioners were drawn from a list of public sector organisations that worked on disaster preparedness, response, or recovery. Community members were selected by the AKF for participation and consisted of their own staff or local representatives who worked on social issues and, crucially, lived in the case study area.

3.3.5 Data Collection and Sample Size

As mentioned above, the research was facilitated by a local NGO called AKF. AKF provided logistical support to the researcher by helping contact participants, arranging transport to the researcher in the local area and providing locations for holding the FGDs in the study area. Figure 3-7 outlines the sample and composition of participants in the study across the stages (and chapter-wise). Nineteen respondents were interviewed for developing CLDs from the three identified stakeholder groups: Community members, academics, and practitioners. Nine respondents were from the community, five from academics working in social sciences and disaster management, and five practitioners working with disaster management agencies from the case study area. Nineteen was considered a sufficient figure as the same topics and issues began to be repeated, and it was felt that information saturation was achieved. After the CLD interviews were completed, one FGD was held to validate the merged CLD. Six participants attended the FGD. After obtaining feedback from the FGD, a final merged CLD was developed, describing the main resilience issues and the Community Resilience Dimensions most affected by hazards in the BNB case study area.

Once the CLDs were completed and the final Community Resilience Dimensions to be modelled were selected, Q-sorts on resilience assessment were developed for each dimension from the Library of Indicators in Chapter 2. These Q-sorts were then used in Q-sort interviews with a purposive sample drawn from the three stakeholder groups with the help the local academic partner at the University of Peshawar and AKF. A total of sixty-eight Q-sort interviews were conducted over three months – a more detailed breakdown of participants is shared in Chapter 5. A minimum of fifteen participants for each dimension, five from each stakeholder group, was thought sufficient from previous Q methods literature (Huggins et al., 2015). However, additional interviews were conducted for the social resilience dimension as a pilot (with eleven participants), and this was also added to the final number for analysis. An FGD for validating the Q-sort indicator selection results was conducted with five participants, resulting in the final selection of indicators (and their weights) to use in the System Dynamics model of Community Resilience.

It is important to note that of the 19 participants in the CLD interviews, only one was female. Similarly, of the 68 Q-sort interviews, only 7 were female. Although this may be considered a problem when investigating issues of social resilience, where demographic factors can play a critical role in overall resilience, in this research, the lack of gender balance in the sample can be explained and mitigated somewhat due to several reasons, such as the focus of the research and local cultural and religious sensitivity. The research aims and objectives focus on community-level impacts and aggregate these impacts across the entire community. The primary focus of the study was on broader community resilience mechanisms rather than specific demographic subgroups, which was a deliberate choice to address the overarching resilience strategies applicable to the entire community. If the main resilience problem was identified as gender-based in the community, then the stakeholder analysis would have shifted to include those organisations and groups responsible for catering to the needs of gender groups within the community. Additionally, the social and cultural context of working in Peshawar, Pakistan, a very conservative society where gender segregation is applied strictly in most social settings, required the researcher to consider local cultural sensitivities. Since the problem was not identified as gender-based, the researcher, who is male, took into consideration the local cultural and religious sensitivities, engaged with the local community as expected and interviewed male members of stakeholder groups but allowed the inclusion of female participants where possible.

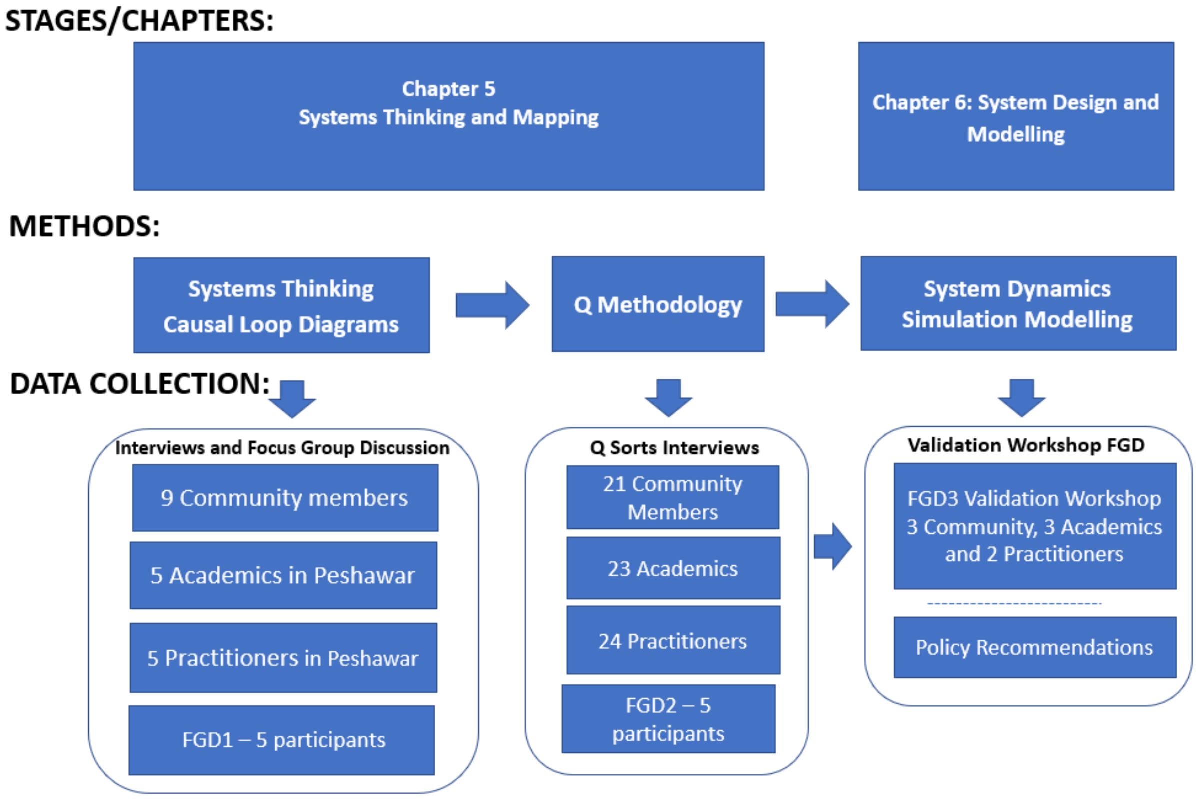


Figure 3-7 Sample size and composition

Finally, for the Artefact Validation, eight participants (three each from academics and the community, two from practitioners) agreed to join a Validation Workshop FGD on the Participatory Approach to Modelling Resilience. These participants had already participated in the Q-sort interviews and were familiar with the nature and purpose of the research. The three community members who participated belonged to the AKF, the NGO working locally on different resilience issues. The three academics all had a background in disaster management regarding the BNB area. The two practitioners who attended the FGD were section officers from the Disaster Management Authority tasked with developing disaster risk reduction programmes for the BNB area. The eight participants also discussed the Stakeholder Defined Scenarios (SDS) and provided feedback on the model refinement and testing stages. The feedback and comments contributed to the policy recommendations outlined in Chapter 7.

3.4 Artefact Validation

Artefact validation in systemic design research is a crucial step in ensuring that the designed artefact effectively meets its intended purpose and delivers the desired outcomes within the broader system it is designed for. Validation assesses the artefact's functionality and usability as an outcome from the defined problem or need. In this research, validation was used to evaluate the accuracy, reliability, and effectiveness of the Participatory Approach to Modelling Community Resilience utilising a case study. The following section covers the theoretical basis for Artefact Validation that was conducted with participants from the three stakeholder groups in the research: academics, practitioners, and community members. The primary application method was a semi-structured questionnaire administered to participants in a Validation workshop or FGD (Dresch et al., 2015).

3.4.1 Criteria for Artefact Validation (Theoretical)

Theoretical testing of an artefact in design science research involves assessing how well the theoretical foundation and principles upon which the artefact is based align with observed phenomena, existing theories, or established knowledge (Nickerson et al., 2013). Researchers in design science research have suggested theoretical testing for artefacts as a critical step to confirm that the design of the artefact is theoretically sound and that it contributes to advancing the understanding of a particular domain (Prat et al., 2014). Accordingly, Prat et al. (2014) have identified a hierarchy of criteria for artefact validation in design science research that can be used to assess if the artefact is appropriate for use in the context setting and these three primary criteria were used in this research, namely Goals, Environment and Structure as shown in Figure 3-8 below.

According to Prat et al. (2014), Goals consist of three criteria which cover: (1) efficacy, the ability of the artefact to achieve its goal or objective; (2) validity, which refers to its reliability in use where it will still achieve its goal if used in similar contexts, and (3) generality, where it can be used in more than one context (Prat et al., 2014). Similarly, Prat et al. (2014) also explain how the Environment in which the artefact is used conforms to or is consistent with the people, technology and organisation using it. Similarly, clarity, completeness, and level of detail are evaluated for the Structure of the Artefact.

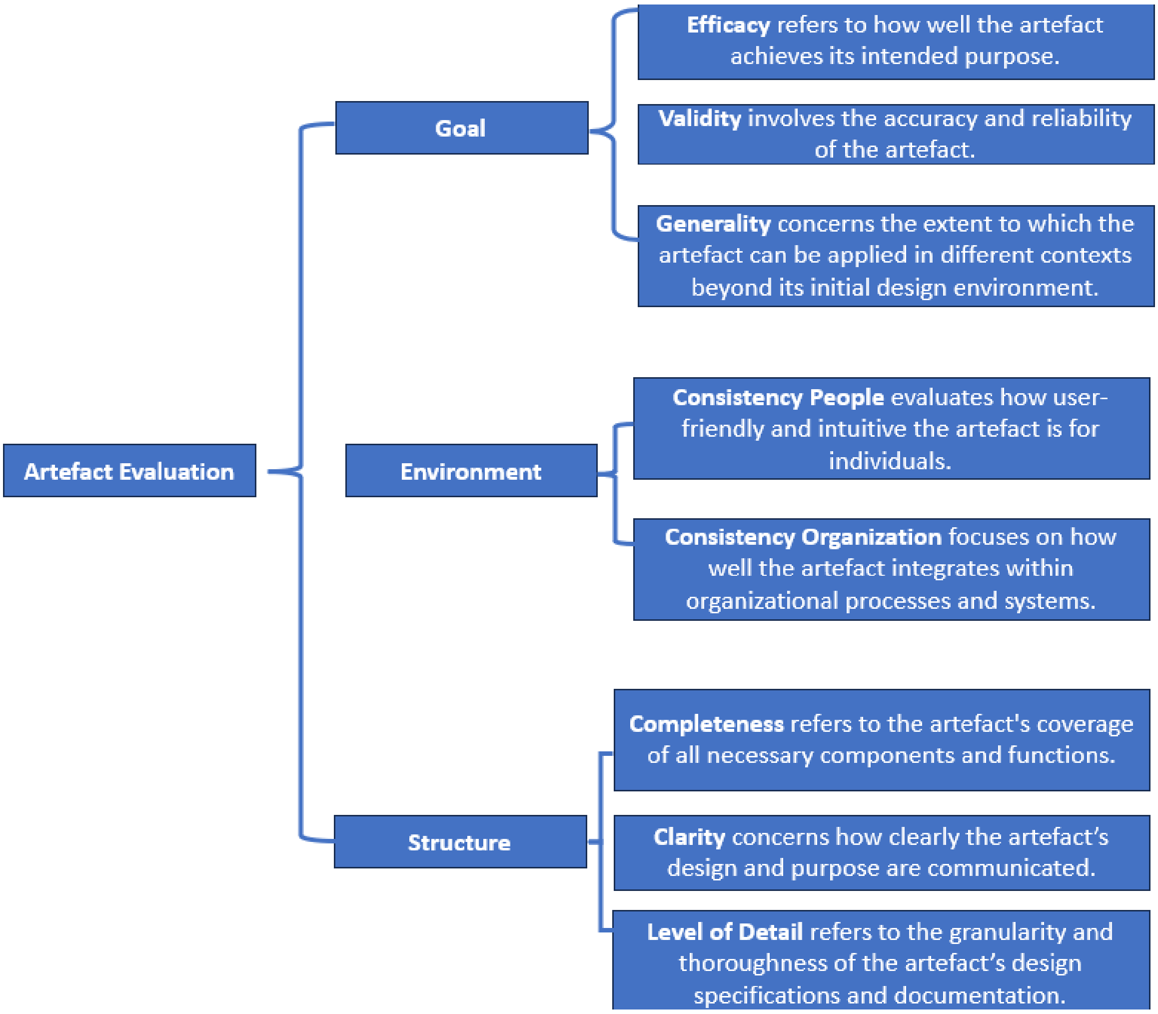


Figure 3-8. Selected Criteria for Artefact Validation. Adapted from (Prat et al., 2014).

Validation by Workshop using Focus Group Discussion

Focus group discussions (FGDs) can be valuable for artefact validation in design science research (Hevner et al., 2010). When designing and developing artefacts, such as software systems, physical products, or frameworks, gathering feedback from multiple stakeholders is essential to ensure that the artefact aligns with their needs, expectations, and intended purpose (Tremblay et al., 2010). Tremblay et al. (2010), recommend FGDs for validation because they are: (1) Flexible, they can be used in a wide range of topics and domains; (2) they enable Direct Interaction with Respondents, allowing the researcher direct access to domain experts and potential end-users; (3) FGDs generate a large amount of Rich Data, both qualitative and quantitative, allowing a more profound understanding of respondent reactions and the environments that the artefact might be used in, and (4) Building on Other Respondent's Comments, the FGD allows for interactions that encourage the emergence of ideas or opinions that will not usually be captured in an interview.

Two types of FGDs are used in systemic design research for artefact validation: (1) Exploratory FGDs, on the validation artefact design to propose improvements, and (2) Confirmatory FGDs, to establish the utility of the artefact in field use (Hevner et al., 2010). Two Exploratory FGDs were conducted with experts during the development stage of the artefact – one at the end of each data collection period to test and validate the outcomes. A final confirmatory FGD was held at the end of the case study to validate the Participatory Approach to Modelling CDR. For Exploratory FGDs, the duration was one hour, and for the Confirmatory FGD, it was two and a half hours at the end of the research.

The two exploratory FGDs were open-ended and focused on the outcomes of the two data collection stages. The final confirmatory FGD used a semi-structured Questionnaire to capture participant feedback on three aspects of the design: (1) Goals, (2) Environment, and (3) Structure, as explained in the previous section. The section on Goals asked participants about efficacy (i.e., does the artefact achieve its stated goal or purpose?), validity (i.e., can the artefact be used again in this context to achieve the same results?), and generality (i.e., can the artefact be used in another context for similar analysis?). For Environment, the questionnaire probed the participants on whether they or their organisation would consider using the artefact in their work. Finally, for structure, they were asked about the ease of use, comprehensiveness, and the level of detail it provides.

3.5 Summary

This chapter details the theoretical background and the research design being utilised in the study. It starts with a discussion of the methodological paradigm underlying the research design and then goes into further detail about the approach and techniques used in the study. Following a brief introduction to design science and systems science approaches, the researcher selected systemic design as the appropriate methodology to investigate the subjective development of tools for community resilience measurement at the local level. Subsequently, systemic design and its application were discussed. Finally, the case study was discussed, followed by the approach to validation used in the study. The next chapter will look at the artefacts developed in this research.

Chapter 4 Participatory Approach to Modelling Community Resilience

4.0 Overview

Chapter 4 looks at the development process of the Participatory Approach to Modelling Community Resilience proposed in this research. This chapter builds on the findings of Chapter 2 literature review and presents the artefact for achieving the following two objectives stated in Chapter 1:

Objective 2: To investigate a participatory approach for customising disaster resilience parameters (dimensions, capacities, and indicators) relevant to the local context being considered. (Sections 4.2 Systems Thinking and Mapping)

Objective 3: To create a computational model that can represent the dynamic nature of resilience parameters and simulate the level of disaster resilience in a community at the local level. (Section 4.3 System Design and Modelling)

Section 4.1 introduces the design of the Participatory Approach to Modelling Disaster Resilience. Section 4.2, on Systems Thinking and Mapping, covers the development of the participatory approach used to customise the CDR measurement from the community stakeholders' perspectives. Subsequently, Section 4.3 on System Design and Modelling develops the System Dynamics modelling approach that incorporates the outputs from the participatory approach from 4.2 to simulate the level of resilience in a community. Finally, Section 4.4 provides a summary and a link to the next chapter.

4.1 Designing the Participatory Approach to Modelling Resilience

As part of **Developing an Awareness of the Problem**, Chapter 2 reviewed current community disaster resilience frameworks and the methods and approaches used to define and evaluate community disaster resilience. The frameworks were assessed on whether they used subjective or objective techniques to define and measure resilience; what data collection methods they used; what data they depended on for assessments, and what dimensions were included in the measurement process. Subsequently, the study revealed gaps in the CDR literature across the subjective-objective continuum. Additionally, the review suggested that more subjective or participatory approaches are needed to improve the usage of CDR frameworks among stakeholders for resilience measurement. Participatory methods can increase situational awareness and diagnosis, ensuring the correct problem identification of resilience issues at the local level.

Moreover, using more subjective approaches for measuring resilience enables users or stakeholders to contextualize and adapt the assessment process to their needs. Designing CDR frameworks that are customisable according to requirements and context by using qualitative data and subjective indicators enables the co-creation of solutions for joint action at community levels (Maxwell et al., 2015). Such subjective-based CDR frameworks or combined mixed subjective-objective approaches improve problem identification regarding critical vulnerabilities and leverage local knowledge and experience to address Disaster Risk Reduction (DRR) issues at the local level (Jones, 2019).

For complex systems such as communities, recent literature has shown the benefit of involving participants in understanding the broader context and issues, the different perspectives involved, and how to potentially develop joint action plans, especially for climate change (Clare et al., 2017). To conduct a subjective community-level assessment of disaster resilience, the tentative design artefact includes participatory methods that map the complex and dynamic interactions of social, economic, ecological, and physical systems. Several of the CDR frameworks reviewed earlier used participatory approaches for capturing this complexity using tools such as concept mapping, network diagrams (Cimellaro et al., 2010), casual loop diagrams, behaviour over time graphs, stock and flow diagrams, computer models (Peck and Simonovic, 2013, Links et al., 2017), rich pictures and hazard ranking matrix (MacOpiyo, 2018) among many others.

Several "toolkits" have been published in Systemic Design and Systems Thinking research where participatory methods for making sense of complex systems are featured for use in the social policy planning and programme design fields (Williams and Hummelbrunner, 2010, Allen and Kilvington, 2018, GOScience, 2022, Jones and Van Ael, 2022). Allen and Kilvington (2018) categorise these tools according to three functions: (1) Understanding the System, (2) Co-designing Solutions, and (3) Monitoring, Assessing, and Adapting with all three functions supported by additional tools for dialogue and collaboration between the stakeholder groups involved in the design, as shown in Figure 4-1 below. In the context of this research, these participatory methods are used by participating stakeholder groups for the adaptive management of resilience in these community systems. These participatory tools ensure greater engagement among the stakeholder groups, both the experts and community members, by ensuring that the right problems are identified and addressed. Lay and non-expert groups, in particular, feel heard and thus engaged in the process, along with subject matter experts and practitioners who may be interested due to professional reasons.

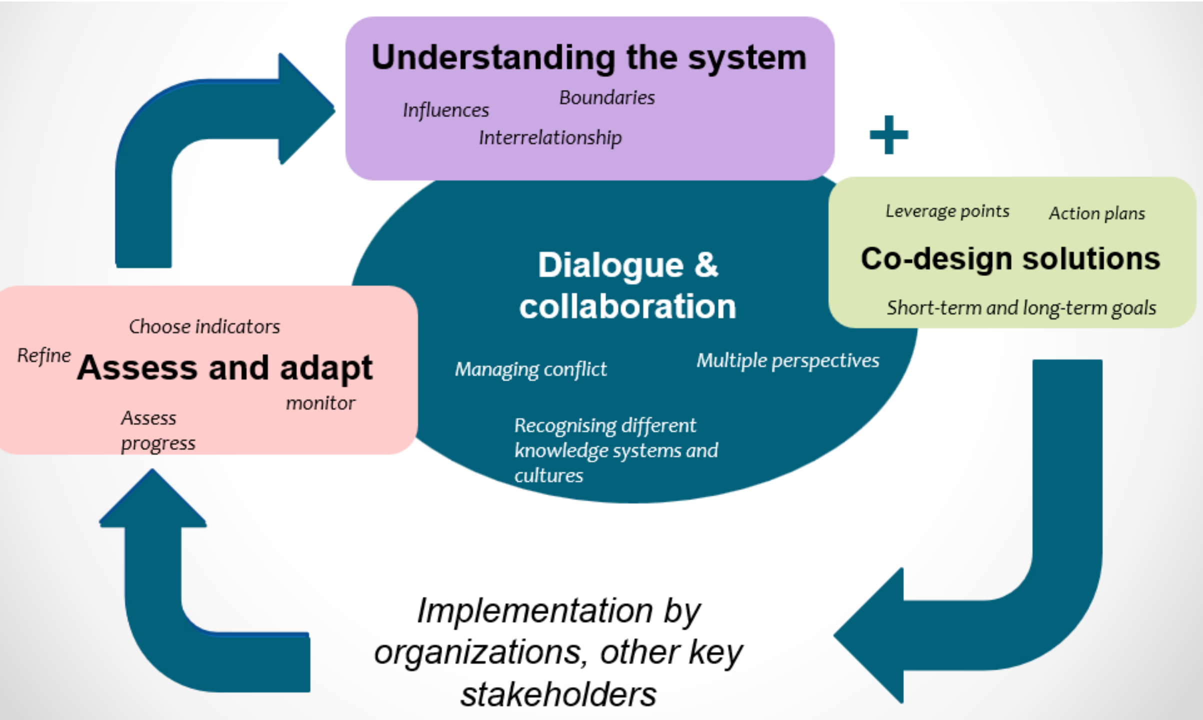


Figure 4-1. Systemic Design classification of tools/methods by function (Allend and Kilvington, 2018, p.30) .

Tools for Understanding the System help map the complex and dynamic interactions of social, economic, ecological, and physical systems (Williams and Hummelbrunner, 2010). According to Williams and Hummelbrunner (2010) these tools help describe situations systematically and focus on three core concepts common to all systems science approaches; interrelationships (how things are connected), perspectives (framings or world views), and boundaries (what to include and exclude). In other words, these tools and methods help 'see' things. The next set of tools is for Co-Designing Solutions; they provide deeper insight so that the leverage points can be identified, long and short-term goals can be set, and action plans developed (Allen and Kilvington, 2018). These tools or methods require more skill to build and deploy on the researcher's part, are more time and resource-intensive, and may use computer-assisted modelling tools such as system dynamics (Jones and Van Ael, 2022). These tools help find desirable solutions.

The third set is Monitoring, Assessing and Adapting tools to optimise the solutions (Allen and Kilvington, 2018). According to Allen and Kilvington (2018), these tools help monitor interventions, assess progress, and, if required, change direction to achieve desirable outcomes, such as the adaptive management of complex systems. These tools need the highest level of skill and motivation to apply and achieve considerable buy-in from stakeholder groups to participate in the process (Jones and Van Ael, 2022). These tools help assess progress for adaptive management. Finally, cross-cutting all these functions are tools for Dialogue and Collaboration which enable researchers to understand multiple perspectives, recognise different knowledge systems and cultures, and manage conflict (Jones, 2020, GOScience, 2022). In other words, tools for working together.
As mentioned in the objectives in Section 4.0, the design artefact needed to include understanding the local context of resilience through participatory approaches and customizing the parameters required for modelling. The design artefact consists of tools and methods from "Understanding the System" in the research for situational awareness and mapping the system to derive the context of the resilience assessment - from the stakeholders' perspective. Mapping the system leads to better problem identification for hazards affecting a community, its impacts, causes and consequences, and identifying the correct stakeholders to include in the participatory approach in the study. The next objective required the creation of a computational model that can model resilience at the community level. Accordingly, this research includes a method that allows for the "Co-design of solutions", namely system dynamics, to model resilience as a multi-dimensional dynamic variable that changes over time. Including the simulation model in the approach helps identify policy levers or leverage points that can help improve community resilience. Therefore, the artefact designed in this research achieves the objectives mentioned above by including participatory methods that help "Understand the System" and "Co-Design Solutions," as well as tools for Dialogue and Collaboration within the context of the approach to modelling disaster resilience. The third set of tools for adaptive management of interventions might be possible as an extension of the current research or future work as it requires greater formal organisational support and embedding within an intervention design process.

As part of "Finding Solutions and Forming a Tentative Design" (Step 2 in the Systemic Design methodology), the Participatory Approach to Modeling Community Resilience addresses some of the needs of the practitioner community by drawing on their knowledge, opinions, and beliefs. This approach co-creates tools that help develop fit-for-purpose resilience measurement instruments to support everyday decision-making processes. The approach developed in this research seeks to complement the existing decision-making structures. It offers itself as an additional support tool within the risk assessment process that may inform decision-makers of the resilience issues of the local community. The Participatory Approach to Modelling Community Resilience helps bridge the gap between decision-makers and key stakeholders such as disaster management authority staff, local government officers, and community members. The Approach achieves a more equitable form of resilience assessment where stakeholder viewpoints are shared among the groups and where tracking progress on local, national, and international commitments may improve the community's overall resilience. One additional important aspect that was mentioned in discussions with experts and practitioners and also found in the literature was that participatory tools must be relatively quick to deploy, cost-efficient, and easy to learn and use, especially if they are to be used in the community setting for investigating resilience (Williams and Hummelbrunner, 2010). Similarly, several studies have used a combination of systems thinking, participatory rural appraisal (PRA), and other action research tools to achieve greater situational awareness using relatively easy-to-use, cost-effective and time-efficient tools in public health, water resources and flood management (Inam et al., 2015, Albano et al., 2019, Asif et al., 2023, Moons et al., 2023)

The Systemic Design methodology strongly emphasises experiential learning across the research and design process, especially for the organisations involved. The Approach for Modelling Community Resilience facilitates knowledge exchange among the participants for understanding and measuring disaster resilience (Jones, 2014). Systems thinking tools for situational understanding are relatively easy to use, even for people unfamiliar with the language and terminologies used in systems science, hence, requiring a relatively lower investment of time and resources to learn (Allen and Kilvington, 2018). On the other hand, computer-assisted modelling methods, such as system dynamics, are more technical, requiring a significantly higher skill level, and it can be difficult to train people to use them without significant time and resources (Mishra et al., 2019). For ease of use and implementation, the approach must differentiate between an understanding of the system phase that does not require a high skill or expertise level for application and a modelling phase that requires a higher level of expertise to utilise the basic building blocks of system dynamics simulation modelling.

Accordingly, a stepwise participatory approach based on a combination of systems thinking and system dynamics modelling tools addresses some of these challenges. The approach seeks to engage key stakeholders (e.g., local government officials, disaster management officers, experts, and community members) in a conversation about community resilience, identifying the critical resilience issues and co-creating tools for measuring resilience. Participatory mapping tools, in conjunction with a System Dynamics simulation model, are used to test potential preparedness and mitigation solutions and to encourage awareness and discussion. The approach guides the CDR measurement process by proposing the use of participatory tools for data collection, an activity for index formulation, and a model that can be used to enhance understanding and provide analysis of resilience options for the community. The approach may be used to build consensus (or at least understand the disagreements) between groups on potential policies that address the core resilience problems faced by a community. Generating awareness of different perspectives is usually the first step to bridging the gap between stakeholder groups and can be instrumental in developing consensus (Stroh, 2015). The approach is divided into two phases: Phase 1, Systems Thinking and Mapping is used to understand the local risk context and develop the resilience measurement tool, and Phase 2, System Design and Modelling is used to model the resilience of the community at local levels and test policy scenarios for insight as shown in Figure 4-2. Each phase consists of six steps to implement in field settings easily.

The Systems Thinking/Mapping stage used in this research is covered in the following steps: (Step 1) Definition of the Problem, (Step 2) Stakeholder Analysis, (Step 3) Individual interviews, FGDs and Causal Loop Diagrams, (Step 4) Merged CLDs and Selecting Dimensions, (Step 5) Q sort interviews for Indicator Selection, and, finally, (Step 6) Index and Model Parameters for use in the next phase. The System Design and Modelling Phase includes (1) Model Formulation, (2) Model Refinement of the selected resilience dimensions (physical, health, economic, environmental, organisational, and social) and impacts, and formal parameterisation of the capacities of each Dimension, (3) Model Testing of the overall resilience model through structure-behaviour and reality tests, (4) Scenarios simulation, (5) Validation Workshop, and (6) Policy Recommendations.

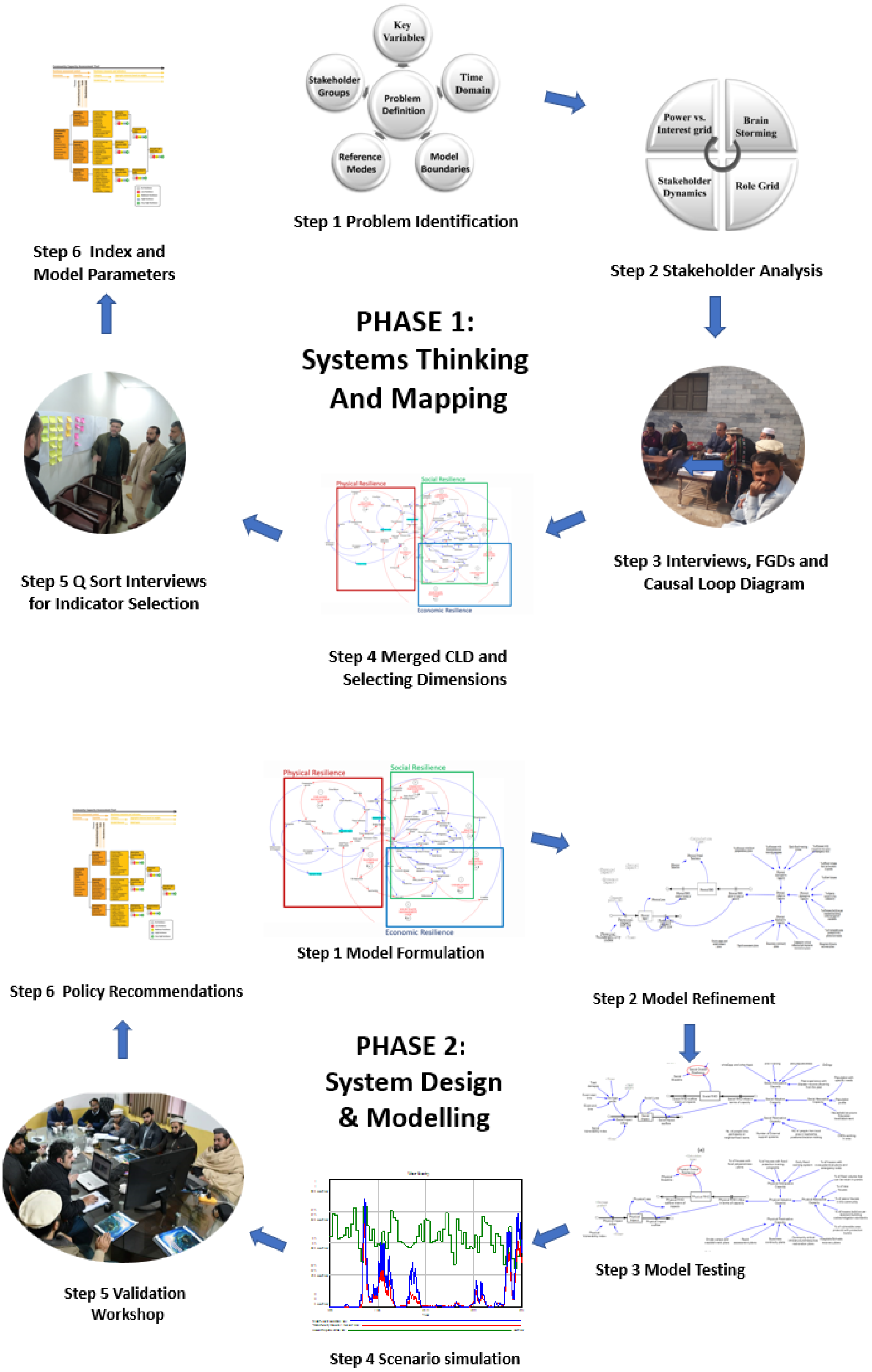


Figure 4-2. Phases and Steps in the Participatory Approach to Modelling Resilience

4.2 Systems Thinking (ST) & Mapping Phase

The ST and Mapping Phase uses participatory tools from systems thinking, such as CLDs, for systems mapping and problem identification. Similar methods have been used in several of the CDR frameworks in the review, whereby stakeholder involvement in the model-building process has been essential for the correct identification and scoping of the problem (Peck and Simonovic, 2013, Links et al., 2017, Elboshy et al., 2019). In CDR frameworks such as CCAR and COPEWELL, CLDs are used to develop conceptual, qualitative models of resilience issues faced by a community and to map the causes and consequences of major shocks and disruptions. Moreover, other frameworks in the review used participatory ranking tools to capture stakeholder viewpoints and perspectives on critical issues and identify the main factors for resilience assessment and analysis (Brooks et al., 2013). Frameworks such as CoBRA and TAMD use such ranking activities to identify community capacities and vulnerabilities and to develop indexes or scorecards to measure resilience at the local level (Jones, 2019).

Building on the design features from the CoBRA and TAMD frameworks, which use subjective measures to measure community resilience, a similar activity was designed to select dimensions and indicators from the library of indicators in this research. The library of indicators contains a collection of validated CDR measures categorised by six broad resilience dimensions: Physical, Health, Economic, Environmental, Organizational and Social Resilience. The activity enables users to choose their criteria for resilience measurement and contextualise community resilience assessment to local settings or conditions. Three participatory methods were considered for this selection or ranking activity: AHP, Delphi and Q methodology. Q methodology was chosen for the activity because it captures diverse viewpoints, can be used with small groups, and provides a statistically significant consensus on the ideal "set" of items or statements (Huggins et al., 2015). It is also relatively cost-effective, easy to use and can engage lay audiences with a simple ranking technique that can be used for data collection in community settings (Raadgever et al., 2008, Lundberg et al., 2020). The ranking and selection activity for the indicators ensures that the Participatory Approach to Modelling CDR has a subjective approach to selecting indicators to create an index to measure a community's resilience. The ability to adapt and customise the resilience assessment to suit the needs of local stakeholders may help stakeholder engagement in Disaster Risk Reduction planning and intervention design (Clare et al., 2017).

The phase is divided into six steps to represent the major data collection activities in the research. Steps 1 and 2 define the resilience problem at the community level and the stakeholders involved in the participatory research. Steps 3 and 4 include face-to-face interviews and require the development of CLDs to determine the causes and consequences of the community's major hazards and identify the significant resilience dimensions necessary for modelling in the subsequent stages. Steps 5 and 6 include the second round of interviews for the indicator selection and index formulation used in the System Design and Modelling Phase.

4.2.1 Problem Identification (Step 1)

Problem Identification is the first step in any systemic design or systems modelling project, as it identifies the nature of the problem, those involved in the process, and the trends or dynamics present in the system (Vennix, 1996, Battistoni et al., 2019). This step is grounded in the initial interactions with representatives of stakeholder groups and in a literature review on the problem area or issue to fully understand the potential complexity of the issues present in a system (Hovmand, 2014). In a recent flood risk management study, Perrone et al. (2020) recommend using the stepwise approach to problem definition, typically done in systems thinking, for identifying key variables, boundary selection and the time horizon. Similarly, the UK Government Office of Science (GOScience, 2022) report on systems tools also suggests using reference modes in addition to the above three steps. Accordingly, from the systems thinking literature cited above, the following five tasks are included in this step: (1) selection of the problem theme and key variables; (2) selection of the time horizon; (3) definition of the model boundaries; (4) development of reference modes (plotting the problem variable graphically over time), and (5) identification of stakeholder groups (iteratively updated throughout the research) (Hovmand, 2014, GOScience, 2022, Perrone et al., 2020).

Before beginning a community-based system dynamics study, Hovmand (2014) recommends conducting a fact-finding meeting (or a FGD) with the primary stakeholder group (local community or organisation) to gain situational awareness regarding the problem issues, the main stakeholder groups involved, the main variables affecting the problem and the historical trend of those variables. Additionally, in development and disaster management studies, awareness of local contexts is crucial for problem definition and understanding the underlying conditions before, during, and after a hazardous event (Pasteur, 2011). As mentioned in Chapter 2, several of the CDR frameworks reviewed use a combination of participatory tools from Systems Thinking and Participatory Rural Appraisal (PRA) to understand resilience issues at the local level better (UNDP, 2014). Phillips (2014) also encourages disaster researchers to use qualitative participatory techniques to understand a hazard event's conditions, causes, consequences, and chronology. Finally, from a systemic design perspective, Battistoni et al. (2019) recommend a Holistic Diagnosis of the situation with a combination of a desk study of the literature and an in-depth meeting or FGD with the "client" organisation or group requiring help with a real-world problem.

Accordingly, as part of this step, the Participatory Approach to Modelling CDR required a preliminary FGD with the community's primary stakeholder group to capture their views on the hazards and stresses faced by the community historically and their hopes and fears about the future. For example, in the case study used in this research, the primary stakeholders were identified as the Al Khidmat Foundation, a local Non-Governmental Organisation (NG0) working on social issues in the flood-affected area. The participants for the Focus Group Discussion (FGD) need to be selected based on the specific community involved, tailored to suit each unique context.

Table 4-1 and Table 4-2 shows some of the Participatory Rural Appraisal (PRA) tools adapted for the study. Other PRA tools and techniques from the literature can also be used if required, depending on the research problem and objectives. These techniques are used to rapidly understand the critical resilience issues that can guide a subsequent literature review and desk study.

Table 4-1. Hazard Risk Matrix. Adapted from MacOpiyo (2018)

	Variable Scores (Low=1, Medium=2 and High=3)					
Natural Hazard	**A: Likelihood of Event**	**B: Impact on population**	**C. Impact on livelihood**	**D Impact on Physical Infrastructure**	**E: Impact on homes**	**Total Risk Score = A(B+C+D+E)**
Hazard 1						
Hazard 2						
Hazard X						

In the Hazard Risk Matrix exercise in Table 4-1, the participants are asked to list the number of hazards the community faces locally and rank them according to the likelihood of occurrence and the magnitude of impact on the people, livelihoods, physical infrastructure, and residential houses (MacOpiyo, 2018). The Matrix provides an overview of the different hazards a community faces and their impacts on the various dimensions of the community. It can guide the subsequent design of the questions in the interview schedule used in the later steps.

Table 4-2. Analysis of Hazards and Stresses. Adapted from Pasteur (2011)

Hazard Priority 1:	**Issues and vulnerabilities**	**Capacities and opportunities for resilience**
Frequency, duration, seasonality, trends		
Warning signs, early warning		
Groups affected		
Assets and services affected		
Immediate response		

Building on the previous activity, the Analysis of Hazards and Stresses exercise requires gathering information on the hazard priority identified in the Hazard Risk Matrix. The activity includes the frequency, duration, trends, and significant incidents remembered in living memory (Pasteur, 2011). The exercise provides an overview of the issues and vulnerabilities of the community regarding warning signs noted and early warning mechanisms within the community (if any) and the groups and assets most affected by the hazard. It also gathers information on the response of the community. Once the issues and vulnerabilities are noted, researchers can discuss capacities and opportunities for resilience with the participants. The two exercises generate information which can help determine the time horizon (by noting the frequency and duration of events), the boundaries (by noting the magnitude and extent of impacts), and the reference modes (or behaviour over time graphs that show the trend of impacts over time) that can be used in the model design stage. The insights gathered during these activities are reviewed and confirmed by all participants before concluding the FGD. Any discrepancies or alternative perspectives are duly recorded by the researcher. The two detailed techniques can be combined with other PRA tools to gather information quickly and efficiently in a case study area and guide the design and implementation of the research instruments in the following stages. The information from this step can also be verified and double-checked with secondary data, such as administrative records, news reports, and other data from relevant sources, to ensure the validity of the findings.

It is important to note that the problem identification step is iterative and can be modified, if required, later in the process if it is found that important information or data was missed at the initial stage. Alongside these steps, a thorough literature review is conducted to identify critical themes and problems already identified in the area. The review might inform the researcher of a persistent and systemic problem that may have already been investigated and for which data might be available for use in the modelling phase of the research. Once the initial problem scoping step is complete, a thorough Stakeholder Analysis is done for a more representative stakeholder engagement.

4.2.2 Stakeholder Analysis (Step 2)

During the problem identification stage, careful attention must be placed on identifying the correct stakeholders in the problem under investigation for inclusion in the participatory model development and consultation process (Bryson, 2004). In the participatory modelling of social-ecological systems (SES), stakeholder analysis is particularly vital as it largely determines who to include in the data collection and group modelling process and at what stage (Reed, 2008). Several approaches to stakeholder analysis exist in the literature, depending mainly on the nature of the problem being investigated and the research objectives (Reed et al., 2009). This process can also be iterative as more information and data are collected on the problem issue(s), and more stakeholders may be revealed (Elsawah et al., 2015).

For this study, the researcher adapted the approach for stakeholder analysis used by Freeman (2010) which consists of 4 steps: (1) developing a list of all stakeholders, including marginal ones, through literature review and brainstorming, (2) categorising the list according to roles, (3) prioritising them for inclusion according to their attributes, and (4) selecting stakeholders for inclusion in the data collection according to the stakeholder analysis concerning the research problem. The four steps indicated above have been used effectively in several disaster management studies where participatory methods were used and hence are adapted for use in this study (Inam et al., 2015, Albano et al., 2019)

Experts	**Decision Makers**
Implementers	**Users**

Figure 4-3.Stakeholder categories' grid adapted from the European Commission (2003), p. 31

A system for classification of the stakeholders identified in the research can help decide who to involve in the subsequent stages. After forming a preliminary list of stakeholders from the literature review and brainstorming, the list of groups or organisations is categorised by their roles according to the European Commission (EC 2003) framework for determining their types, that is experts, decision-makers, users, or implementers as shown in Figure 4-3. The list can then be used for drawing a purposeful sample which can be contacted for participation in the study. This list can be verified and refined throughout the research process, especially during data collection. Additional stakeholder analysis can also be conducted to understand any stakeholder dynamics or changes in the stakeholder groups over time. The list of participants in the data collection can be further refined by classifying them according to three relational attributes based on their level of power, legitimacy and urgency within the system, as defined by Mitchell and Wood (2017). Conducting a stakeholder typology, such as in Figure 4-4, can help determine the definitive stakeholders in the resilience problem being investigated and the other stakeholders' power level and legitimacy. Power refers to a stakeholder's decision-making or change-bringing capability within the system. At the same time, legitimacy implies stakeholders have the legal or moral obligation to act, while urgency signifies for whom the problem is critical (Mitchell and Wood, 2017). Conducting a thorough stakeholder analysis can help significantly in selecting the right participants for the study, particularly for the validation needed in the case study.

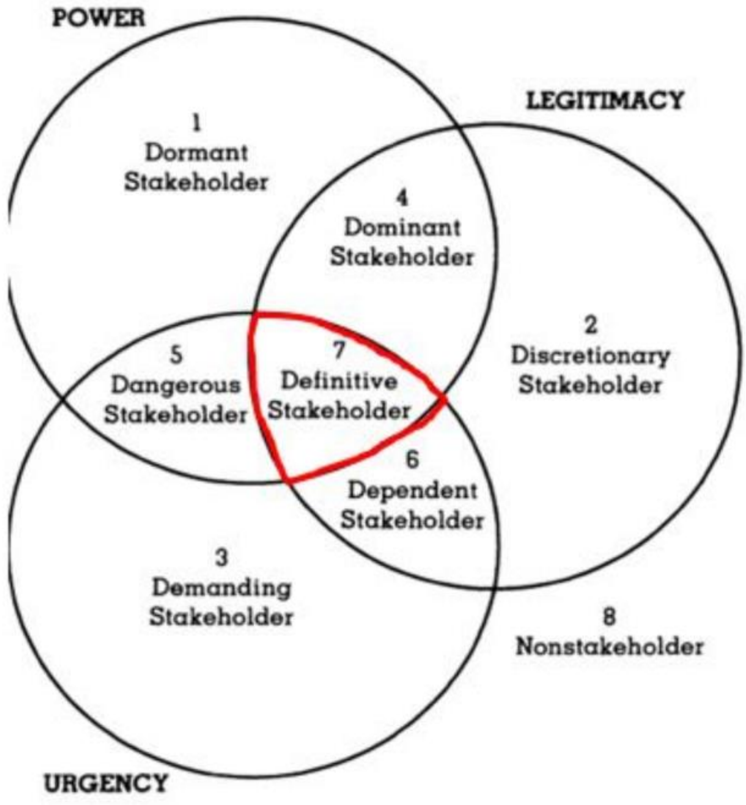


Figure 4-4. Stakeholder Typology. Adapted from Mitchell et al. (1997), p.874.

An analysis of stakeholder dynamics to refine and adjust the list of stakeholders should also be undertaken if there are potential delays or significant structural/political changes in the area during the data collection period. Delays and disturbances in the data collection period can mean significant changes to the situation on the ground, resulting in different local contexts that might not have been perceived at the beginning of a study.

4.2.3 Interviews, FGDs and CLDS (Step 3)

After the stakeholder analysis was completed, respondents were selected from the identified stakeholder groups for the individual interviews and FGDs in the study. In Step 3, interviews are used to develop CLDs of the problem issues a community is facing. CLDs are used because they can visually illustrate the main points clearly and quickly, and they can be verified with the respondent before the end of the interview (Schaffernicht, 2010). Once verified and combined into a larger CLD, they can be validated by a larger group in a FGD.

In this research, CLDs effectively describe participants' mental models and perspectives about the resilience problem issue or variable being explored, which can be probed in more detail during the interview (Williams and Hummelbrunner, 2010). CLDs can facilitate a better understanding of complex problems that different groups may perceive differently and have been used effectively in public health, water management, education and many other fields (Sherwood, 2011, Yearworth and White, 2013). For modelling resilience, CLDs are used to visually capture cause-and-effect relationships between variables and provide a language for describing the dynamics and interconnections between them in the system (Kiani et al., 2009, Yearworth and White, 2013).

In the interviews, participants were asked about the community's main hazards and some of the main resilience problems or issues that have affected them and their communities. Once the primary hazard is identified, the following seven questions adapted from Vennix's four steps (explained in Chapter 2) can be used as the interview guidelines (Vennix, 1996):

1) How has the resilience problem developed over time?
2) What are the main direct and indirect causes of the resilience problem's development, including link polarities?
3) What are the consequences of the resilience problem?
4) What are the primary feedback processes?
5) What kind of short-term policies can be adopted to solve this resilience problem?
6) What kind of long-term policies can be adopted to solve this resilience problem?
7) What are the main hurdles to the success of these policies?

During the interviews, participants were asked to identify the primary hazard impacting upon the community. Next, participants were asked about the causes of the hazard occurring or reoccurring (as the case may be). The objective of the interviews and the seven questions above is to get as much information as possible but in a structured form to identify the direct and indirect causes of the resilience problem from their perspectives and then to collect information on the direct and indirect consequences as they perceive them. Once both are identified, feedback loops can be identified and linked back from consequences to causes. Once causes and consequences have been noted, the short and long-term policies that might change or influence the system can be identified.

Using interviews and FGDs to develop CLDs is a constructive tool for stakeholder engagement. It has been used successfully in many applications, including complex social issues such as poverty, urban planning and flood management (Stroh, 2015, Albano et al., 2019). Other advantages of using CLDs are: (1) they require relatively little skill to make and can be made directly with stakeholders after a brief introduction; (2) they can be made quickly depending on the time given by the respondent or group (15 to 45 minutes are usually sufficient), and (3) because of the graphical aspect of the diagrams, they are relatively easy to understand by the stakeholders and hence helpful for closer engagement in fostering a sense of "ownership". The CLD map generated is beneficial for the subsequent modelling stage (Inam et al., 2015). CLDs can contribute to a sense of learning among participants by involving them in the modelling process, which can also be used to gain insight into other tangential issues (Ghosh, 2015).

4.2.4 Merged CLDs and Thematic Maps Development/Models (Step 4)

After completing the individual stakeholder interviews and their CLDs, the researcher can analyse, compare, and combine the diagrams into a merged CLD representing the overall views of all the stakeholder groups (experts, local government officials and community members). The CLDs derived from the process can be verified and validated in an FGD with a bigger group of stakeholders to create a final merged CLD. In this research, the final merged CLD also help researchers determine which dimensions to select for inclusion in the modelling process in the following stages of the study.

The merged CLD is colour-coded so it is easier to read with variables and feedback loops classified according to the six dimensions (Physical, Health, Economic, Environmental, Organizational, and Social Resilience) identified in Chapter 2 (Allender et al., 2015). The process of merging the CLDs into one larger CLD offers challenges and limitations where, for example, potentially vital information could be lost, or it can also lead to a very complex and unreadable diagram defeating its original purpose of enhancing understanding (Schaffernicht, 2010). The CLD of community-level resilience with six dimensions can be over-complicated and not particularly useful; hence, the application of simplification methods such as the Thematic Maps Development (TMD) approach developed by Asif et al. (2023) is utilised. The TMD method uses the following four steps: (1) classification of the variables according to their nature, i.e., Physical, Health, Economic, Environmental, Organizational, and Social Resilience dimensions; (2) identification and marking of overlapping variables that are common to one or more dimensions; (3) identification and labelling of the loops to avoid mixing the variables during the removal process, and (4) reduction, which involves dividing the complex CLD into different sub-dimensions as per the nature of the CLD being considered, such as physical, social and economic resilience (Asif et al., 2023).

The Thematic Maps Development (TMD) method allows researchers to simplify the merged CLD into smaller sub-modules, such as community dimensions. The key variables and loops of importance were placed in these sub-modules to form smaller models that are clear to read and follow. TMD can help simplify complex system models to help novice stakeholders understand while maintaining the system's integrity. Consequently, this simplification approach can help further increase stakeholder engagement in participatory modelling exercises. The TMD method allows for more focused discussions with stakeholders based on individual resilience dimensions and the study of the feedback loops within each dimension separately. On the other hand, the merged CLD can still be used to provide an overview of the whole system, the feedback loops in the overall system, and how the dimensions interact with each other through those identified loops. There can be many overlaps between the CLDs simplified by the TMD approach, but its application in previous studies has shown that using singularly focused themes for the diagrams means greater stakeholder understanding of the CLDs and, hence, greater engagement in the process (Inam et al., 2015, Asif et al., 2023).

The choice of which resilience dimensions to focus on is based on the case study participants and the resilience problem they have chosen for investigation, signified by the number of variables used to describe that issue. These dimensions' importance must be checked thoroughly and validated through the FGD. It is important to note that the individual thematic CLDs and the merged CLDs cannot infer quantitative relationships within the system but can help highlight the underlying issue or problem, identifying knowledge gaps between and within stakeholder groups and encouraging a greater understanding of different viewpoints between groups. In addition to the variables and dimensions, this step identifies the short- and long-term policies used (or proposed) to address the resilience problem. These policies are listed separately and can be used to develop stakeholder-defined scenarios (SDS) in the System Design and Modelling stage. Finally, the merged CLD and the list of policies are then shared in a validation FGD with selected participants from the primary stakeholder group or organisation to ensure the resilience issues and policies identified correspond to the actual ground realties of the community.

4.2.5 Q sort interviews and Selection of Indicators (Step 5)

After the thematic models have identified the main CDR dimensions to model, the next stage of the process requires the selection of the indicators to operationalise CDR measurement. Q-methodology enables participants to sort through the Library of Indicators (developed in Chapter 2 and shared in Appendix A) and select the most appropriate indicators according to their preferences to build an index to measure community resilience, called the community capacity index.

Q methodology is a mixed methods approach for investigating qualitative, subjective perspectives which uses a quantitative method for ranking preferences (Barry and Proops, 1999). It involves sorting and ranking statements or items based on subjective viewpoints (qualitative), followed by statistical analysis to identify patterns and clusters of perspectives (quantitative) (Watts and Stenner, 2012). The approach is ideally used when there is a wide range of potential perspectives around an issue or topic, especially when the problem issue is not easy to define (Zabala, 2014). The Q method approach can investigate multiple contrasting views on an issue and help the researcher find a statistically significant factor or an "ideal" Q sort representing a consensus among the views (Alderson et al., 2018). The technique provides transparency around the qualitative data collected and a scientific basis for selecting a set of items, statements or indicators, as in our resilience case study. Q methodology can also be used to generate a set of weights based on the factor scores generated from the statistical analysis that can be used in the modelling stage (Brown and Rhoades, 2019, Ma et al., 2023)

As the dimensions of resilience are identified through interviews and CLDs, the library of indicators can be used to generate the required list per dimension. The list of indicators can be reviewed and contextualised for the case study context and location to consider the ground realities and practical considerations of the stakeholders involved in the process. Particular attention should also be given to the wording and language of the text of each indicator set to make sure they are easy to understand in the local context. After contextualising the indicators, the final list can be prepared for the Q-sorting exercise to be used in interview settings with participants. Q-Sort interviews typically include some basic background questions followed by the Q-Sort exercise. This study uses the Q-Sort to select and rank the preferred indicators to measure the resilience dimension under consideration. After completing the Q-Sort, participants are asked for the reasoning behind choosing the most (and least) important set of indicators. By selecting and ranking the statements, participants reveal their preferences. The Q-Sort data generated from the interviews can be used for statistical analysis while providing rich qualitative data on why those indicators were chosen or rejected.

The sorting process allows stakeholders to prioritise essential indicators in the CCI per dimension, ranking them in order of preference from the most important (+3) to the least important (-3). The Q-Sorts exercise uses a forced choice, a quasi-normal sorting distribution designed for use with a 16-item Q-set per dimension. The distribution contains seven ranking values ranging from +3 to -3, which sets the number of items at each value (one at +3, two at +2, and so on). The Q-Sort distribution is shown in Figure 4-5 below.

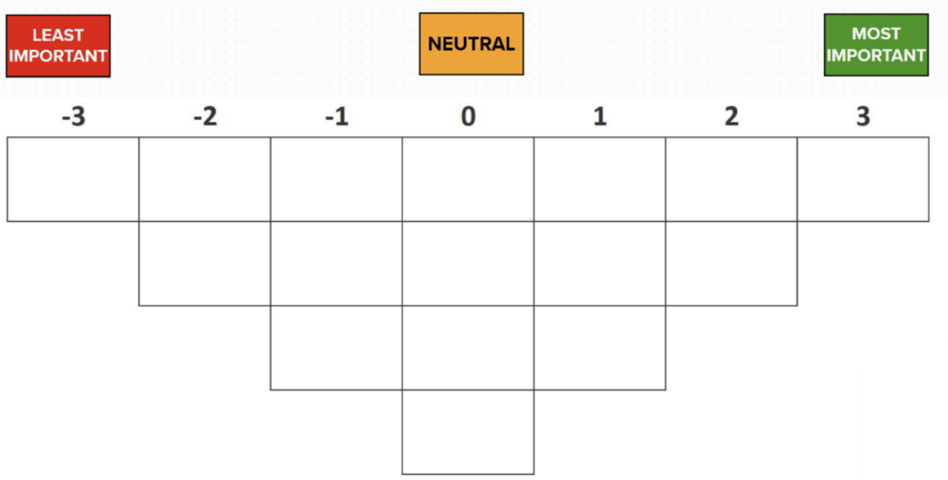


Figure 4-5. Example of the Q-Sort table used in the study. Note that each box represents a statement or indicator of community resilience as determined from the literature.

After the data collection, the Q sorts' data sets can be compiled in Microsoft Excel and used for analysis in Ken Q Analysis v2.0.0 – a free online Q methods software (Banasick, 2023). Ken Q Analysis was developed by Shawn Banasick, a Ph.D. researcher with a programming background, in 2018 to facilitate and encourage researchers to use Q methods in their research. The analysis can generate descriptive statistics to find the average rankings in the three groups and then combine for all the groups (Tariq et al., 2021a), followed by Centroid Factor Analysis (CFA) to capture the underlying patterns in the data that may help in understanding what major perspectives emerge from the combined groups as factors (Watts and Stenner, 2012).

CFA entails analysing the patterns of commonality between the Q-Sorts by first looking at the correlation or degree of similarity between each Q-Sort and then extracting a portion of the common variance explaining the similarity one factor at a time (Akhtar-Danesh, 2017). The varimax rotation technique is used on the factor loadings' matrix to make the factors more interpretable (Brown and Rhoades, 2019). The analysis results in an ideal Q-Sort representing each significant factor illustrating the perspective that emerges from the whole dataset. The factors are checked for significance using the Kaiser-Guttman criterion, the Scree Plot test and Humphrey's rule (Watts and Stenner, 2012)These three statistical tests ensure that the total number of factors considered ideal Q-Sorts is significant for analysis.

These factor-wise ideal Q-Sorts can be used to understand what statements (or indicators) are the most important from the perspective of the participants in the study – leading to identifying the consensus (and disagreement) statements between them (Alderson et al., 2018). Once the factors are identified, CFA also shows how much of the variance between the Q-Sorts is explained by each factor and their relative scores in the ideal Q-Sort (Brown and Rhoades, 2019). In this research, the explained variance between the factors and their relative scores can be used to derive weights for each indicator statement that can be used as parameters in the System Design and Modelling stage. The weights for the indicators are based on the degree of consensus (or disagreement) among the participants in the study and are proposed as a novel way to derive weights for an index based on participatory methods such as Q methods for System Dynamics modelling.

In addition to using Ken Q Analysis software to quantitatively analyse the Q-Sort data, Nvivo 12 can be used to analyse the interview data qualitatively. The Q-Sort interview schedule, which includes questions on the participant's background and the reasoning behind the selection of the top and bottom three indicators, is shared in Appendix B.

4.2.6 Index Formulation and Model Parameters (Step 6)

In the final step, the Community Capacity Index for every identified dimension is operationalised to provide a stakeholder-defined resilience assessment tool to measure community resilience according to their requirements. The Community Capacity Index ensures a more "fit-for-purpose" assessment tool based on the community's key stakeholders' perspectives, experiences, and needs. The Community Capacity Index is an index of selected indicators for each dimension that is then aggregated into a CDR score for use in the SD modelling stage. The Community Capacity Index is formulated using the composite indicators' construction method proposed by Wong (2006) and is summarised in Figure 4-6. below. According to Wong (2006), developing a composite indicator requires a thorough understanding of the measured concept. Chapter 2 in this study conducted a systematic review of 36 CDR frameworks, including a textual analysis that resulted in 360 measures being compiled into a library of 86 indicators further divided into six dimensions: Physical, Health, Economic, Environmental, Organizational, and Social Resilience dimensions. The systematic review provides a solid conceptual basis for the composite indicator construction being undertaken in the research.

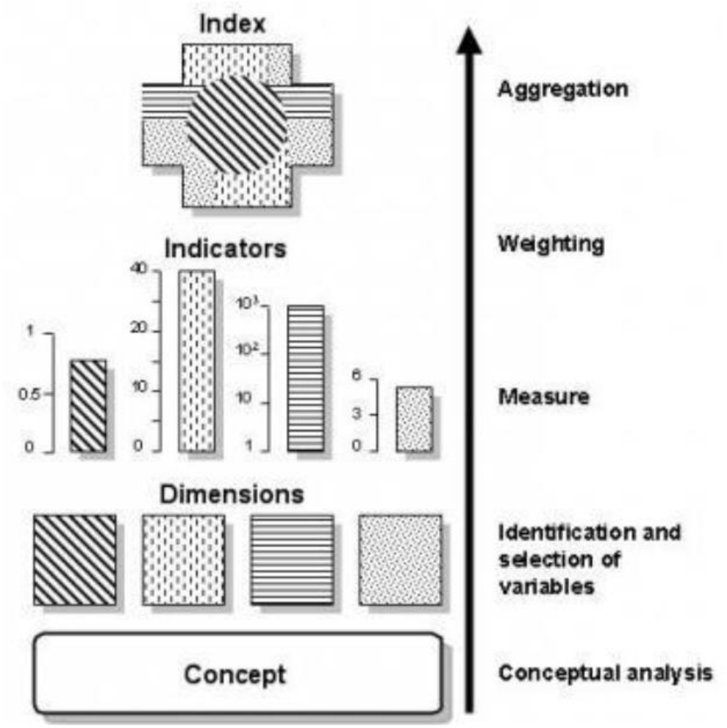


Figure 4-6. Composite indicator construction method (Wong, 2006, p.109).

It is vital to confirm that the indicators in the library do indeed conceptually measure community resilience to the hazard selected and are relevant for each application of the participatory approach to measuring resilience used in this research. Steps 1 and 2 in the ST and Mapping stage ensure that the research problem identified (i.e., resilience issues in a community) is appropriate and relevant for conducting a bottom-up community disaster resilience assessment as proposed in this research.

Following the method described in Figure 4-6, the merged CLD generated from the interviews in Steps 3 and 4 provides the basis for selecting the appropriate dimensions to include in the modelling process. Step 5 provides the basis for ranking the indicators according to the participants' preferences in the research and provides a mechanism to generate weights for those indicators using factor scores from the Q methodology analysis. It is important to note that although the indicators (and measures) used in the research have different units and scales, they are normalised and converted to become unitless for aggregation into a score (between 0 and 1). Step 2 of The System Design and Modelling stage goes into the mathematical explanation of this process.

Finally, Step 6 develops the final aggregated Index that can be used as an input into the System Design and Modelling stage. As a stand-alone assessment, the Index can generate a score representing the Community's Capacity as a "snapshot" at one point. Additionally, the scores can be used as parameters for developing targeted interventions and act as inputs into the system dynamics modelling process in the next phase. This Community Capacity Index allows for greater customisation and adaptability to the disaster resilience context of a specific community. These scores can also be used to compare resilience across communities, but with a caveat, as the different stakeholders participating in the process may create very different Capacity Indices. Hence, this is a key limitation of the approach. Community Capacity Indices can be used as parameter inputs into the CDR system dynamics simulation model that can be developed to test the 'what-if' scenarios of potential strategies and policies identified in the previous step.

Once the indicators have been selected, they are compiled into an Excel sheet, as shown in Table 4-3. Each indicator in the Index corresponds to a specific decision rule based on the indicator's logic. Table 4-3 presents the Social Resilience indicators from the library for illustrative purposes as a representative index after CCI construction. For example, Anticipatory capacity can be measured by the overall level of community participation in DRR, the availability of DRR plans, and Communication (Social Media or Smart Phone access) that can help in the event of a disaster. Each indicator has a decision rule attached to it; for example, for Restorative capacity, Local Leadership in Decision-making (DM) is prefaced by how many elected representative positions there are in the area, Y, and how many of those seats, X, are occupied by residents or citizens from the case study area. The decision rule I = (x / y). The more local elected representatives from the area, the more likely it is those in power can arrange funds for relief and recovery for the area (Leadbeater, 2013, Beckham et al., 2023).

Similarly, the Absorptive capacity can be linked to Social Demographics (Population density, population under 16, and others). Value rules can be attached to these indicators; for example, areas of lower density earn a higher score than densely populated areas like urban areas. Once the Excel sheet for each Capacity Index dimension is completed, it can be sent to subject matter experts such as academics and professionals with knowledge of the dimensions for additional verification and validation before use in the System Design and Modelling phase.

Table 4-3. Social Resilience Index example.

No.	Social Resilience Indicators	Effect Direction	Linked in Library (see Appendix for measures)	Data source
1	Community Participation in DRR	+	Community Engagement	Expert opinion or field survey
2	Community-Based DRR Plans	+	Community Processes (Plans)	Expert opinion or PDMA
3	Communication (Social Media)	+	Clear communication	Census, 2017
4	Community awareness goals/priorities	+	Community Goals (Efficacy)	PDMA or expert opinion
5	Religious Beliefs & Norms	+	Faith-based engagement activities for DRR	Expert opinion or field survey
6	Local Culture and Norms	+	Same	Expert opinion or field survey
7	Fair Access to Basic Needs	+	Same	Expert opinion or field survey
8	Social Demography	+	Population Profile	Census, 2017
9	Community Inclusiveness	+	Same	Expert opinion or field survey
10	Community Shared Values	+	Traditional coping mechanisms	Expert opinion or field survey
11	Mobility of People and Families	+	same	Census, 2017
12	Household Structure	+	same	Census, 2017
13	Local Leadership in Decision Making	+	Social Cohesion	Expert opinion or administrative records
14	External support systems	+	Social Support	Expert opinion or field survey
15	Effective Civic Organizations	+	Social Networks	Expert opinion or field survey
16	Diverse Skill Set (Workforce)	+	same	Census, 2017
Anticipatory Capacity = Yellow, Absorptive Capacity = Orange, Restorative = Blue				

Index Validity

When developing an Index of community resilience indicators, it is important to consider its validity as an instrument of measurement. The validity of an index of community resilience indicators is crucial to ensure that it accurately measures what it intends to measure (Beccari, 2016a). According to Rubin and Babbie (2016)Index validation typically involves assessing different aspects of validity, including content, construct, and criterion-related validity. Content validity assesses whether the indicators included in the resilience index adequately represent the construct of community resilience. Content validity can be ensured by either a literature review (Chapter 2), Stakeholder Input, or Expert review (Kuc-Czarnecka et al., 2020). Stakeholder input and expert review are key parts of the process undertaken in this research in both Phase 1 and 2. If content validity is established, it means that the indicators in the index adequately represent the core aspects of community resilience (at least from the perspective of participants in the study) (Rubin and Babbie, 2016).

Construct validity assesses whether the resilience index accurately measures the underlying construct of community resilience and distinguishes it from other related constructs (Rubin and Babbie, 2016). Construct validity can be checked in this case study by comparing the Community Capacity Index score with previous resilience assessments done in the area. For example, the case study community is defined as a high-risk area according to studies like Ali et al. (2022), where vulnerability and exposure are available. If results from the CCI also show low resilience, the index could be considered to have achieved construct validity. Triangulation between the validity tests can ensure that the Index measures what it intends to measure. Establishing these two types of validity ensures that the index developed is reliable and accurate for assessing and measuring community resilience.

4.3 System Design & Modelling Phase

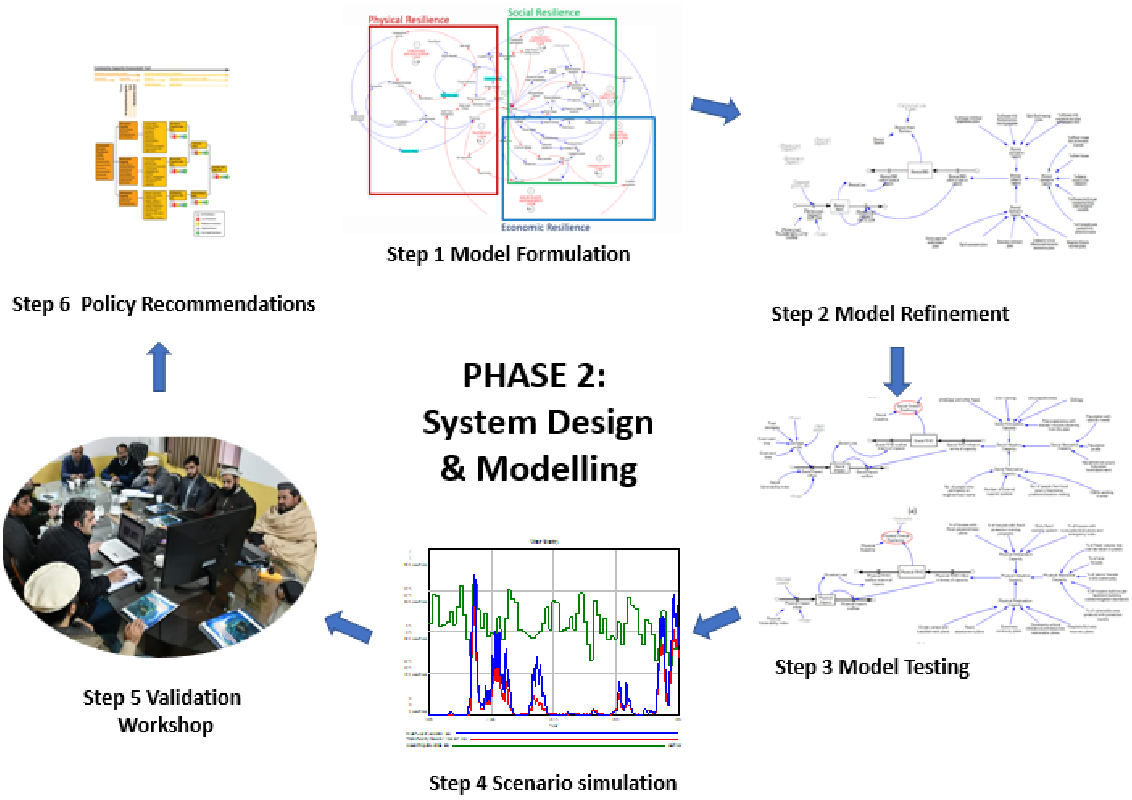


Figure 4-7. Phase 2 System Design and Modelling.

To recap from earlier, The System Design and Modelling Phase includes (1) Model Formulation, (2) Model Refinement of the selected resilience dimensions (physical, health, economic, environmental, organisational, and social dimensions) and the impacts and formal parameterisation of the capacities of each dimension, (3) Model Testing of the overall resilience model through structure-behaviour and reality tests, (4) Scenarios Simulation, (5) a Validation Workshop, and (6) Policy Recommendations. These six steps follow the conventional four steps of system dynamics simulation modelling (Problem Identification, Model Formulation, Model Refinement, and Model Use) but add two additional steps from the researcher's Design Science methodology for overall artefact validation and dissemination of results.

In addition to the Systems Thinking and Mapping tools used in the previous sections, the Participatory Approach to Modelling Community Resilience includes computer-assisted methods such as System Dynamics to simulate community resilience and test 'what-if' scenarios to provide additional insights into the system. In the systematic review, three CDR frameworks used System Dynamics modelling: CCAR, ResilSim and COPEWELL (Peck and Simonovic, 2013). These three frameworks consider community resilience as a dynamic variable that changes over time, with multiple factors influencing it. System Dynamics simulation modelling can help co-design high-impact, low-cost solutions to problems such as disaster preparedness and mitigation (Links et al., 2017).

The System Design and Modelling phase uses the insight and inputs from Phase 1 to develop a conceptual model of community resilience at the local level. The system design phase includes the model formulation and refinement of the selected resilience dimensions (physical, health, social, environmental, economic, or organisational) and impacts, the parameterisation of the capacities of each dimension, the testing of the overall resilience model, an exploration of possible disaster scenarios and the final simulation results. The phase ends with a Validation Workshop, incorporating a discussion of policy recommendations that could potentially be used for advocacy and influencing decision-makers.

4.3.1 Model Formulation: Resilience dimensions and impacts (Step 1)

As part of the review of CDR frameworks, three were identified as those that considered resilience from a system of systems perspective and used system dynamics to model resilience over time dynamically. As shown in Chapter 2, COPEWELL used a system dynamics model for preparedness and response, ResilSim for physical infrastructure and CCAR for coastal city resilience. Building on the system dynamics models used in those frameworks, this research adapts the modelling framework to include a more participatory approach to defining and evaluating the community resilience parameters used in the model. Accordingly, this research integrates the capacity approach to operationalise community resilience (Constas et al., 2014, Thayaparan et al., 2016). It uses the resilience triangle (Cimellaro et al., 2010) to represent a community's capacities to anticipate, absorb and restore itself from hazards and shocks. Several of the frameworks in the literature review use the resilience triangle as a conceptual model to explain capacities, capabilities, and resilience, particularly the following; (1) PEOPLES (Cimellaro et al., 2010); (2) CoBRA (UNDP, 2014), (3) COPEWELL (Links et al., 2017), (4) ResilSim (Irwin et al., 2016), and (5) CCAR (Peck and Simonovic, 2013).

This research will adapt and operationalise the resilience triangle for use in the Participatory Approach to Modelling Community Resilience.

Building on previous research by Thayaparan et al. (2016), Sfetsos et al. (2017) and Tariq and Pathirage (2017), Chapter 2 has already defined the three capacities to represent the overall adaptive capacity of a community which determines the resilience of a community at the local level (Tariq et al., 2021c). The adaptive capacity of each community resilience dimension can be represented as a combination of (1) Anticipatory capacity, the ability of a system to anticipate and reduce the impact of climate vulnerability and extremes through preparedness and planning; (2) Absorptive capacity, the ability of a system to buffer, bear and endure the impacts of climate extreme in the short term and avoid collapse, and (3) Restorative capacity, the ability of a system to be repaired quickly and efficiently and also to transform or "build back better." Figure 4-8 shows how the different values of the three capacities influence the behaviour of the resilience loss triangle: (a) represents a higher level of resilience and hence a smaller loss; (b) represents a lower resilience level and a higher loss, and (c) represents the least resilience with the highest amount of loss.

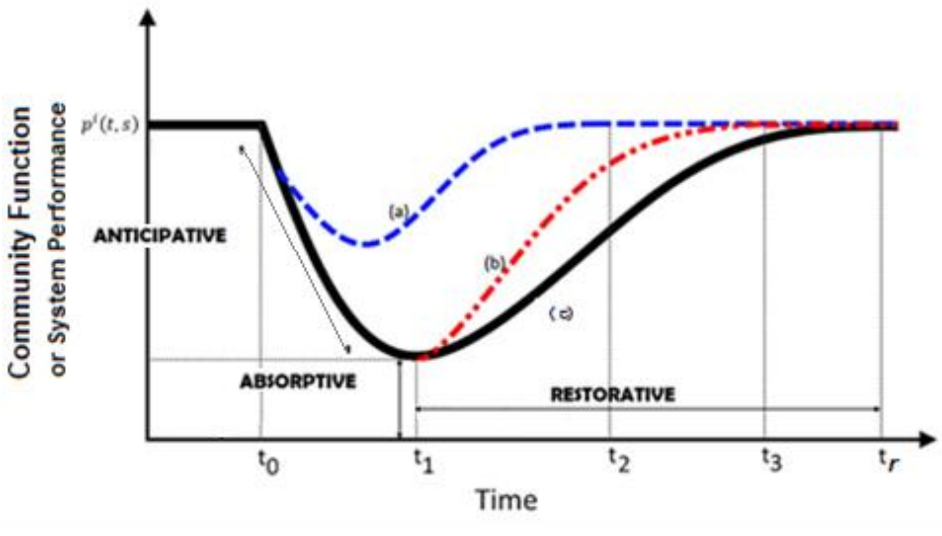


Figure 4-8. Resilience triangle and community capacities; (a) is preferred over (b), and (b) is preferred over (c) the baseline curve. Figure adapted from Cimellaro et al. (2010), p.3642.

Community Disaster Resilience System Model.

The model architecture is adapted from Cimellaro et al. (2010), Peck and Simonovic (2013), Simonovic and Arunkumar (2016), and Tariq and Pathirage (2017). It has been adapted to include participatory methods as inputs into the system design phase and use capacities such as Anticipatory, Absorptive and Restorative as parameters in the model architecture. Figure 4-8 graphically illustrates some of the terminologies used in the research, the three capacities, and the System Performance (SP) as the base output of community function. SP performance represents the typical activities of a system operating normally. It can be set as 100 (or 1) to represent baseline values and less than 100 (or 1) to represent a shock or stress to the system. Typically, the values of System Performance are abstractly defined to represent the overall functionality of a system but can be linked to real-world variables by expert opinion or the research participants in a group model-building or FGD session. For example, suppose Physical Infrastructure is represented by the percentage of households with electric power. In such a case, 100 per cent represents the system's normal functioning, and a shock resulting in a power loss to 40 per cent of the households will reduce the SP of the system to 60 per cent functionality at the current resilience capacity levels. Alternatively, suppose the resilience capacity of the community was higher. In that case, the power loss might only extend to 20 per cent of the households in the area, and the system's SP will only fall to 80 per cent functionality.

The inputs from participants in the ST and Mapping phase help in (1) identifying the hazard event attributes (resilience from what?), vulnerability, i.e. the social, economic and physical (resilience of what?) and exposure factors in the population (resilience of who?); (2) estimating community capacities (Anticipatory, Absorptive and Restorative), i.e. the presence or absence of protection and management measures, using the capacity index scores; (3) setting the normalised System Performance (SP) base values and units (the level of functionality within the system being modelled), and (4) estimating damage or disruption feedback from different system components and processes. Stakeholder groups or expert participants define and review these variables based on their experience, historical data (if available) or expected future projections. Variables are then classified in stocks and flows using their units as a guideline. Each stock's base/initial values are approximated in the following step.

The generic model architecture is shown in Figure 4-9. The generic model is the building block from which larger models can be developed. The dynamics in the model are controlled through two stocks and four flows. System performance stock values indicate system efficiency. System performance stock fluctuates through the inflow of system performance improvement and the outflow of system degradation. System performance improvement further depends upon the adaptive capacity, a function of absorptive, restorative, and anticipative capacities, whereas system degradation depends on system loss. Adaptive Capacity parameters are directly derived from the qualitative output from the Systems Thinking and Mapping Phase. System damage at each time step is determined through the difference between impacts (stock) and the baseline value of the system. If there is no damage (non-occurrence of disaster event), the impact will be zero, and the system will be at its base value. Impact stock represents system strength to bear any damage/event. It is controlled through the inflow of system performance improvements and the outflow of system degradation. Inflow can be increased or decreased through performance improvement (function of adaptive capacity) and base flow. Base flow is the routine work the community performs in a system from time to time, such as system repairs (e.g., road, infrastructure, buildings, and others). System resistance outflow is controlled through the damage profile of any event and system utilisation. System utilisation is the system's wear and tear over time. Damage profile denotes any harmful event as a function of time. It can be instantaneous, such as an earthquake or flood due to a cloudburst, or gradual, such as a drought or a disease outbreak.

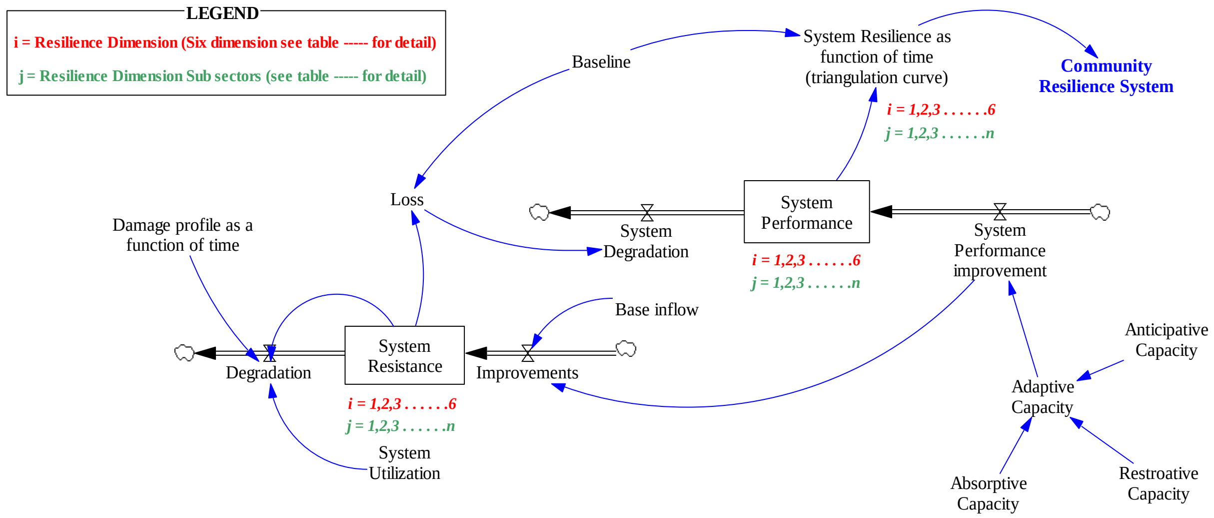


Figure 4-9. Generic Model Structure of Community Resilience

The CDR model structure in Figure 4-9 can consist of up to six resilience dimensions (P^i(t,s), i = 1, 2,….6), such as, Physical, Health, Economic, Environmental, Organizational, and Social Resilience dimensions. The dimensions were identified and selected after the interviews, and qualitative data was collected during the previous System Thinking and Mapping Phase. Based on the scale of assessment, each resilience dimension can be further divided into different sub-sectors (P_j^i(t,s), j = 1, 2, …… n) as defined by participants and shown in Table 2. For example, the physical resilience dimension can be subdivided into transport linkages, critical facilities, utilities, buildings, and others. The current study focuses on developing a generic system dynamics model for estimating the resilience of each sub-sector identified in the case study, which, combined, can assess the resilience of a particular resilience dimension. All six resilience dimensions together holistically define a community resilience system.

When modelling a complex multiple-dimensional resilience issue (as indicated by the stakeholders), individual stock and flow diagrams of each Resilience dimension can be built and combined into a higher-level model to illustrate the interconnectedness and interdependencies of the Resilience dimensions within a community. The ST and Mapping phases allow participants to select the dimensions to be investigated according to the complexity of the resilience problems faced by the community. The Resilience dimensions and the selected indicators allow researchers to frame and model the correct resilience issues of concern according to stakeholders through co-creation and refinement throughout the model-building process.

Modelling of Resilience

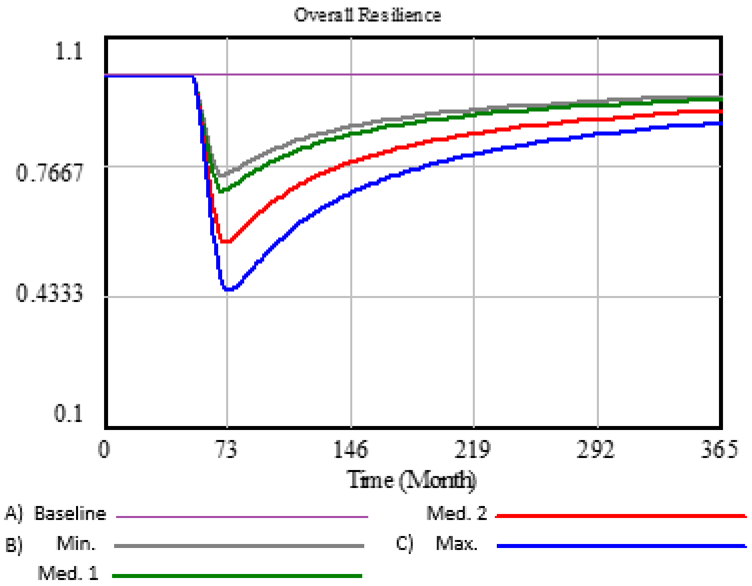


Figure 4-10. Resilience triangle and in the model according to different capacity levels; (a) Baseline performance is preferred over (b), and (b) is preferred over (c) the curve with Maximum impact.

This section presents the mathematical approach to modelling a community's resilience behaviour due to the system performance at the local level, as illustrated in the stock and flow model above in Figure 4-9 and the resilience curve in Figure 4-10. To measure the loss of performance for each resilience dimension (i), we need to calculate the area under the system performance (SP) curve between t_o at the start of the shock event till t_r when the recovery from the shock event is complete, as shown in Figure 4-10 In our stock and flow model, the change in the stock of SP, ρ, can be represented mathematically by Equation (1):

Equation 1

$$\rho^i(t) = \int_{t_0}^{t} [P^i_{(t0)} - P^i_{(t)} \ ]dt \ \ where\ t \ \in [t_0, t_r]$$

In this representation, $P^i_{(t0)} = P^i_{(t)}$ when SP does not decrease in response to a shock event, indicating a high level of resilience. Similarly, $P^i_{(t)} = 0$ when there is a total system failure in response to a massive shock event, indicating an extremely low level of resilience. Hence, system resilience is dependent on the system performance at t and is represented by, $r^i(t)$ for a given resilience dimension i as in Equation (2) below:

Equation 2

$$r^i_{(t)} = 1 - (\frac{\rho^i_{(t)}}{P^i_{(t0)}})$$

Figure 4-8 shows that SP, under the impact of a shock, reduces the curve below the initial level and then recovers over time according to the resilience level of the community. Equation (2) normalises the units and eliminates the units of SP, allowing stakeholders to compare SP using different dimensions and indicators. The shock event results in a reduction of system resilience from value 1 (max) at t_0 to the lowest level $r^i(t)$ at time t_1, as illustrated in Figure 4-8. During the recovery, if the resilience score returns to 1, then full recovery is achieved, and system performance reverts to its original state before the shock. However, the resilience score can typically be above (or below) the initial level when bouncing back better (or worse, as the case may be). Following this approach, the overall integrated CDR measure for all resilience dimensions at a given time can be represented as shown in Equation (3) below:

Equation 3

$R^i(t) \; = \; [\prod_{i=1}^{M} r^i(t)\,]^{\frac{1}{M}}$ where M is the total number of dimensions

The product function is taken to the power of 1/M to derive an average of all the dimensions, as the dimensions have the potential to influence each other and the function is adapted from Srivastav and Simonovic (2014) for this study.

Although conventional static resilience assessments are still helpful in developing a baseline or a pre-event snapshot of a community, dynamic resilience measures can help test adaptation options. Dynamic approaches such as the participatory SD modelling approach used in this research can help a community discuss, consider and test how to adapt to a hazard event (Cutter, 2016a, Mishra et al., 2019). The indicators that measure these capacities are formed through a participatory approach and represent the capability of the community to anticipate, absorb and recover from shock events such as hazards.

Graphically these capacities can be broken down into the three areas of the resilience triangle as shown in Figure 4-8 and Figure 4-10. The Anticipatory capacity can delay the onset of the shock event and impact upon the depth and width of the resilience triangle; hence, the slope of the downward curve is represented. The depth of the downward curve can show the Absorptive capacity in the resilience triangle, and the Restorative capacity determines the shape of the recovery portion of the curve in the diagram. These three capacities are combined into an overall indicator for Adaptive Capacity (AC), as shown below:

Equation 4

$$AC_{(t)} = f\left(C_{j(t)}\right) \quad j = 1, 2, 3$$

Where f() is the mathematical function combining the effects of three capacities C's, j is the index for each Capacity C; and t represents the time period. The AC of the community can then be used to understand the change in SP due to the impact on Dimension (i) of a shock event or hazard. Hence, the effect of the shock on system performance (P) at the community level can be calculated by solving the following differential Equation (5) in System Dynamics:

Equation 5

$$\frac{\partial p^i(t)}{\partial t} = AC^i(t) - P^i(t)$$

Where AC^i represents the community's adaptive capacities concerning the impact of Dimension i and P^i represents the system performance of that Dimension as shown in Equation (4). Each Dimension i has a different adaptive capacity ACi, determining its ability to withstand a shock event. A community's adaptive capacities can be determined by establishing a capacity index score developed through consultation with community stakeholders.

Cimellaro et al. (2010) propose a subtle distinction between two types of system capacities that can help us understand resilience: (1) capacities as "ends" can be used to measure resilience at a point in time, and (2) capacities as "means" can be used to improve resilience over time as a process. Absorptive capacity (C_1^i) and restorative capacity (C_2^i) consist of measures in an index that calculate the "ends" by which resilience can be improved where existing structures, organisations and the status of critical variables can be considered in a snapshot in time as a case for what those capacities are at any single point of time, *t*. Anticipative capacity (C_3^i), on the other hand, can be defined as measures that calculate the "means" by which communities can become more resilient over time (i.e., plans for mitigation, preparedness, and risk reduction) and can directly contribute to improving values in the other two capacities (for example, through a delayed feedback loop).

For example, constructing a retention pond diverts excess water flow into a safe reservoir, potentially reducing the inundation to safer levels. Construction of the pond indicates an intervention that has improved the absorptive capacity as an "end", making the community more resilient overall. In the dynamic analysis, the community may be resilient to one or more flood events. Still, each subsequent event can also potentially erode this capacity, making it less effective over time without regular maintenance (linking maintenance with anticipatory capacity and preparedness) before the next cycle of flooding, hence providing a mechanism to include the "means" or process of resilience into our analysis. These adaptation options can help us propose a dynamic hypothesis on how the loss of resilience due to hazard events and shocks can be minimised by investing in and improving community capacities. Therefore, resilience can be assessed as a system profile over time and as a single measurement. Hence, the overall Community Adaptive Capacity for all of the dimensions over time can be shown by Equation (6):

Equation 6

$$\frac{\partial R(t)}{\partial t} = AC(t) - \prod_i P^i(t)$$

Each resilience dimension can be assessed as a combination of these three capacity indices into an overall index that calculates resilience for each Dimension separately. Finally, all resilience measures from each Dimension (physical, health, economic, environmental, social and governance) can be integrated into a single Resilience Index (RI) measure:

Equation 7

$$RI = \sum w_i R_i$$

where

$$\sum w_i = 1$$

Where i is the resilience dimension, w_i is the weight assigned to the Dimension i (based on local stakeholder input), R_i is the Dimension resilience score. The RI can be developed for one or more dimensions specified by the stakeholders. The overall Resilience Index for all dimensions is shown in the expanded form below:

Equation 8

$$RI = w_1R_1 + w_2R_2 + w_3R_3 + w_4R_4 + w_5R_5 + w_6R_6$$

The RI index can be translated into the resilience triangle shown in Figure 4-8 and Figure 4-10 using the SD stock and flow diagram in Figure 4-9.

4.3.2 Model Refinement (Step 2)

The model refinement stage in system dynamics modelling of community resilience involves enhancing the accuracy and realism of the model to represent the complex dynamics of community resilience better. In this step, the model is reviewed in the context of the case study and the definitions of variables and relationships are refined within the model. This ensures that the variables accurately represent the underlying dynamics of community resilience to disasters. This may involve adding, modifying, or removing variables. This step also requires engagement with stakeholders and experts to review and provide input on the refined model. Their expertise can help identify any overlooked nuances, critical variables, or areas for improvement. The model refinement stage is essential for enhancing the accuracy and utility of a system dynamics model for studying community resilience to disasters. It ensures that the model's behaviour aligns with empirical evidence and expert knowledge, making it a valuable tool for decision-making, policy analysis, and disaster preparedness efforts.

4.3.3 Model Testing (Step 3)

System dynamics provides a flexible modelling environment which helps include socio-economic, environmental, and physical processes. This flexibility allows for different resilience dimensions to model a CDR system. However, at the same time, it imposes a challenging situation regarding model testing and evaluation. Model testing is essential in building confidence in the model's intended use. In the proposed modelling approach, conventional modelling tests based on statistical methods, e.g., RMSE, NSE, R2, and ME, may not be applicable due to the limited availability of field data (Inam et al., 2017a). Hence, due to this data limitation, the Community Resilience model is based on expert assessment and many stakeholder-defined assumptions, making it necessary to test the model before use. Accordingly, researchers using the Approach need to include the views of local experts, academics, and practitioners to address this limitation and ground the assumptions in subject matter and area-specific knowledge. Subject matter experts identified during the stakeholder analysis are used through one-on-one sessions (mostly online through Microsoft Teams) to capture the general values, trends over time, and upper/lower limits by using Behaviour over time Graphs (BoTG) and integrating them with the Lookup curves function in Vensim.

Due to the data limitations and the use of expert assumptions, the following four tests can be used to check the validity of the modelling process: structure validity test, behaviour validity test, dimensional consistency, and reality checks. Structure validity tests can be used to test the structure of the model concerning variables, stocks and flows and the parameters of the model. Next, behaviour tests can be used to validate the behaviour arising in the model with subject matter experts. Thirdly, dimensional consistency tests can be conducted for unit consistency among the variables used in the stocks and flows used in the model. Finally, reality checks can be utilised to confirm that behaviour within the model is within logical ranges. The model is then ready to be validated by the FGDs in the next steps.

4.3.4 Scenario Simulation: Stakeholder Defined Policy Scenarios (Step 4)

After the model has been developed, refined, and tested in the previous steps, it can now be used to develop scenarios for use in the model. These scenarios can be developed to convey the impact of the different levels of hazards experienced by a community, or the different policies implemented in a community, or any combination of the two. Ideally, the policies of interest will have been already selected in a previous step, and in this step, the researcher can focus on developing Stakeholder Defined Scenarios (SDS) based on their preferences. SDS can be used to explore alternative futures or outcomes within a dynamic system and are generated based on the input and perspectives of individuals or groups with a vested interest in the modelled system. Developing a detailed SDS requires working closely with a stakeholder group or organisation and using their direct input as expert opinions into the model. Data from other sources or previous studies defines and models the scenarios. Stakeholders participate in workshops, discussions, or interviews to share their insights, opinions, and assumptions about the system being modelled. They are asked to describe potential developments, policies, or events they foresee. These inputs are then used to construct a set of scenarios, each representing a different vision of how the system may evolve over time. Scenarios may include policy, technology, behaviour, or external factors variations.

For example, flood risk maps of an area can provide the extent of flood impacts, such as 1 in 5 years, 1 in 10 years and 1 in 100 years in terms of percentage change as to whether a flood might occur, and can form the basis for three impact scenarios of different magnitudes on a community. Using SDS ensures that the scenarios interest the stakeholders, and they can feel a sense of ownership of the process while also using the modelled scenarios to understand better how it might impact the community. The SDSs are applied in the model to better understand a policy's effect on mitigating the adverse impacts of a disaster or shock event on the community.

4.3.5 CDR Workshop (Step 5)

Step 5 entails conducting a final validation workshop with the representatives of the primary stakeholder groups to share the CDR model, demonstrate the SDS and share the insights gained throughout the research process across both the ST and Mapping stage and the System Design and Modelling stage. The CDR workshop brings together representatives of the different stakeholder groups to develop a consensus on policies or actions to increase the community's overall resilience. At the end of the workshop, participants will be asked to fill out a semi-structured questionnaire for Artefact Validation, as mentioned in Chapter 3.

4.3.6 Policy Recommendations (Step 6)

After the workshop, participant feedback can be included in the CDR model by revising the model structure to incorporate any needed changes. Accordingly, insights from the workshop discussion and the resultant policy recommendations can be shared with a broader audience. Additional dissemination activities can be undertaken as required. The model can be expanded to include further analysis, such as a cost-benefit analysis of policy interventions according to the feedback and recommendations from the validation workshop. Using the Participatory Approach to Modelling Community Resilience can engage stakeholders in the resilience measurement process and potentially improve intervention design and implementation by more inclusivity and collaboration throughout the design process than previous approaches.

4.6 Summary

This chapter covers the stages and steps of the Participatory Approach to Modeling Community Resilience at the local level. The chapter is divided into Stage 1: Systems Thinking and Mapping and Stage 2: System Design and Modelling, each phase consisting of six steps. In the following two chapters, Chapter 5 and 6, the Participatory Approach to Modelling Community Resilience is evaluated in a case study.

Chapter 5 Evaluation of Systems Thinking and Mapping

5.0 Overview

Chapter 5 uses a case study to evaluate the Participatory Approach to Modelling Community Resilience proposed in Chapter 4 in a field setting. In this chapter, the first phase of the approach is used to capture local perspectives and map the causes and consequences of hazards, as well as disaster risk reduction, preparedness, and mitigation policies in the Budhni Nullah Basin (BNB) case study. Chapter 6 will cover the evaluation of the second phase of the case study, as shown in Table 5-1 below.

Table 5-1. Research Objectives and Methods

Research Objectives	Research Methods	Chapters
Objective 5: To validate the artefact as an approach to understanding community-based resilience dynamics using a case study	Case Study • In-depth Interviews (IDIs) • Focus Group Discussion (FGD) • Causal Loop Diagrams (CLDs) • Q methods	Chapter 5: Evaluation of the Systems Thinking and Mapping (Phase 1)

Figure 5.1 shows the six steps in the Systems Thinking and Mapping phase as applied in the case study in Peshawar, Pakistan. The rest of the chapter is divided into individual sections for each step. Step 1 will identify some of the hazards and resilience issues the case study community faces with local hazards. Step 2 shows the outcome of the Stakeholder Analysis conducted in this study, while Step 3 reports on the nineteen interviews completed for developing CLDs. Next, Step 4 reveals the merged CLD and how thematic models for each dimension of interest are highlighted for further discussion and analysis. One FGD was used in Step 4 to validate the findings of Step 3. Next, steps 5 and 6 cover applying Q methods for Indicator selection and Index formulation. Sixty-eight participants were interviewed using Q-Sorts for Step 5. Finally, one FGD was conducted to validate the Community Capacity Index developed in Step 6.

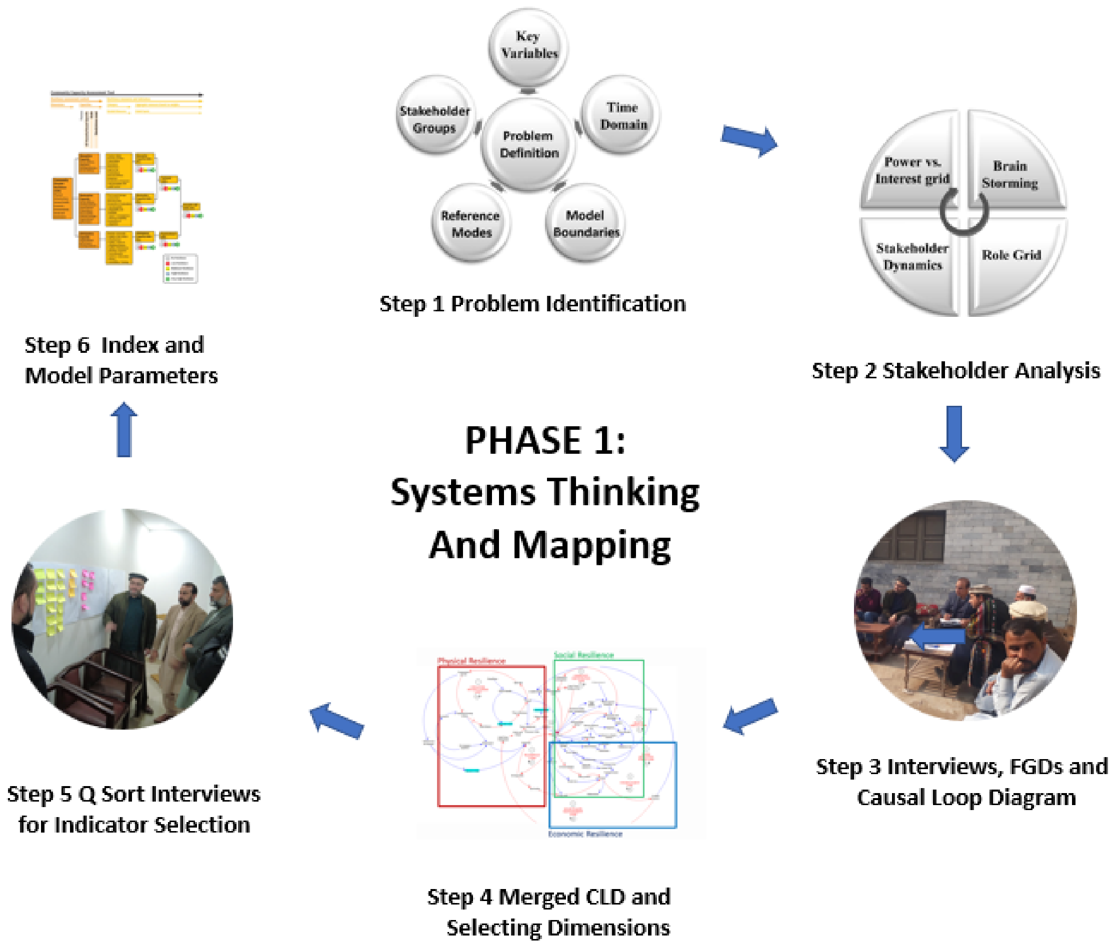


Figure 5-1. Steps in the Systems Thinking and Mapping Phase.

5.1 Problem Identification (Step 1)

According to the guidelines developed for Step 1, preliminary data about the case study area was collected by conducting an FGD with senior staff members of Al Khidmat Foundation (AKF), the local NGO and host organisation, in their offices in the case study area. As selection criteria for the FGD, the AKF was asked to provide participants who lived in the area and were actively involved during the last flood incident in the area, either as residents or as social workers. The FGD consisted of five community members, including senior management of the NGO, all of whom consented to the research and agreed to participate in individual interviews later. Hevner et al. (2010) and Hovmand (2014) consider between five to ten participants as the ideal size of an exploratory FGD at the start of a research project. For increased situational awareness of the local context and circumstances, two activities were used to capture contextual information about community vulnerabilities, hazard impacts and coping capacities: the Hazard Risk Matrix and the Analysis of Hazards and Stresses (Pasteur, 2011, MacOpiyo, 2018). The FGD was structured to identify the main problem themes in the case study area, as shown in Table 5-2 and Table 5-3. The interview schedule with probing questions to ask during the FGD is provided in Appendix B.2.

In the Hazard Risk Matrix exercise, the participants, who were all residents of the area, were asked about some background information, followed by the matrix ranking exercise. They were asked to list the number of hazards they faced locally and score them according to their likelihood of occurrence and the magnitude of impact on the people, livelihoods, physical infrastructure, and residential houses. They were asked to score them according to low (1), medium (2) and high (3). The matrix and the scores are shown in Table 5-2 below. The Hazard Matrix identified Flooding as the primary hazard impacting the community in the case study area.

Table 5-2. Hazard Risk Matrix. Adapted from (MacOpiyo, 2018).

	Variable Scores (Low=1, Medium=2 and High=3)					
Natural Hazard	A: Likelihood of Event	B: Impact on population	C. Impact on livelihood	D Impact on Physical Infrastructure	E: Impact on homes	Total Risk Score = A(B+C+D+E)
Earthquake	2	3	2	2	2	18
Cyclone	2	3	3	2	2	20
Pollution	3	2	1	0	0	6
Dengue	3	3	2	0	0	15
Flooding	3	3	3	3	3	36
Hails Storm	2	1	2	1	1	10

Participants in the FGD listed several different hazards, and the scores highlighted flooding as the most important hazard, followed by Cyclones or extreme wind events and then Earthquakes. After participants identified the hazard priority, they were asked additional questions about the community's history of hazard events and disasters and their concerns for the future in the next exercise, Analysis of Hazards and Risks. This activity was conducted with Flooding as the priority hazard.

For the exercise, a flip chart was attached to the wall, and information was written directly onto the paper using sticky notes as and when offered by the participants. Probing questions were asked on the priority hazard, namely, flooding, followed by its impacts. Participants were asked about the frequency and duration trends of flooding, the warning signs (if any), the major groups affected, assets and services affected and the community's immediate response. The information was verified with all participants before posting it on the chart to ensure consensus among the group – the researcher noted any divergence or disagreement separately. After the FGD, the chart and post-its with the information were written up in Microsoft Word. Table 5-3 below reports the outcome of the Analysis of Hazards and Stresses exercise with participants in the FGD.

Table 5-3. Analysis of Hazards and Stresses. Adapted from Pasteur (2011).

Hazard Priority 1: Flooding	Issues and vulnerabilities	Capacities and opportunities for resilience
Frequency, Duration, Seasonality, Trends	Flash flooding every two years. It lasts a few days unless it is a major event, then for at least a week or more. More frequent events than before. Before 2008 – only the 1975 flood is remembered. After 2008 – almost every two years	Preparedness plan for local people, school kids
Warning signs, Early Warning	Extreme heat in weeks before Heavy rainfall Mosque announcements SMS/calls on the phone	Connection with upstream communities – advance notice Early Warning System from government agencies
Groups affected	School children Elderly Those with major Health issues All affected during major events: Houses, Livestock owners, Agriculture lands.	Transport arrangements for children and the elderly
Assets and services affected.	Water Wells (up to a month) Electricity (up to a week) Roads and transport (a few days) Mosque/Hujra (community centre) Assets: Livestock killed and houses damaged Commercial activities	Generators for electricity Water Pumps for Well Clearance Mosque/Hujra cleaning drive with volunteers Disposal of dead livestock
Immediate response	Evacuation to higher land (hours before) Arrangement of food– volunteer communal kitchen is the major activity (the day after)	Strong links with neighbouring communities Stockpiles of Food and Medicines (and tents in extreme cases)

	Medical Camps for Water borne diseases (days later) Shelter if major event – arrangement for temporary shelter with other communities (in extreme cases tents)	List of Volunteers for Communal Kitchen and Medical Camps

This group of participants indicated that they were alarmed by the increased frequency of flood events over the past decade, and 2008 was mentioned as the year when a major flood impacted the area. Before 2008, the 1975 flood was cited as the most significant flood event in living memory. The group expressed concern about the frequency of flood events since then, with events occurring almost every two years. When asked about Warning Signs and Early Warning, they indicated that the Mosque loudspeakers (on a minaret) were used to inform the community of any information regarding flood waters. Previously, the District Administration would send police constables to each mosque to ensure the announcement of any flood risk from upstream. Currently, this is done through mobile phones by SMS/WhatsApp messages and calls to the mosques in the area and the local elected representatives by the local authorities.

When asked about the most affected, it was reported that older people and children were most affected in minor events, whereas everyone was adversely affected in major events. When asked what assets and services were affected, they indicated that water wells were the most immediate problem as the water level is low in the area and flood waters contaminate the local water supply and damage the water pumps. Other services like electricity, transport and roads were also affected. Crucially, the community emphasised the importance of restoration times for each, ranging from a few days for roads to a few weeks for electricity and up to a month for the local water wells to be cleared. Finally, details on the community's immediate response were asked, and they reported on a volunteer system for organising evacuation in the hours before the flood, arrangements for a communal kitchen in a high elevation area during the days of the flood and the arrangement of volunteer medical personnel for medical camps due to the spread of waterborne diseases post-flood.

After the first set of questions on Issues and Vulnerabilities was completed, they were asked about Capacities and Opportunities for resilience at the community level for each mentioned issue. The group noted the need for flood preparedness training programs for local people, especially school children. This emphasis was perhaps because AKF has three schools in the area. By flood preparedness, they meant early warning systems, an evacuation plan, awareness and stronger connections with neighbouring and upstream communities. Suggestions for updating and maintaining their volunteer lists for operating communal kitchens and medical camps were also mentioned, as well as increasing stockpiles of necessary goods and medicines. The outcomes of the FGD enabled the researcher to achieve a quick situational awareness of the problem issues regarding the primary hazard in the area and to answer some of the questions regarding the nature, scope, and extent of the problem.

When developing a system study, it is crucial to determine the time horizon of a study, model boundary and stakeholder groups involved in the research. Several factors can determine these considerations, including the research questions, the unit of analysis (individual, household, or community level), the purpose of the model (impacts, capacities, or policies), and time and resources for the research investigation.

In this research, based on the initial discussion, the respondents were concerned about how local preparedness and response might be improved to deal with repeated cycles of flood events (occurring every two years) or to face the expectation of a major flood event like in 2022 (every ten years). The boundary was chosen as the Village Council (Neighbourhood) of Sardar Ghari, where the population density (GoP, 2017), high flood risk (Ali et al., 2022) and a large number of vulnerable populations (under 16s and over 65s) in the area meant that it was potentially vulnerable to future major hazard events (Khan et al., 2022).

In addition to the time horizon, some key variables and their trends were identified using reference modes (or behaviour over time graphs). Participants were asked to draw a graph on A4 white sheet of paper. The Sheets were put up on the wall for discussion, and consensus among the participants was sought on the general trends of the variables discussed. Variables such as the frequency of flood events (historical and perception) increasing over time, the local community-based early warning system mainly being the same over the years, the increase in the number of vulnerable populations (general population increase), and the need for some preparedness training. Additionally, a brainstorming session was held with the participants at the end of the FGD to develop a list of stakeholders for the urban flooding occurring in the area. Chart paper and Post-it notes were used to form a list of stakeholder groups and organisations that may be involved or affected by the identified priority hazard, flash flooding. Finally, after the preliminary data collection, the information in the FGD exercises was checked thoroughly using sources from the literature, administrative records (Census Data, Flood Impact Assessments), and local news sources.

5.2 Stakeholder Analysis (Step 2)

After forming the preliminary list, the stakeholders were categorised by their roles according to the European Commission (Commission, 2003) guidelines for determining stakeholder types or roles, namely, experts, decision-makers, users, or implementers, as shown in Figure 5-1 below. The roles were arranged in a grid, and each stakeholder identified was placed on a yellow note according to their role (as perceived by the researcher). Twenty-three stakeholders were identified from the first FGD, the initial literature review and input from the focal persons from Peshawar Living Lab (PLL) and Al Khidmat Foundation (AKF). Nine stakeholder groups were added after the interviews in step 3 (Agri. Dept. = Agricultural Department (Soil Conservation), DDMUs = District Disaster Management Unit, C&W = Communication and Works Department, EPA = Environmental Protection Agency, NHA = National Highway Authority, WAPDA = Water and Power Development Authority, Land Mafia, Land & Revenue Dept., and the Forrest Dept. were identified during the interviews). The PLL and AKF were the local partners for facilitation and helped provide access to academics, experts, practitioners, and community members identified in the stakeholder analysis.

Four stakeholder groups or organisations were arranged in the Expert quadrant: the Provincial Disaster Management Authority (PDMA), the Pakistan Meteorological Department (PAK-MET), Academics at the University of Peshawar (UoP), and Academics (elsewhere). The Academics group from the UoP were those academics who had conducted research or written about hazards or disasters in Peshawar or the BNB area specifically. Academics (elsewhere) included academic experts from outside Peshawar who might have conducted research or written about disasters in the case study area. Seven stakeholders were placed in the Decision Maker quadrant: the Elected Representatives (Mayor, Councillors, Parliamentarians), the Local Government Department, the Water and Power Development Authority (Utilities), the Environmental Protection Agency, the Relief and Rehabilitation Department and the National Highway Authority (NHA). These groups were determined to have some power in the case study area and the ability to directly affect decision-making about preparedness, mitigation, and recovery efforts, including access to funding and resources. Note that during the study period, major changes to the legislation in the country led to power devolution to local bodies, thus increasing the power of local Mayors at the expense of those in parliament and national assemblies.

The rest of the stakeholders were placed in the remaining two quadrants: Implementers, those who were going to implement the decisions taken by the decision-makers, and the Users, who were the groups or organisations directly being impacted by the hazards and the intended targets of any actions taken by the Implementers, i.e., potential disaster risk reduction interventions. Implementers were the largest group and consisted of organisations like the Irrigation Department, Health Department, the Municipal Corporation, and others shown in Figure 5-2. The Users were Local Community-Based Organisations (CBOs), the Business Community, the Marble and Granite Industry, local Masons and Artisans, and other local groups and institutions. The Business Community was diverse enough in the case study area that our initial discussions and analysis indicated they be separated into three: those that ran local businesses (like retail and other commercial entities), the Marble and Granite Industry, a power subset of local companies who hired a lot of local people and had considerable impact on the environment (especially on the waterway), and the Local Masons and Artisans who worked for the Marble and Granite Industry and lived in the area.

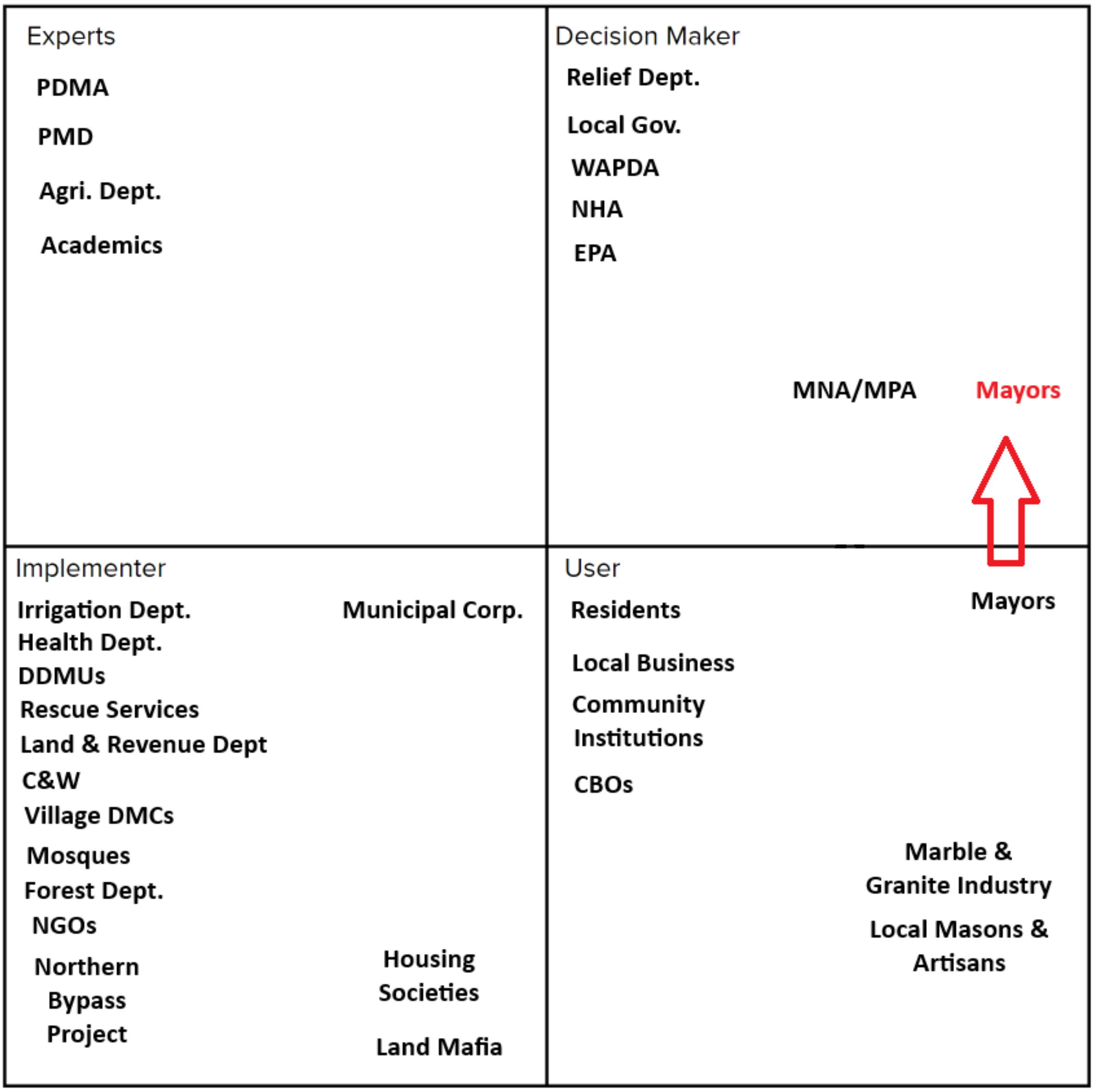


Figure 5-2. Community Resilience stakeholders and their roles in the Case Study Area. (PDMA = Provincial Disaster Management Authority, PMD = Pakistan Meteorological Department, Agri. Dept. = Agricultural Department (Soil Conservation), Relief Dept. = Relief and Rehabilitation Department, Local Gov. = Local Government, MNA/MPA = Member of National or Provincial Assembly, DDMUs = District Disaster Management Unit, C&W = Communication and Works Department, Village DMC = Village Disaster Management Committee, NGOs = Non-Governmental Organisation, Municipal Corp. = Municipal Corporation, CBOs = Community Based Organisation, EPA = Environmental Protection Agency, NHA = National Highway Authority, WAPDA = Water and Power Development Authority)

Once all stakeholder roles were identified, purposive sampling was used to determine which organisations and groups to include in the interviews. The literature and previous studies determined that two respondents from each expert, decision-maker group and user group would help capture the core issues in the system (Inam et al., 2015, Albano et al., 2019, Perrone et al., 2020). At the same time, one from each implementer would be sufficient. The results of the stakeholder analysis and the purposive sampling were shared with the focal persons at the PLL at the UoP for contact with Experts, Decision Makers, and Implementers, as well as the AKF for communication with the Users from the VC Sardar Ghari area.

While the first set of interviews was being conducted, when time permitted, the stakeholder list was also shared with some respondents, and they were asked to add any stakeholders that may have been missed in the initial analysis. As the list was further populated with participant feedback, an analysis of the stakeholder dynamics was conducted. The list was classified according to three relational attributes based on their level of power, legitimacy and urgency within the system, as defined by Mitchell and Wood (2017) and shown in Figure 5-3. Due to the duration of the study period and the intervening events of the COVID pandemic, significant political changes and the Floods of 2022 in Pakistan, additional care was taken to keep the list updated. For example, specific legislative changes to the Local Government structure also occurred during this time, resulting in a change in roles for two stakeholder groups, the mayor and the local member of Parliament, where their roles in spending funds locally were changed and reversed.

After the stakeholder analysis was reviewed, the purposive sample was further refined to reflect the results of the changing dynamics of the case study area. Stakeholders were assessed based on their possession of Power, Legitimacy, and/or Urgency, with a score of 1 assigned for each attribute present and 0 for those absent. Those stakeholders included in all three attributes were considered definitive stakeholders and were prioritised for inclusion in the case study. Definitive stakeholders included local community leaders, the Irrigation Department, the Municipal Corporation, and the District Disaster Management Unit. Finally, the stakeholders were also ranked in the power vs. interest grid to determine who had the most power and interest to bring changes into the system: the Irrigation department, the PDMA and the mayors (and councillors) were identified as the most willing interested and able to leverage the system while stakeholders like local artisans, farmers, small businessmen and a women's CBO were also included as marginal groups whose were included in the participant list. The problem of flash flooding affected all groups, and it was deemed sufficient to have at least one from each category in case something was missed in the qualitative analysis.

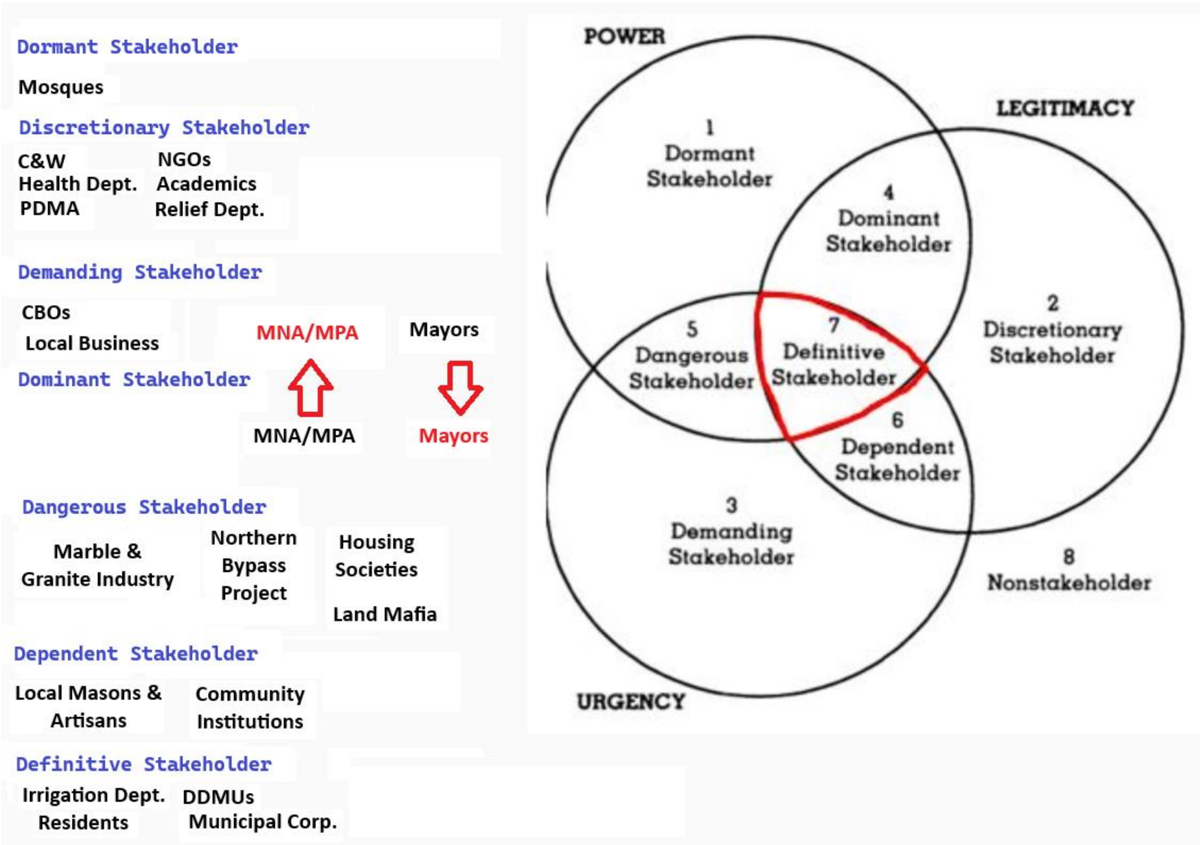


Figure 5-3. Stakeholder Dynamics identified in the Case Study, adapted from Mitchell and Wood (2017).

5.3 Stakeholder Interviews, FGDs and CLDs (Step 3)

Step 3 involved the first set of interviews carried out in the research. Nineteen interviews were conducted to develop Causal Loop Diagrams to gather information on the causes and consequences of the flooding in the case study location. As mentioned in Chapter 3, nine respondents were community members, five were academics, and five were practitioners. For experts and practitioners, the participants were contacted through the University of Peshawar and the Peshawar Living Lab. The community members in the sample were approached through the AKF, usually through a call or a personal visit informing potential participants about the research and seeking their permission and consent to participate. Once the participant agreed, a time was arranged to visit their office, home, or a nearby community centre, whichever was convenient. The interviews began with sharing the consent form and a participant information sheet (both translated into the local language), which was left with respondents in case they would like to contact the interviewer, their supervisor, or the local partners in the study. The information sheet also had the contact information of the focal person at the Peshawar Living Lab at the UoP, the local academic partner facilitating the study. The interviews were conducted on chart paper, and sticky notes were placed in front of the subject to facilitate the interview process and record the views directly onto the paper. Before the start, participants were asked if the interview could be recorded.

The interviews were conducted using the seven-question format indicated in Chapter 4, Section 4.3.3. They were asked about the resilience problem over time, the main direct and indirect causes, and the consequences. They were then asked about the primary feedback processes in simple language to maintain engagement and interest. Finally, they were asked about the short—and long-term policies that were or could be adopted and what some of the main hurdles were in implementing these policies. Probing questions from the findings from the previous FGDs were used to check and validate the information gathered previously. The interviews typically lasted between thirty minutes to one hour. Examples of the CLDs drawn during the interviews are shown in Figure 5-4 to Figure 5-6. The researcher used chart paper and sticky notes to draw a CLD during the interview, with prompts from the participant about the placement of the sticky notes. The relationships between the sticky notes were given a + or—sign depending on the nature of the variable as determined by the participant. In some interviews, particularly those in the Irrigation Department and the Provincial Disaster Management Authority, the participant asked permission to involve other colleagues in the interview and the CLD was developed in conversation and discussion with two or more participants, resulting in a more detailed larger CLD, as shown in Figures 5-5. After the interviews, the researcher analysed the chart paper and sticky notes and made a digital version in Vensim software for the record. The individual CLDs were considered one by one and thematically analysed for the common variables and loops, including unique variables and loops that provided additional insight before combining them into a larger merged CLD, as presented in Figure 5-7.

Figure 5-4. CLDs from interviews in the community. (source: CLDPKC1 and CLDPKC)

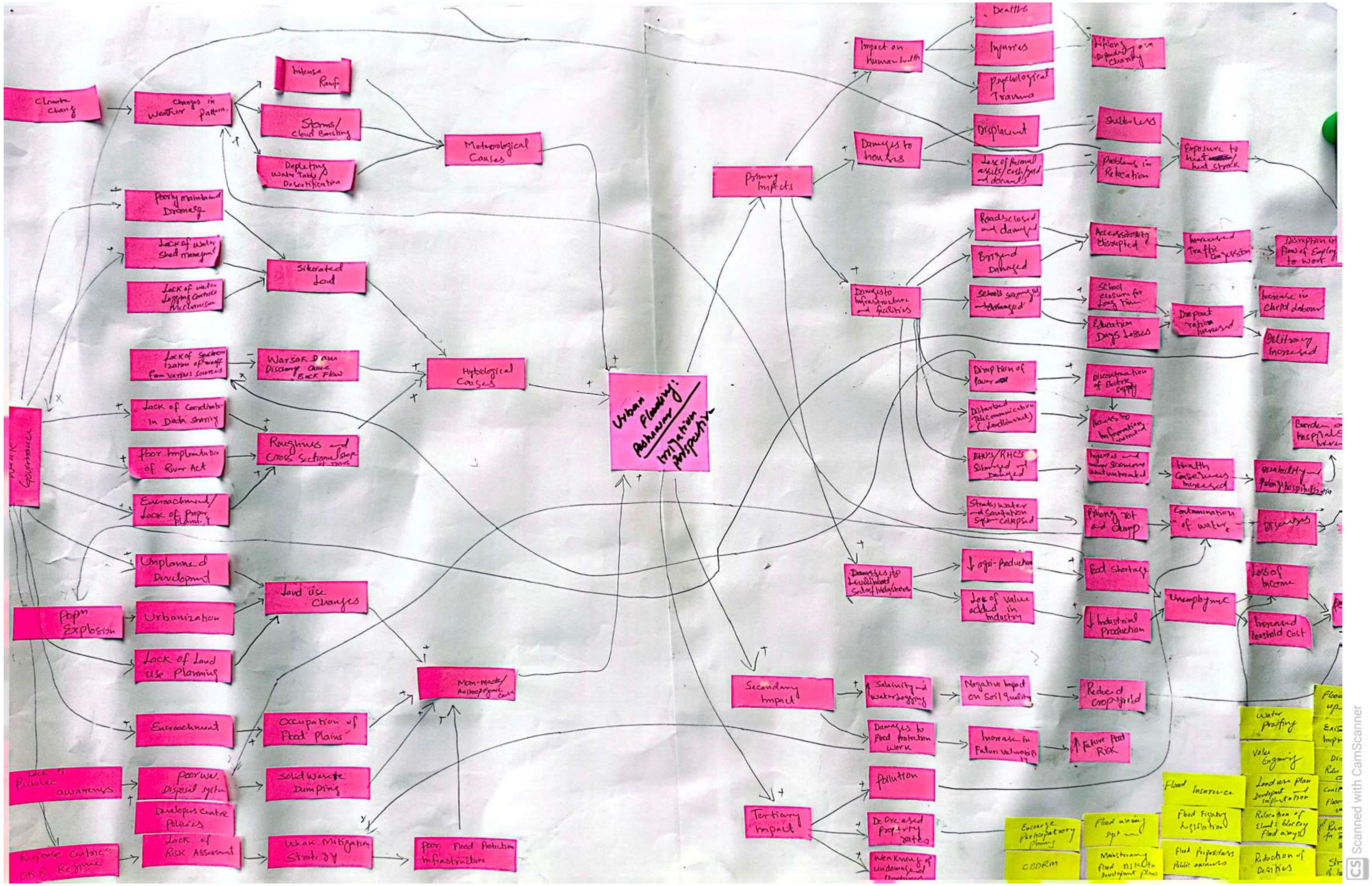


Figure 5-5. CLD discussion on Floods in the case study area with the Irrigation Department. (Source: CLDPKP4)

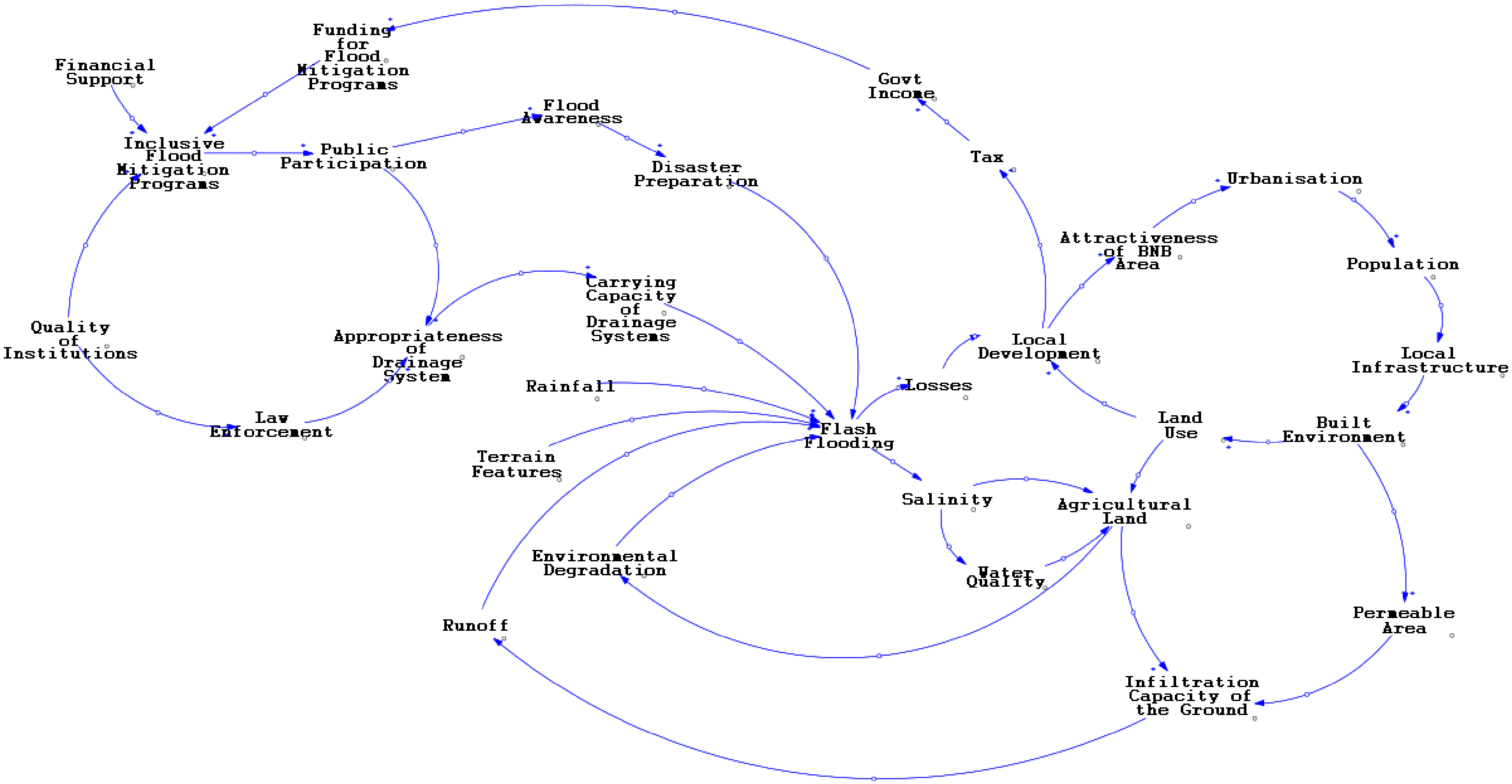


Figure 5-6. Sample CLD interview converted to digital form in Vensim (source: CLDPKA4)

Almost all of those interviewed (n=17/19) for the CLDs indicated that the risk of future flood events was increasing, with nearly half of those (n=7/19) mentioning that increasing variability in the weather due to climate change will result in a major flood event soon. As mentioned in Chapter 3, although the impact of the 2022 Floods was fresh in the minds of the community members, the BNB area was relatively less affected by the mega disaster that affected most of the country. Two respondents (n=2/19) mentioned that the previous governments had done considerable mitigation work, like retention ponds and waterway linings, demonstrated by the relatively low damages in the case study area in 2022.

Overall, the participants identified eight direct causes that may lead to flood events in the area: Excessive rainfall, Increase in Bult Area (i.e., Housing), New Construction (Highways), Encroachment into Waterways, Blockage of Waterways (Debris), Improper Design (Waterway), Backflow from River Kabul (Water Management), and Dam Discharge (Water Management). Most participants (n=17/19) agreed that erratic rainfall bursts were the leading direct cause of flooding. At the same time, others (n=11/19) also emphasised the role of unplanned housing development (for example, the Regi Lalama Housing Scheme) upstream as the reason for the increased risk of flooding. Other participants mentioned rainfall and unplanned housing but added additional causes like improper design (of waterways and mitigation features), failure of water management, corruption, and the lack of law enforcement (of debris clearance and encroachment) among the reasons for repeated flood events in the area.

Secondary causes or indirect causes were also mentioned in the interviews. Many participants (n=13/19) indicated that the lack of investment in physical protection measures or the failure to implement physical flood defences in the most needed areas also contributed to the increased damages from the flood events. As noted in Chapter 3, these periods of intense rainfall, often dumping the average monthly rainfall in one day, can cause flash flooding downstream. Most participants (n=17/19) agreed and emphasised that rainfall events are further compounded when the canals and waterways are blocked with debris from solid waste from industries or silt from previous flooding incidents. Additionally, several participants (n=6/19) noted that the new construction of major roads/bridges by the Highway Authority contributes to further encroachment into the waterways, resulting in less water flow space than before. The new construction is expected to worsen the channels' encroachment as those projects are near completion. Many (n=11/19) also noted that the proximity of Warsak Dam has had a considerable impact, either through faulty water management or its long-term impact on the area's water table. A higher water table impacts the ground's ability to soak up water and contributes to faster surface water runoff (Inam et al., 2015, Geris et al., 2022). Finally, improper water management of the Kabul River when it overflows was mentioned by several (n=6/19) participants. Water management was mentioned for the Warsak Dam and its discharge when threatened with overflow (when excessive rainfall occurs) and the Kabul River (when that river overflows due to excessive rain in the northern regions and glacial melt). Interestingly, managing the discharge from Warsak Dam is the responsibility of WAPDA, an electric utility company, and water management in the Kabul River is directly from the Provincial Government (source: interviews). After the causes were mapped on the left side of the problem variable, the participants were asked to fill in the right side of the diagram about the direct and indirect consequences of flash flooding in the area.

Six direct consequences of urban flooding in the BNB area were captured in the interviews: House damages, Physical Infrastructure (buildings, roads, basic health units, and other structures), Schools, Water Supply, Livelihoods (income, agriculture), Livestock (killed or missing), and others. Almost all the participants (n=17/19) reported that one of the major consequences of flash flooding was the damage to houses, businesses, and physical infrastructure, which resulted in the loss of lives and livelihoods for a large portion of the population. For example, CLDPKC7 mentioned that "…in the 2008 floods, almost everyone was severely affected. Back then around seventy percent of the houses were built from adobe or mud bricks." Another significant consequence of the flash flooding, according to the respondents (n=13/19), was school closures. Several (n=7/19) also mentioned the problem of students as young as 13 leaving education to start earning a living to support their families. According to CLDPKC1, "School dropouts increase after every flooding event, and this has a long-term impact on the whole community, as you can imagine it will largely determine what sort of work they do and income they get." Another participant (CLDPKA4) also mentioned that "After particularly severe flood events [like 2008 and 2010], school closure for weeks or months and the problem of loss of income or livelihood led to school dropouts as the families need to supplement their income sources in hardship." Previous studies in the literature, both in Pakistan and other parts of the world, have shown that such impacts can have severe consequences for the long-term economic growth and development of the community (Mudavanhu, 2014, Ahmed et al., 2022, Lassa et al., 2023).

Additionally, some respondents (n=8/19) also mentioned that the damage to physical infrastructure increases the community's vulnerability to other hazards, and the community becomes susceptible to other shocks and stresses. For example, CLDPKP4 mentions, "Damage to physical structures can make them weaker and more likely to fail if any other event occurs. We have had weakened house walls and ceilings collapse months after a flood due to later storms or even earthquake events which they would have withstood in normal circumstances." Damage to critical infrastructure such as health, power, and transport infrastructure (like bridges) can long-term impact community health and the economy (Iqbal et al., 2022). After populating both sides of the problem variable, participants were asked about any connections they could observe between the consequences and the causes and to draw feedback loops that connected consequences with causes to understand better the problem and the long-term dynamics in the community system. The primary feedback loops compiled from all the interviews are discussed in detail in the merged diagram, and the subsequent thematic models according to dimensions in the next section.

Finally, the participants were asked about the short- and long-term policies they were aware of or should be considered by the decision-makers. This question resulted in a list of 25 policies, as shown in Table 5-4 below. The table also shows how and when some of these policies have been implemented or planned for implementation and those only proposed by the participants. It also shows which stakeholder groups suggested or mentioned the policy for inclusion in our list. In addition, several policies based on improving information exchange between stakeholder groups and using technology like GIS and flood risk mapping tools to improve awareness and early warning were also noted. Overall, the list provides the research team with 25 policies which were considered too large a number to consider for the modelling phase. It was decided to limit this to a manageable number by asking participants in the validation FGD to select the most important and effective to address the local resilience issues, which can then be included in the simulation model design stage and will form the basis of the Stakeholder Defined Scenarios used later in the research.

Table 5-4. List of Policies from the interviews. (Key: Yellow= Scenarios Selected, Red = Mentioned in Interview, Green= Implemented)

Policies (Source: Field interviews, 2023)	**Practitioner**	**Academic**	**Community**	**Status**
1. Community-Based Disaster Urban Flood Management Projects				Proposed
2. Community Training and Awareness on DRR				Proposed
3. Evacuation and Emergency Response Exercises (Mock Drills)				Once in 2015
4. Protection walls based on risk assessment results.				Implemented 2009-10 & 2011-12, approved but not started (lack of funds)
5. Clearance of Nullah/Canal and Debris removal				Implemented 2008-9 & 2021-22
6. Localised Disaster Risk Reduction Plans				Proposed
7. Localised Flood forecasting Modeling				Proposed
8. Upgradation of river profile				Implemented 2008-9 & 2015-16
9. Micro-level GIS Bases Mapping of the area				Proposed
10. Community-Based Early Warning System				2021-22 (attempted but abandoned due to lack of funds)
11. Yearly basis Anti-encroachment drive				Implemented 2008-9 & 2015-16 only
12. District-level Monsoon Planning				2020-21 Planned but not completed
13. Establishment of Response Coordination Hub				Proposed
14. Data Sharing Platform for access to real-time data				Proposed 2022
15. Transparent compensation mechanism and process				Proposed
16. Stoppage of land mafia exploitation				Proposed
17. More funding for Ten Billion Tsunami Tree project				Implemented 2014 till now
18. Allocation of mitigation and preparedness funds				Implemented (only after disaster)
19. Local masons trained in flood-resistant house construction.				Proposed
20. Performance Services Accountability				Proposed
21. Safety equipment provision to Community-Based Organisations				Proposed
22. Strategy to avoid and prevent political interference in DRR				Proposed
23. Risk-Sensitive Urban Planning				Proposed
24. Construction of temporary retention ponds				Implemented 2009-10, no maintenance
25. Mainstreaming Flood Risk into Development Planning				Proposed

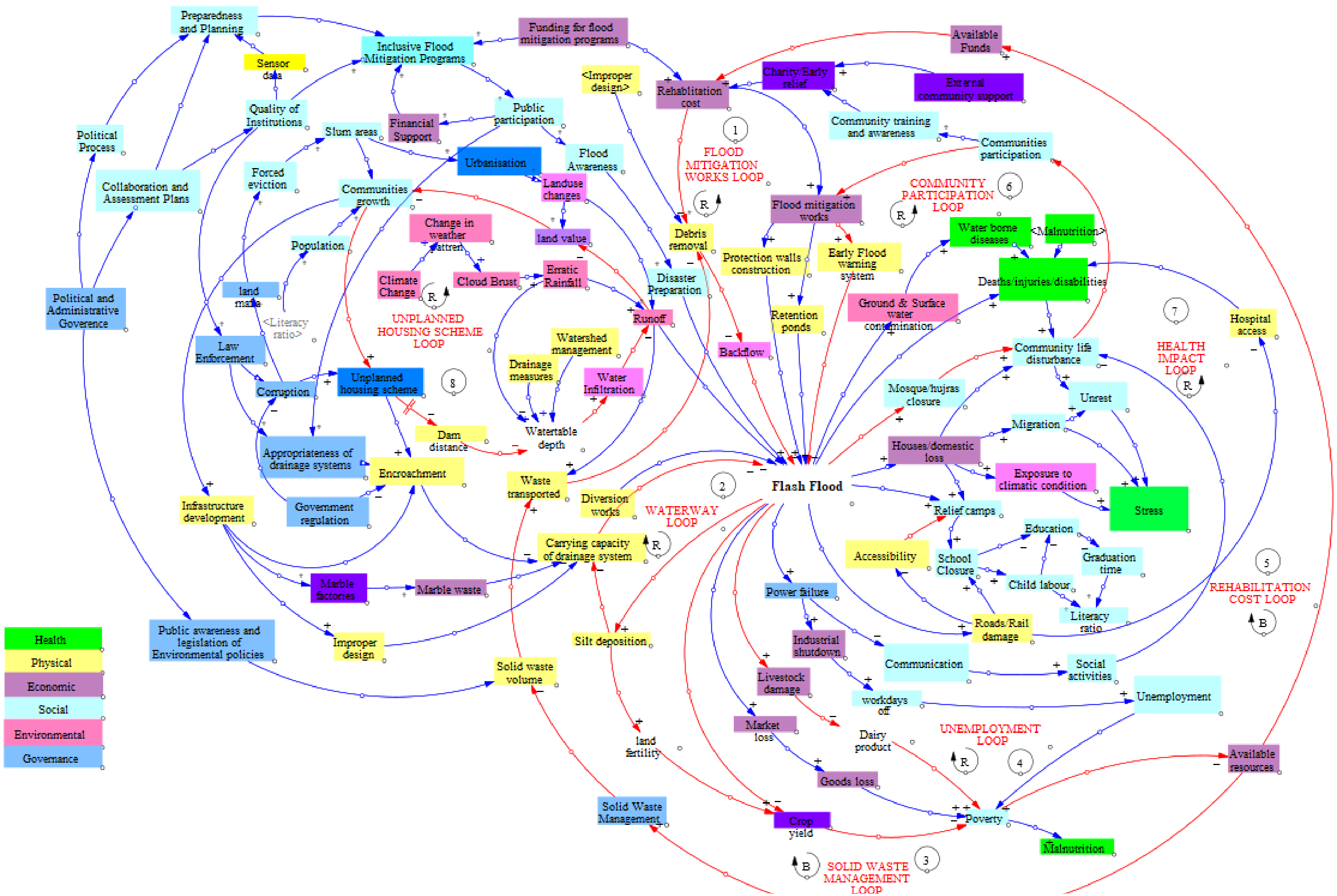


Figure 5-7. The Final Merged Causal Loop Diagram of Flooding in the BNB case study area.

5.4 Merged CLDs and Thematic Models (Step 4)

After completing the interviews with stakeholders from the three identified stakeholder categories and converting them to digital form in Vensim, each CLD was reviewed to identify the common and unique variables and feedback loops. This analysis developed a combined list of variables from all individual CLDs, and the list was consolidated by combining similar or synonymous variables to avoid redundancy. For example, where "public knowledge" was mentioned in some individual CLDs, this was consolidated into "community awareness". The feedback loops were similarly analysed for similarities and divergence where loops can overlap and be combined. Special care was given to ensure that each feedback loop is logically consistent with the combined variables. Subsequently, any conflicts or inconsistencies in the CLDs were discussed individually with colleagues from the PLL and AKF, and consensus was used to resolve differing views on how certain variables interact. Finally, the unified list of variables and integrated feedback loops were combined into a merged diagram, as shown in Figure 5-7. The merged CLD reveals eight feedback loops, two balancing loops and six reinforcing loops acting in the system. The eight feedback loops illustrate some dynamics around the community's recurring flash flooding problems. These feedback loops include the Canal Waterway, Solid Waste Management, Unemployment and Loss of Income, Flood Mitigation Works and Preparedness, Health Impacts, Unplanned Housing Scheme, and Rehabilitation loops. These loops are shown in detail in Figures 5-8 to 5-10 in the next section.

Loop 1 Flood Mitigation Works Loop (see Figure 5-8)

Loop 1 Flood Mitigation Works Loop highlights a significant challenge faced by the community-the lack of resources for flood preparedness and mitigation activities. This loop demonstrates that major works, such as constructing flood protection walls and water retention ponds, require substantial funding, which is often only allocated after a critical event. Once these mitigation works are built, funds for their upkeep and maintenance are usually unavailable, leading to disrepair and silting up (as shown in Loops 2 & 3). This underscores the need for sustainable solutions and long-term planning to address the community's recurring flash flooding problems.

*Loop 2 Waterway Loop (see **Figure 5-8**)*

The second loop looks at the state of the Waterway that runs in the middle of the community and is one of the area's primary sources of flash flooding. Loop 2 – the Waterway Loop indicates a reinforcing loop where the flash flooding increases the silt deposits in the waterway, reducing the canal's cross-section volume and increasing the risk of further flood events. Until maintenance is carried out, the risk of flooding continues to rise.

*Loop 3 Solid Waste Management Loop (see **Figure 5-8**)*

The illegal dumping of solid waste from industry and construction into the canal also reduces the waterway's cross-section volume. Loop 3 shows a balancing loop effect where the lack of funding and resources leads to a lack of maintenance and clean-up of the channel, resulting in reduced effectiveness of the waterway and increased chances of flash flooding from rainfall events.

*Loop 4 Unemployment Loop (see **Figure 5-9**)*

Loop 4 – Unemployment and economic impact of flash flooding indicate the role of frequent disasters on the income level of the local population and, hence, resource availability. The flash flooding damages local commercial and industrial infrastructure, resulting in decreased working days, unemployment, and a further increase in local poverty levels. Loss of income in the local area results in loss of revenues for local government, leading to reduced or cancelled maintenance, clean up and removal of silt and solid waste from the canal.

*Loop 5 Rehabilitation Loop (see **Figure 5-9**)*

Loop 5 is a balancing loop connecting the lack of available resources and funds to the total rehabilitation cost. With fewer resources and funds available, essential services like debris removal and mitigation works are impacted. With routine debris removal affected, there is a bigger chance of obstructions in the waterway that could lead to backflows and flooding, like Loop 2, but this time resulting from backflows.

*Loop 6 Community Participation Loop (see **Figure 5-10**)*

The Community Participation Loop shown in Loop 6 offers another reinforcing loop where the level of awareness and interest in disaster early warning systems is based on the previous events suffered by the community. As the frequency and intensity of flash flooding events increase, the community is more aware and actively participates in local early warning initiatives and other community-level activities, like issuing early warnings through local religious and social institutions. Due to this participation and awareness, some respondents reported a significant change in the local people's behaviour and increased participation after major events that are not seen after minor events. For example, after significant flooding in 2008, community participation in political (elections) and social activities (like volunteerism) was reported to increase, which might have placed pressure on the authorities to approve funding for major mitigation works.

*Loop 7 Health Impact Loop (see **Figure 5-10**)*

The flash flooding also contributes to adverse human health outcomes for the local community, as shown in Loop 7 – health impact loop. After a flood, ground and surface water contamination contributes to increased waterborne diseases, particularly malaria and dengue. Increased levels of illness in the area and the lack of access to hospital services due to reduced accessibility from inundated roads and damaged bridges result in overall adverse health outcomes for the local population, impacting their ability to earn livelihoods and causing further poverty. This usually affects low-income families, as those well-off can afford to move temporarily and access health care and other facilities elsewhere.

*Loop 8 Unplanned Housing Scheme Loop (see **Figure 5-10**)*

Finally, Loop 8 – The unplanned housing scheme loop shows how frequent flooding and damage to local communities drive down the price of land, making it cheaper to purchase residential plots. The availability of large parcels of land at affordable rates encourages housing schemes to buy up large tracts of land and develop them. Development usually entails paving roads and increasing the built-up area without planning for surface runoff water and other risk assessments. Reduced permeability of the surrounding land leads to increased surface runoff and higher volume and speed of water in the canal waterways, thus increasing the risk of flash flooding in the area. The reinforcing loops create a spiral of new housing schemes, luring more population into the area, increasing the number of houses exposed to flooding and making it harder to plan for and manage.

The diagram has been colour-coded according to the six dimensions of Physical, Health, Economic, Environmental, Organizational, and Social Resilience to make it easier to read. A total of 93 variables are identified in the merged Diagram, and Table 5-5 looks at the breakdown of variables according to the CDR dimensions. The merged CLD illustrates that most variables describe the social, physical, and economic dimensions, which are also qualitatively represented in the identified loops.

Table 5-5. Variables describing the Loops in merged CLD in Figure 5-7 by Dimension

Dimension	Number of Variables in the Merged CLD
Social	26
Physical	21
Economic	18
Environmental	13
Governance	9
Health	6
Total	**93**

5.4.1 Focus Group Discussion for Validation of the Merged CLD

After the individual CLDs were compiled into the merged CLD, a FGD was held with experts and community members in a Validation Workshop attended by six participants. The participants comprised two experts from the Urban Planning and Irrigation Departments at the Municipal Corporation, two academics from the Centre of Disaster Preparedness and Management (University of Peshawar) and two senior staff members from Al Khidmat Foundation, who were residents of the study area. The workshop began with a presentation on the research study, the scope, context and data collection, followed by the merged CLD and the feedback loops identified. After a detailed discussion on the merged CLD and each of the loops, the participants were asked to select which of the six dimensions (Physical, Health, Economic, Environment, Governance, or Social Resilience) were the most important for modelling in the study. The policies from the interviews were also shared for ranking and selection. After the workshop, participants were asked to comment on the accuracy of the diagram's causes, consequences, and loops. After the presentations, the FGD structure was open-ended, and participants were asked to comment on the merged CLD, the loops, their usability, and the level of detail captured by the method used.

During the FGD, the participants were asked to select the most critical dimensions to capture the resilience issues in the case study community. After a discussion among the participants, they decided on the Social, Economic and Physical Resilience dimensions as the three most essential dimensions representing most of the variables in the system. Additional dimensions like health and governance could also have been included. Still, the participants agreed that with the scope and context of this research, the analysis should be conducted within those three dimensions. Additionally, Table 5-4 was also shared with the participants, and they were asked to select the most critical policies on the list for building resilience in the community. After deliberation, they formed a consensus on four policies that they thought were the most relevant for community resilience in the case study area: Community training and awareness, Clearance and Debris Removal, Funds for Preparedness and Mitigation and Construction of Ponds, as highlighted in Table 5-4.

Finally, the participants mainly indicated positive feedback about visually representing information about the flooding in the CLD. They were satisfied with the breadth and depth of information collected from the interviews. When asked about the accuracy of the information, most (n=4/5) responded positively that, to their knowledge, the diagram covers the major causes and consequences of the flooding in the area. At the same time, some (n=2/5) indicated the need for minor changes in the diagram—these changes were related to adding two more loops (Encroachment and Diversion Loops – see next section) and providing more variables to add additional details about some of the identified loops. The participants were then asked about the practicality of the participatory mapping tool (the sequence of questions and the CLD tool) used in the research and if they would consider using similar methods. Most (n=4/5) of the participants agreed that the tool was relatively easy to learn and could be applied to their work, and some (n=2/5) requested further information, including a request for training. Additionally, when asked about the data collection process, most (n=4/5) stated that nineteen interviews were too many and similar information could have been taken with fewer respondents.

5.4.2 Dimension-wise CLDs and Policy Loops

The Thematic Map Development (TMD) approach can make the CLDs more readable and usable for stakeholder engagement and quantification of the model at later stages (Asif et al., 2023). The Participatory Approach uses the TMD method to produce thematic sub-modules of CLDs that are easier to read, still convey the main variables and feedback loops and can be used with stakeholders for greater engagement. Accordingly, the merged CLD was divided into three thematic sub-modules by dimension: Social, Physical Infrastructure and Economic Resilience. The sub-modules allow users to evaluate the details of different aspects of the system, thus enabling them to be easily shared with stakeholders for discussion and feedback. The TMD approach can help support the development of quantification in the System Design and Modelling phase by allowing the capture of system structure and interrelationships. Thus, the TMD method was used to produce dimension-level CLDs that capture the interaction between the critical variables that produce the loops explained below. Figures 5.8, 5.9 and 5.10 illustrate the Physical, Economic and Social dimensions and their loops. In addition to the merged diagram, dimension-wise diagrams were used in the validation FGD to explain the loops and their impacts on the community resilience system.

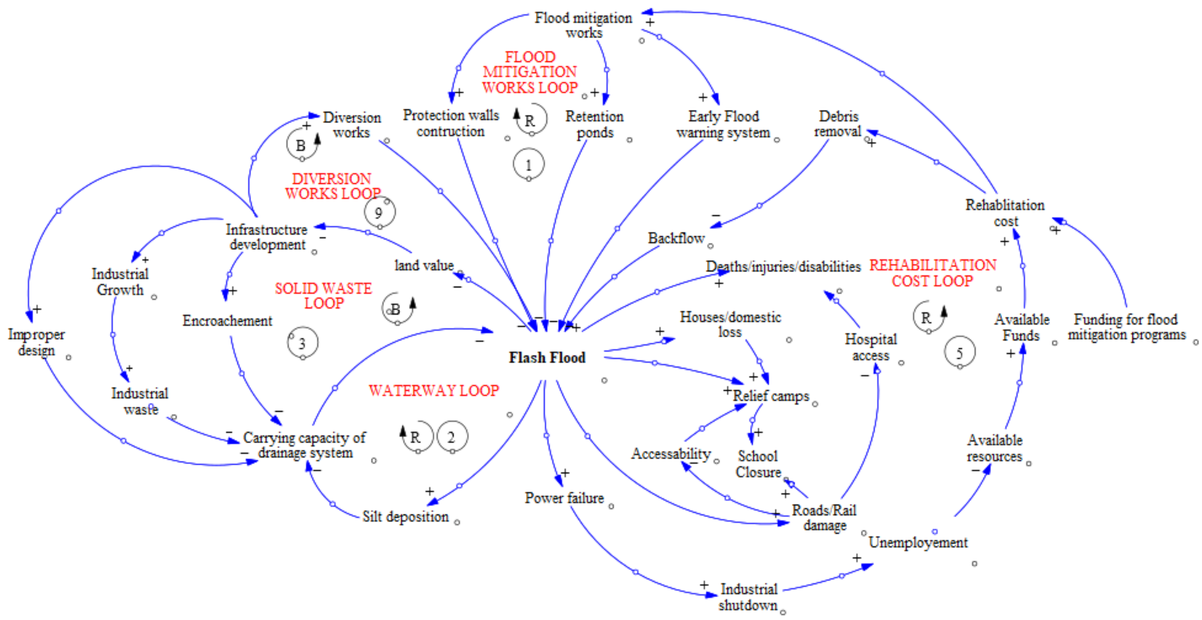


Figure 5-8. Physical Infrastructure Resilience and associated loops.

The Physical Resilience thematic map in Figure 5-8 includes five loops: the flood mitigation works loop, the Waterway loop, the Solid Waste Management loop, the rehabilitation cost loop, and the diversion works loop. The Flood Mitigation Works loop significantly contributes to physical resilience but requires large-scale funding. The Waterway and Solid Waste management loops play an essential role in the waterway system, as any reduction in the water flow capacity can lead to overflow, inundation and flash flooding events. Additionally, several interviews noted the presence of Diversion Works where new infrastructure development, such as bridges for the Northern Bypass project, contributed to encroachment of the waterway and could increase the risk of flooding. The Debris Clearance and Retention Pond construction policies can change some of the behaviour depicted in this diagram.

Additional Loop 9 – Diversion Works

The blockage of the Waterway (Loop 2) is partially due to the Solid Waste (Loop 3) being dumped and partially due to the encroachment of the waterway by the construction of the new roadways and bridges underway as part of the Northern Bypass project, as mentioned above.

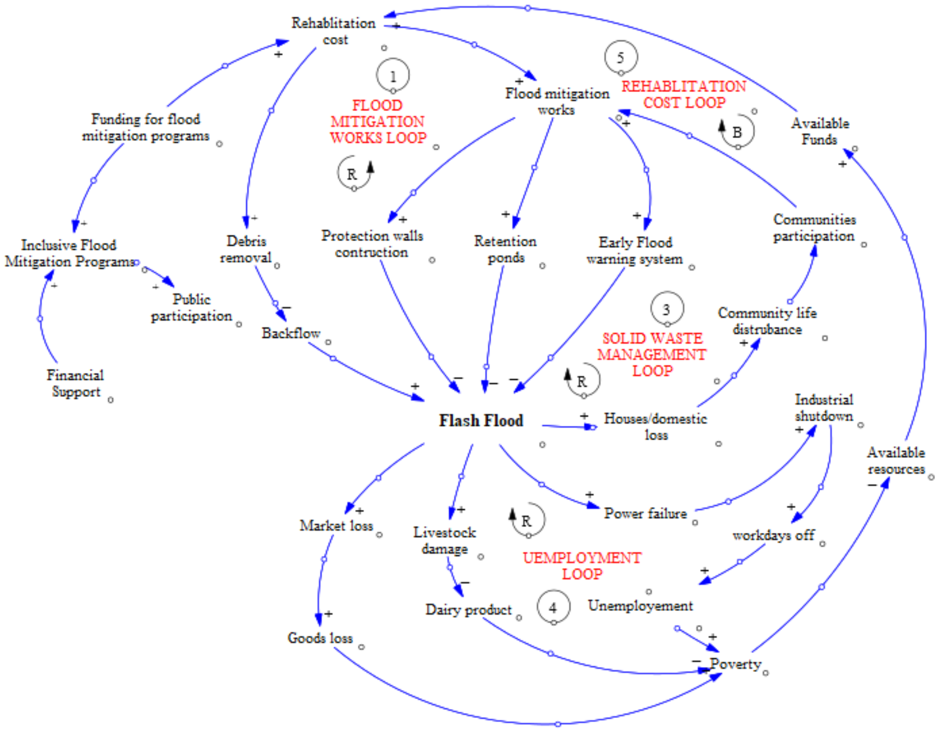


Figure 5-9. Economic Resilience and associated loops

Similarly, Figure 5-9 illustrates the Economic Resilience dimension and its involvement in four identified loops: Flood Mitigation Works, Solid Waste Management, Unemployment and the Rehabilitation Loops. According to the participants interviewed, the four loops demonstrate how economic factors may contribute to the area's flash flooding. Flood Mitigation Works is mentioned above and depends on funding and the general fiscal climate. The Solid Waste Management loop shows the link between industrial activity and the generation of solid waste that can potentially cause blockages and pollution, as well as the lack of funding for maintenance. The Unemployment loop creates poverty, reduced revenues, and underdevelopment. The Rehabilitation loop activates when a flood event occurs, and funds are released for recovery or mitigation. The Funds for Preparedness and Mitigation policy can influence the behaviour of some of the loops in this diagram.

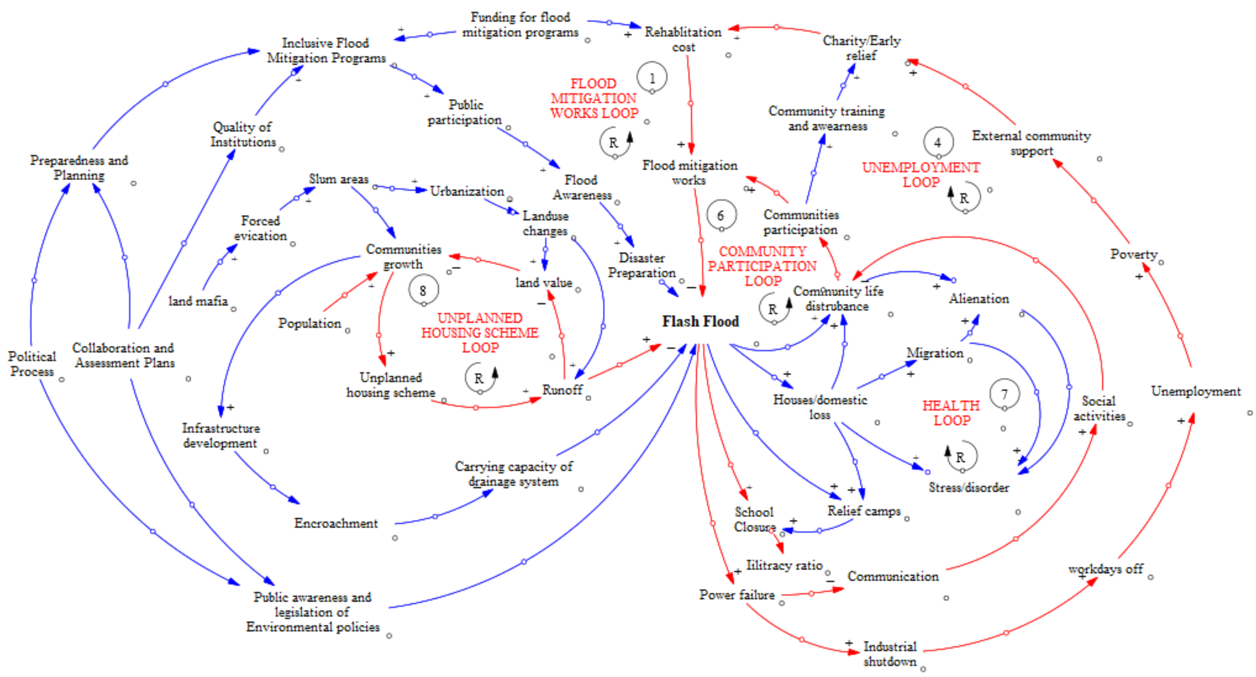


Figure 5-10. Social Resilience and associated loops.

Finally, the Social Resilience Dimension is shown in Figure 5-10. It consists of five loops: the Flood Mitigation Works loop, the Unemployment loop, the Community Participation loop, the Health loop, and the unplanned Housing Scheme loop. The diagram demonstrates the major social issues contributing to the flood problem. It gives an idea of what leverage points can be used to change some loops' behaviour. The Flood Mitigation Works and Unemployment Loops are discussed above. The Community Participation Loop is only activated when a significant event occurs, which can then influence other loops, like finding support for Flood Mitigation Works (like retention ponds and protection walls). The Health loop shows the impact of flooding on poor health outcomes, while the Unplanned Housing Scheme relates to the social problems arising from the unplanned developments being built in the area. The Training and Awareness Policy selected in the FGD impacts the loops in this diagram.

Selection of Dimensions for Step 5

During the validation workshop, participants identified physical infrastructure (PI), economic and social resilience as the three most affected dimensions in flash flooding events. These findings were then used to select an Index of three dimensions for the next section – Step 5 Q Sort Interviews and Indicator Selection. The inclusion of all six dimensions is a potential area for future work, highlighting the practical application and ongoing relevance of this research.

5.5 Q Sort Interviews for Indicator Selection (Step 5)

The CLDs generated from the interviews and FGDs in the previous sections indicate the importance of the Social, Economic and Physical Resilience dimensions as critical for modelling the CDR of the BNB case study area. This research used the Q methods approach to capture the opinions and perspectives of community members, practitioners and academics working on Community Resilience in the case study area. This section uses the Library of Indicators developed in Chapter 2 to conduct Q-Sort rankings of indicators for each dimension to form a community-level capacity assessment index that can be used to measure community resilience at the local levels. The Community Capacity Index is proposed as a tool for initiating debate and achieving consensus between diverse stakeholder groups working on the same resilience issues or problems by finding common grounds on diverging opinion patterns on how resilience should be measured through indicator selection. This section also looks at how the results from Q sorts are used to derive weights for the indicators to be used in the next phase of System Design and Modelling in Chapter 6.

A typical Q methodology study requires going through 5 steps: 1) Developing the Concourse of Statements; 2) Selection of the most relevant statements for ranking; 3) Selection of the Participants for the Q sorts; 4) Running the Q sorts; and 5) Analysis and interpretation of the Q sort ranking. Due to the limitations of the length of the document, most of the details of the complete Q methods study are placed in Appendix C, and only the results are shared here.

5.5.1 Developing the Concourse of Statement (Library of Indicators)

Chapter 2 contains all the details of how the Library of Indicators was developed for each dimension. Table 5-6 below summarises the three selected dimensions, their definitions, and the number of indicators in our library. From this initial review, the indicators from the library were considered as statements to be used for each of the selected dimensions (Social, Physical and Economic) in our case study. After collecting the statements by dimension, the next step was to refine them further and select the most relevant and appropriate indicators for our case study.

Table 5-6. Library of Indicators by Selected Dimensions. (Chapter 2)

Dimension/Sources	Defined as (boundary conditions)	No. of Indicators/Measures in the Library

Social (Saja et al., 2018, Räsänen et al., 2020)	Social resilience focuses on the capacity of people to connect as individuals, groups and organizations.	16/56
Economic (Rose and Krausmann, 2013, Irwin et al., 2016)	The economic resilience category includes the static assessment of a community's current economy (economic activity) and the dynamic assessment of a community's ability to sustain economic growth (economic development) continuously.	11/35
Physical (Biringer et al., 2013, M.Thayaparan et al., 2016, Koliou et al., 2018)	Those facilities or structures that form a network of systems/structures that perform a vital function of critical importance to the normal functioning of the community (i.e. power/electrical network/grid, telecoms, water mains/supply, road/transportation networks, etc.)	19/124
	Total	46/215

5.5.2 Selection of the statements for the Q sorts

This section will briefly review each dimension and its indicators for the study. In the systematic review, 21 of the 36 frameworks had social resilience indicators as a core part of their community resilience assessment at the local levels. Social resilience is represented by 16 indicators (with 56 measures), as shown in Table 5-6. These indicators include social demographics, social cohesion and trust, communication and awareness, local leadership and coordination, community support systems, cultural and traditional practices, social diversity and inclusion, volunteerism and civic engagement, and the ability of communities to learn and adapt.

Like all the resilience dimensions, social resilience is context-specific and can vary across different communities, cultures, and regions. When measuring social resilience, a combination of quantitative data from secondary sources and primary sources like surveys, interviews, and other participatory methods like CLDs can provide a more comprehensive understanding of a community's capacity to withstand and recover from disasters. Additionally, community involvement in the indicator selection process can lead to a more accurate reflection of their unique strengths and challenges.

Again, from our review, 17 of the thirty-six frameworks included indicators for measuring PI resilience. The review compiled 19 indicators with 124 measures in our Library of Indicators to understand the different critical elements within the PI resilience dimension. These indicators included structural integrity and design standards, operational continuity, early warning, emergency response and recovery plans, resource availability, damage assessments, mitigation measures, and community engagement for preparedness and awareness. After a consolidated review, 16 of the 19 indicators were selected for use in the case study.

It is essential to note that measuring physical infrastructure resilience requires a combination of quantitative data, expert insights, and qualitative information gathered through stakeholder and community engagement. Additionally, the choice of indicators may vary based on the type of infrastructure (e.g., transportation, energy, water), the specific disaster risks the region faces, and the resources available for assessment.

Finally, Economic resilience was covered in 22 of the 36 frameworks, making it a central part of understanding CDR at the local levels in the review. From these frameworks, 11 indicators were added to the library with 35 individual measures of economic resilience. These 11 included income distribution and poverty, employment, diversity of industries, access to financial services, business continuity planning, financial resources, insurance, and recovery plans. As mentioned previously for the other dimensions, our study recognises that economic resilience indicators should be tailored to each community's specific economic structure, resources, and challenges. Combining quantitative data, surveys, interviews, and economic modelling can provide a comprehensive picture of a community's economic resilience. Additionally, the involvement of local businesses, economic experts, and policymakers in the indicator selection process can lead to a more accurate and meaningful assessment.

After reviewing the indicators in each of the three dimensions and prioritizing those indicators in the context of flooding and urban resilience, sixteen indicators per dimension were finalized. A pilot was conducted to refine the wording used in the Q sorts to reflect the local language used in the research. Sixteen indicators for each dimension were narrowed down from the more extensive library of indicators used in the case study. The research team chose these final 16 indicators after consultation with a group of experts to narrow down the list and make the GMB workshops manageable across all stakeholder groups. Initial pilot studies showed that although the academic group could sort many indicator statements without assistance, the practitioners and community members often expressed confusion due to complex language and jargon in the Q Sorts, resulting in longer sort times to explain each statement and, hence, participant frustration. The following table shows the final 16 for each dimension, sorted by capacity for clarity.

Table 5-7 Resilience Indicators by Dimension (colour-coded for capacity)

No.	Social Resilience Indicators	Economic Resilience Indicators	Physical Infrastructure Indicators
1	Community Participation in DRR	Hazard Risk Awareness (Businesses)	Hazard Risk Awareness (Utilities)
2	Community-Based DRR Plans	Private Public Partnership for DRR	Risk Mitigation Training Program
3	Communication (Social Media)	Preparedness Plan	Plans for mitigation
4	Community goals/priorities	Mitigation Measures/Strategies	Early Warning Systems (EWS)
5	Religious Beliefs & Norms	Training Programmes for DRR	Quality/extent of mitigating features
6	Local Culture and Norms	Wealth (Assets)	Age of structure
7	Fair Access to Basic Needs	Income Status	Hazard mitigation standards
8	Social Demography	Diverse livelihoods	Building Characteristics (Kactha, Pacca)
9	Community Inclusiveness	System Failure	Safety design factors
10	Community Shared Values	Severity of Failure	Total Damaged assets
11	Mobility of People and Families	Maintenance	Probability of failure
12	Household Structure	Recovery time	Recovery plans exist
13	Local Leadership in DM	Risk Transfer (Insurance)	Post-event damage
14	External support systems	Household Support	Length of time assessment
15	Effective Civic Organizations	Post-event damage	Restoration time for full operation
16	Diverse Skill Set (Workforce)	Government Relief	Time needed for recovery
	Anticipatory Capacity = Yellow, Absorptive Capacity = Orange, Restorative = Blue		

5.5.3 Q Sort Participants

Participants for the Q Sort interviews were selected from institutions and organisations that had attended or participated in a Disaster Risk Reduction event at the Peshawar Living Lab. Where possible, those interviewed for the CLDs were asked to participate. A participant list was developed and categorised into the three stakeholder groups (academics, practitioners and the community members) according to their background and occupation. The participants either worked on disaster management, urban planning, climate change, and similar disciplines or were study area residents. Requests for participation were sent to those selected through the PLL and the AKF. The AKF recruited community members from their NGO, including staff, social mobilizers, or volunteers, as well as from other Community-Based Organizations operating within the case study area.theThe Q sort interviews were held in person at a participant’s workplace, home or community centre scheduled at their convenience.

Table 5-8 below provides an overview of the number and type of participants for each dimension. The dimensions selected for this step are based on the analysis of the CLDs in the previous section, particularly the variables and loops identified in the Thematic Maps developed in the study. Based on previous studies in the literature, a minimum of five respondents per stakeholder group per dimension was considered for use in the Q methods analysis, where a similar number was used to derive insight into a group's perspectives. (Huggins et al., 2015). The Q methods approach is suitable for small, selected samples of individuals, and caution must be taken as it is not intended to be generalized to a larger population. The participants in this study are not meant to represent the general population but are a purposive sample of experts, practitioners, or residents of the case study area. Hence, the method can be used in this context for ranking among the stakeholder groups used in this study (Raadgever et al., 2008, Brown and Rhoades, 2019). Additionally, there was a gender imbalance in the Q-sort interviews, as only 7 of the 68 participants were female. This lack of female participation in the research is due to the conservative nature of the local community, which has strict segregation in most social settings. Due to the focus of the study on flash flooding and its overall impact on the community this was not considered as a major limitation.

Table 5-8. Q Sort interviews Participants Breakdown.

Dimension	Interviews	Breakdown by Group
Social Resilience	33	12 Academics 11 Community 10 Practitioners
Physical Resilience	16	5 Academics 5 Community 6 Practitioners
Economic Resilience	19	6 Academics 5 Community 8 Practitioners
Total	68	23 Academics 21 Community 24 Practitioners

5.5.4 Procedure for Q sorts

Each interview typically took around 30 to 45 minutes, where the participants were first given a consent form explaining the research, followed by a brief explanation of the Q sort exercise and an overview of the indicators mentioned in the Statements. For the q-sorts conducted during the interviews, the indicators were converted to statements on physical cards that had the title on the front side and, on the back, a short explanation with example measures. Sixteen cards were used for each dimension, each card representing an indicator.

5.5.5 Q Sorts Analysis

Q Sort analysis was conducted using the Ken Q Analysis software for all three dimensions. For each Dimension, the following will be reported: 1) Factor Significance tests, indicating the number of Factors in the data explaining the major perspectives among the participants; 2) Varimax Factor Rotation results, the ideal set of Indicators by Factor and the qualitative evidence supporting it; and 3) Weights by Indicator. For additional analysis and results supplementary to the research, please see Appendix C.

As it is a mixed-method approach with a qualitative component that complements the quantitative results, both must be included. NVivo 12 was used to analyse the qualitative data from the Q-Sort interviews on the reasons for choosing the top and the bottom three indicators. Thematic analysis of the interview text using the indicators as keywords was conducted to parse out the reasons for selection. These results are reported in the tables below. Similarly, since the qualitative data for each dimension is a rich source of information for the modelling phase – supplementary results and additional analysis are provided in Appendix C: Q Analysis. For example, Group-wise Raw Q-sort Rankings, to show patterns of opinion or perspective within the stakeholder groups, are omitted from this chapter but can be seen in Appendix C.

Social Resilience Indicators Ranking and Weights

Thirty-three respondents participated in the Social Resilience Q sort interviews and were asked to rank 16 Social Resilience indicator statements in order of importance from most important to the least. Each participant individually ranked the 16 indicator statements and was only assisted in the process by the researcher when requiring clarifications regarding the meaning and content of the indicator statement on the Q-Sort cards placed before them.

Factor Significance tests

In applying Q-Sorts for analysis, Watts and Stenner (2012) recommend conducting a centroid factor analysis (CFA) that can reveal the ideal Q-Sort, called factor array, for each factor found significant. These factors represent the central patterns of opinion or perspectives in the data and can represent agreement (or disagreement) on those statements. To apply CFA, the researcher needs to select the total number of factors that are found to be statistically significant. Two tests are commonly used to determine significance: the Kaiser-Guttman criterion and the Scree Plot Diagram. When both cannot provide a clear result, a third, called Humphrey's rule, can be used to determine the outcome. The Ken Q Analysis software automatically generates the Kaiser-Guttman criterion and the Scree Plot Diagram, while Humphrey's test requires calculation (see Appendix C – Humphrey's rule results). All three tests were performed for the Social Resilience data set, and three factors were found to be significant for the Varimax Factor Rotation to generate the ideal Q-sorts.

Varimax Factor Rotation results

For the CFA, Ken Q Analysis was used to conduct a Varimax Rotation of three Factors found to be significant to generate Factor Scores with Ranks for each statement. Table 5-9 shows that Factor 1 explains 26 per cent of the variance, Factor 2 explains 11 per cent and Factor 3 only 10 per cent for a cumulative explained variance of 47 per cent. In contrast to other statistical methods like Principal Component Analysis (PCA), which looks at factor loadings of the variables, Q methods look at the factor scores of the Q sorts. In this case, the factor scores are the average value of each factor's Q sorts, representing how each statement is viewed by the factor (Watts and Stenner, 2012). The Rotator Factor Loadings Table (in Appendix C) shows that Factor 1 is defined by 19 Q sorts (with 16 flagged), Factor 2 is defined by 5 Q sorts (all flagged) and Factor 3 is defined by 9 Q sorts (with 5 flagged). These Factors represent the significant patterns of opinion on measuring Social Resilience among the participants interviewed. Table 5-9 below shows the relative scores for each indicator in the three Factors identified. As in a typical Q-Sort, a higher score means greater preference, and, in this case, 3 means ranked highest, and vice versa for those ranked -3. The naming of the Factors usually represents the nature of statements within the Factor that have scored highly and is a qualitative description of the dominant view among the Q-sorts loaded into the Factor. For Social Resilience, these Factors are 1) Community Engagement and Community Capacities, 2) Social Cohesion and Bonds, and 3) Social Demography. Each of the Factors is discussed in more detail below.

Table 5-9. Social Resilience Q-sort Factor Scores and Weights by Indicator.

No.	Statement	Factor 1	Factor 2	Factor 3	Weights per Statement		Normalise	Parameter Weights
		score	score	Score	Equation 1	add 3	Equation 2	(Eq. 2 * 100)
1	Social Demography	-1	-1	3	-0.149	2.851	0.059	5.940
2	Local Leadership in Decision Making (DM)	2	3	1	2.021	5.021	0.105	10.461
3	Household Structure	-2	-2	-2	-2.000	1.000	0.021	2.083
4	Mobility of People and Families	-1	-3	1	-1.043	1.957	0.041	4.078
5	External support systems	0	1	0	0.234	3.234	0.067	6.738
6	Effective Civic Organizations	0	0	0	0.000	3.000	0.063	6.250
7	Community Participation in Disaster Risk Reduction	3	0	-2	1.234	4.234	0.088	8.821
8	Community goals/priorities	1	-2	1	0.298	3.298	0.069	6.871
9	Community Shared Values and Attitudes	-1	1	0	-0.319	2.681	0.056	5.585
10	Community-Based DRR Plans	1	-1	2	0.745	3.745	0.078	7.801
11	Communications (social media)	2	-1	-1	0.660	3.660	0.076	7.624
12	Fair Access to Basic Needs	1	0	2	0.979	3.979	0.083	8.289
13	Community Inclusiveness	0	0	-1	-0.213	2.787	0.058	5.807
14	Diverse Skill Set (Workforce)	0	1	-3	-0.404	2.596	0.054	5.408
15	Religious Beliefs & Norms	-2	2	0	-0.638	2.362	0.049	4.920
16	Local Culture and Norms	-3	2	-1	-1.404	1.596	0.033	3.324
	Explained Variance	26	11	10		Total = 48		Total = 100
	Cumulative % Explained Var.	26	37	47				
	Eigenvalues	8.3568	3.7914	3.3902				

Factor 1 – Community Engagement and Capacities

Factor 1 loaded 19 Q sorts and accounted for 26 per cent of the explained variance in our analysis. This factor represents the perspective of most of the Q-Sort participants from all three stakeholder groups who viewed community involvement in decision-making as an essential component in all aspects of disaster preparedness, response, and recovery. Indicators measuring Community Participation in DRR were given the highest score, followed by Local Leadership in DM and Social Competence. These scores reflect the importance of understanding the level of engagement in the community through political participation, the number of elected representatives from the area and the need for local involvement in disaster planning. Factor 1 also emphasises the role of risk awareness among the community, the use of social media connectedness for the rapid sharing of timely information for preparedness and response (Social Competence), as well as the community's ability to plan for disasters, set goals, and achieve them through regular interaction (Community Goals and Efficacy). On the other hand, Factor 1 shows that indicators for Household Structure, Local culture and religious practices are not crucial for measuring social resilience. Table 5-10 shows some of the comments from participants regarding their choices in Factor 1. The participants were assigned codes by dimension and stakeholder group, which are used to indicate who the quotes belong to in the following tables. For example, SRPAKP5 means Q-Sort interview for Social Resilience with Practitioner number 5 in the Pakistan study (a C was used for community members, and an A was used for Academics).

Table 5-10. Respondent's comments on the choice of indicator statements in Factor 1.

Highest Ranked	**Community Participation in DRR** ***"...is increasingly the most crucial aspect of any resilient community. If your community is actively engaged, aware, and well-prepared, then your community will move towards social resilience."*** **SRPAKP5** ***"…it is one of the important aspects of Social Resilience because, without active engagement, we can't contribute to any plan, so we cannot cope with or face any problem, either disaster or minor problem." SRPAKC4*** ***"community engagement is essential for building community competency and achieving your community goals". SRPAKC7***

Ranked higher than other Factors	**Communicaitons (social media)** *"We got messages on WhatsApp and TikTok of the flood from upstream. We knew the situation was bad…" **SRPAKC10*** **Community Perception and Goals** "The next two important indicators are having Community Goals and Communications. Even if you have everything else, you cannot move toward resilience without community goals. Even if community goals are present, if there is a lack of "Communication", you still cannot progress toward social resilience." SRPAKC7
Lowest Ranked	**Religious practices and norms** *"…as people are moving toward modernization and getting knowledge, we are learning that disasters are not only from God; they are natural, or some are made by us. When people in old age/era thought it was from God, they were not used to [preparedness] actions against it and faced it as it is, but now, they are taking actions because they know it is not only from God."* **SRPAKC4**
	Local Culture and norms *"I awarded the least important position to the indicator "Local culture and norms". It is because, in the older times, the community might be superstitious as some people used to say, 'all good or bad happens to a community is because of their deeds'. Previously, such negative attitude and false perception might have stopped people from taking measures, but now there is awareness, and it is not a factor anymore."* **SRPAKC10**

Factor 2 – Social Cohesion and Bonds

The second factor, Social Cohesion and Bonds explains eleven per cent of the total variance and has five Q sorts loaded. This factor emphasises the need for understanding the role of Community-led leadership, the number of people from the local area in leadership positions in stakeholder organisations, and the number of social groups represented in decision-making at the local level as the vital indicators of Social Resilience. Interestingly, Factor 2 assigns higher importance to Local Culture and Religious beliefs than the other two factors, emphasising that some participants value its measurement more than the participants included in the other two factors. The lowest ranked statement in Factor 2 is the Mobility of People and Families, where the indicators measure land and home ownership in the local area, indicating that the participants in this group did not think these variables are necessary for developing social cohesion or bonds. Some commentary from the interviewees as they filled the Q-sorts regarding these choices is shown in Table 5-11 below.

Table 5-11. Respondent's comments on the choice of indicator statements in Factor 2.

Highest Ranked	**Local Leadership in Decision Making** ***"…local leadership indicator is important because it strengthens the community to cope with any situation inside and outside the community."* SRSLP2** ***"…one of the most important indicators is Local Leadership in DM, which means having strong leadership within the community. A community needs strong link to Local Leadership to progress towards resilience. Knowing this further facilitates community engagement and positively influences the other indicators."* SRPAKA6**
Ranked higher than other Factors	**Local Culture and norms** *"Local culture and norms should be considered because they are still very much part of the daily normal routine and continue to exist. They should be understood."* **SRPAKALA10**
Lowest Ranked	**Mobility of People and Families** *"Social mobility is not as such important because it has been seen that even those without their own land or houses stay here and even smaller [minority] communities show resilience in difficult times."* **SRPAKP5**

Factor 3 – Social Demographics

Finally, Factor 3 consists of nine Q-sorts explaining ten per cent of the total variance. This Factor makes an important distinction regarding the inclusion of socio-economic background characteristics of the community by ranking the indicators for Social Demographics of the local area as the most important. Notably, this Factor also ranks the indicators for Fair Access to Basic Needs and Services and the Mobility of People and Families higher than the other two Factors. Finally, participants in Factor 3 ranked the indicator for understanding the availability and diversity of workforce skills in the community of the lowest importance. Table 5-12 below shows some of the views shared on Factor 3 by stakeholders in the interview.

Table 5-12. Respondent's comments on the choice of indicator statements in Factor 3.

Highest Ranked	**Social Demographics** ***"…many of the other indicators for achieving resilience in the community are dependent on the type of people living there…here [in case study area], we have many people with jobs working in the public sector…other places are not so..."*** **SRPAKP6**
Ranked higher than other Factors	**Fair Access to Basic Needs and Services** *"Access to basic needs plays a very important role in a community - only when a community has satisfied their basic need, so they think for development and plans for hazard or disaster."* **SRPAKC2** *"…considering the list, we have other important indicators, such as the mobility of people and families and fair access to basic needs and services. These factors are crucial for building social resilience in any community."* **SRPAKC6**
	Mobility of People and Families *"…mobility of people got the position that is more important due to the abnormal consequences about a hazard on your land and house which can set you back many years."* **SRPAKP8**
Lowest Ranked	**Diverse Skill Set (Workforce)** *"Diverse skill set will not be so important if we (community) have people from surrounding communities that can work here to achieve their goals, I think other indicators are more important."* **SRPKM4**

The factor scores can also be used to understand our study's consensus and disagreement indicator statements shown in Table 5-13 below. The highest consensus on an indicator statement among the three significant discourses found in the study is on Community Inclusiveness and Equality. All three sets of Q sorts have ranked it in the middle for importance. Another statement all three discourse groups agreed on was the placement of Household Structure on the lower end of the importance. On the other hand, disagreement statements are statements with a marked difference in how they are ranked between three identified discourse groups. There was considerable disagreement between the three groups on Local Culture and Norms, which was ranked from lowest (-3) to second highest (+2). The highest disagreement statement was Social Demography. It was ranked second lowest (2) and the highest (+3), indicating a significant disparity in how vital those indicators are for participants between the factor groups.

Table 5-13. Consensus and Disagreement Statements with factor scores for Social Resilience.

	Statements	Factor 1	Factor 2	Factor 3
Consensus	13 Community Inclusiveness and equality	0	0	-1
	3 Household Structure	-2	-2	-2
Disagreement	16 Local Culture and Norms	-3	2	-1
	1 Social Demography	-1	-1	3

Derving Weights from the Factor Scores

After completing the CFA analysis on the SR Q sort data and determining the three factors and their respective factor scores, this research will propose a strategy for developing weights for each statement that can be used as parameter weights in our System Dynamics simulation model in the next chapter. The strategy uses factor scores from the identified three factors to calculate the weights directly. It can be considered an extension of the subjective approach used to develop the Community Capacity Index for Social Resilience and use it as an input into the System Design and Modelling stage. Estimating the Parameter Weights from the Factor Scores is a novel way to use primary data from stakeholders to determine the weights of the indicators used in our model and complement the other participatory modelling methods used in this study.

Table 5-9 shows the three Factors and the Factor Scores by Statements used to generate the weights. As mentioned in the analysis above, the Explained Variance for each of the Factors 1, 2, and 3 is 26%, 11% and 10% respectively. Equation 9 below uses the Explained Variance with the Factor Scores to determine the weights per statement (Brown and Rhoades, 2019, Ma et al., 2023).

Equation 9

$$WS_i \ = [(EV_1 * \ FS_{1i}) + (\ EV_2 * \ FS_{2i}) + (EV_3 * \ FS_{3i}) \ / \ \sum EV$$

Where WS_i is Weight Per Statement, i is the number of statements, EV_1, EV_2 and EV_3 are the explained variance of factors 1, 2 and 3, respectively, FS_{1i}, FS_{2i} and FS_{3i} are the factor scores of each statement by their respective Factors and $\sum EV$ is the sum of all the explained variance of the three factors considered in the analysis. Once WS_i is calculated, the maximum value in our Q Sort of 3 is added to remove negatives but to keep their values in relation to each other. The total sum of the values in Column 5 is 48, which enables us to use Equation 10 to normalise the values between 0 and 1.

Equation 10
$NWS_i = WS_i / \sum WS$ (2)

Where NWS_i is the normalised weights from 0 to 1, WS_i is the weight per statement (plus 3 to remove the negatives), and $\sum WS$ is the sum of the weight per statement. Multiplying the result by 100 gives the final parameter weights for the SR dimension on Column 7 that can be used in our SD model. The results show that the indicator for Local Leadership in DM gets the highest parameter weight at 10.46. In contrast, Community Participation in DRR and Fair Access to Basic Needs get 8.87 and 8.28, respectively. The Parameter Weights column sums up to 100 to ensure the total is correct for the relative weights for each indicator statement.

The parameter weights in Table 5-9 provide a quantitative method backed by qualitative insights into understanding the preference of how to measure Social Resilience by stakeholders participating in the research. This method ensures that researchers can understand why the indicators are relevant to the participants and that the resilience assessment is validated or “fit-for-purpose” to be used in the research's System Design and Modelling stage. A similar analysis was conducted for the other two dimensions (see Appendix C for a complete analysis), but only their results are shared here.

Measuring Economic Resilience

Economic Resilience (ER) was one of the three CDR dimensions selected, with 19 respondents in the Q-Sort interviews who ranked the 16 statements corresponding to indicators from the Library of Indicators.

Factor Significance tests

ER Q-Sort data was used to generate the results in Ken Q Analysis, and the Kaiser-Gutmann Criterion (where Eigenvalues more significant than 1 in the Unrotated Factor Matrix are noted) revealed two significant factors. The Scree Plott graph similarly showed a slope change at the second factor, indicating significance at the 2-factor mark. Both tests concurred that there were two statistically significant perspectives in the data. The CFA was then conducted using only two factors.

Varimax Factor Rotation results

For Economic Resilience, Varimax rotation was conducted on two factors, which explained twenty-six per cent of the variance and eleven per cent, respectively, for a total cumulative thirty-seven per cent, as shown in Table 5-15. Twelve Q-sorts were loaded onto Factor 1; the remaining seven were loaded onto Factor 2. After reviewing the Factor Scores by Indicator in Table 5-15, Factor 1 was emphasised Awareness and Preparedness and Factor 2 prioritised indicators for Income and Wealth and was named Community Prosperity.

Factor 1 – Awareness and Preparedness (among businesses)

Factor 1 was defined in the study by 12 Q Sorts with an explained variance of 26%. Of the 12 Q Sorts, five belonged to Practitioners, four to Academics, and only three Community members subscribed to this view. Perhaps reflecting this professional outlook, Factor 1 places the most importance on Hazard Awareness among the economic actors in the BNB area for greater overall resilience, following that Preparedness Plan (Business Continuity) and Wealth (Assets) indicators are the next most important. In addition to these two indicators, Mitigation planning, Communications and Diverse livelihoods indicators were also important in the respondent Q sorts in Factor 1. Finally, at the bottom end, Post-event Damage Assessment, Recovery Time, and Household Support are considered the least essential indicators. Participant views on these choices are shared in Table 5-14.

Table 5-14. Respondent's comments on the choice of indicator statements in Factor 1. (Economic Resilience)

Highest Ranked	**Hazard Awareness** ***"Awareness is the most important indicator for economic resilience in disruptive situations. If a business or company knows the hazards from the beginning, they can be prepared and cope with the disaster in advance."*** **ERPAKP6** **"Hazard Awareness is the root of reducing disaster risk, especially for livelihoods in the economy and is needed for proper planning and decision making." ERPAKA4**
Lowest Ranked	**Post-Event Damage Assessment** "Event Damage Assessment might be important, but first we should focus to make a system where there is less chance of system failure; then we should focus on post-event damage assessment…" **ERPAKP6** *"Post-event damages, recovery time, and recovery plans are categorized as least important because they occur after a disaster. They are part of the response and recovery phase rather than proactive measures…"* **ERPAKP7**

Factor 2 – Community Prosperity

The remaining 7 Q sorts comprise the discourse in Factor 2 around Community Wealth and Prosperity and account for 12 per cent of the variance in the CFA. Three of the seven Q sorts in this discourse belong to the Academic group, with two each from the other groups rounding out the Q sorts. The most important set of indicators for measuring ER in this group is the Wealth and Income of the Household, which can directly impact the stages of a disaster: the level of preparedness, the ability to take mitigation measures, and recovery from the impact of hazards. Factor 2 also assigns high value to Hazard Awareness among the business community, like the participant Q-Sorts in Factor 1. Factor 2 also considers Government Relief, Preparedness, Learnability and Training as good indicators of a community's resilience while System Failure (total loss in business or commercial activity), Severity of Failure (Number of businesses affected) and Recovery Time were considered the least important. Views on Factor 2 from respondents are shared in Table 5-16.

Table 5-15. Economic Resilience Q-sort Factor Scores and Weights by Indicator.

No.	Statement	Factor 1	Factor 2	Weights per Statement			
		score	score	Statement	Add 3	Normalise	x 100
1	Hazard Risk Awareness (Businesses)	3	2	2.684	5.684	0.118	11.842
2	Preparedness Plan	2	1	1.684	4.684	0.098	9.759
3	Disaster Mitigation Measures/Strategies	1	-1	0.368	3.368	0.070	7.018
4	Private Public Partnership for DRR	1	-1	0.368	3.368	0.070	7.018
5	Training Programmes for DRR	-1	1	-0.368	2.632	0.055	5.482
6	System Failure	0	-3	-0.947	2.053	0.043	4.276
7	Severity of Failure	-1	-2	-1.316	1.684	0.035	3.509
8	Diverse livelihoods	1	0	0.684	3.684	0.077	7.675
9	Maintenance	0	-1	-0.316	2.684	0.056	5.592
10	Income Status	0	3	0.947	3.947	0.082	8.224
11	Wealth (Assets)	2	2	2.000	5.000	0.104	10.417
12	Post-event damage assessment	-3	0	-2.053	0.947	0.020	1.974
13	Recovery time	-2	-2	-2.000	1.000	0.021	2.083
14	Government Relief	0	1	0.316	3.316	0.069	6.908
15	Household Support	-2	0	-1.368	1.632	0.034	3.399
16	Risk Transfer (Insurance)	-1	0	-0.684	2.316	0.048	4.825
	per cent explained variance	26	12		Total=48		Total=100
	Cumulative explained variance	26	38				
	Eigenvalues	5.5068	1.831				

Table 5-16. Respondent's comments on the choice of indicator statements in Factor 2. (Economic Resilience)

Highest Ranked	**Income** ***"Income is the most important indicator for economic resilience, so I kept it in the most important category. It is because when a community is poor, and a disaster hits that community, it will go below the poverty line. As we say, poverty leads to vulnerability, and vulnerability leads to disaster, so when a community have high Income Status, they will show more resistance to disaster. They will be more resilient and vice versa."*** **ERPAKC3** ***"After that, our "income" comes into play. If a household has multiple sources of income, it will quickly move towards resilience. If one source of income is affected, they will have other sources to rely on."*** **ERPAKP7**
Ranked higher than other Factors	**Wealth** *"Wealth (Assets) is the basic component of the economic resilience to disaster because, without wealth, no activity or action can be taken."* **ERPAKA6** *After the income, the indicators "wealth" and household support" are important because when you have rich and supportive neighbours or relatives, they may support you in crucial situations and that can reduce the impacts of disaster ERPAKC3* *Government Relief* *"Government Relief is crucial in supporting affected individuals, businesses, and communities in their recovery efforts."* **ERPAKA6** *"A lump-sum amount of relief from the government is also of equal importance because, in the tough times, money is the only medicine for all kinds of pains."* **ERPAKC4**
Lowest Ranked	**System Failure** *"The indicator "System failure" may not be very important compared to the others, that's why I awarded in the least important category. System failure won't tell us how it failed but only for how long."* ***ERPAKA5***

Weights from the Q Sort Values

Finally, the weights for Economic Resilience are calculated using the same equations as in the previous sections and are shown in Table 5-15. The highest parameter weight of 11.8 is given to Hazard Awareness among Businesses, followed by 10.4 for Household Wealth, 9.75 for Preparedness and Training, and 8.22 for Household Income.

Measuring Physical Infrastructure Resilience

The third and final resilience dimension identified in Chapter 5 was Physical Infrastructure Resilience, an important dimension that can form a baseline for resilience assessment linked to others. Sixteen respondents participated in the PI Resilience Q sort interviews, with 5 Academics, 5 Community Members and 6 Practitioners in this study phase.

Factor Significance tests

Like the previous two analyses, according to the Kaiser-Gutmann Criterion, a comparison of the Eigenvalues greater than 1 in the Unrotated Factor Matrix was conducted to reveal that only 2 of the Factors were significant. This result was double-checked with the Scree Plott diagram, indicating that the slope changes at the second factor. Accordingly, CFA was then conducted using only these two statistically significant factors.

Varimax Factor Rotation results

Table 5-17 shows the Factor scores for PI Resilience, with Factor 1 explaining forty-four per cent of the variance and consisting of eight of the sixteen Q-sorts. Factor 2 consisted of the remainder of eight Q-sorts and explained another ten per cent of the variance for a total cumulative explained variance of fifty-four per cent. The two identified factors were Factor 1 Hazard Awareness and Mitigation Planning and Factor 2 Early Warning Systems for Local Area.

Factor 1 Hazard Awareness and Mitigation Planning

Eight Q Sorts loaded onto Factor 1, which explained 44% of the variance. The eight respondent Q Sorts in Factor 1 were from three Academics, three Practitioners and two Community Members. This discourse highlights the importance of situational awareness of Hazards by the local utilities and critical service providers, as well as the importance of Mitigation Planning. The three lowest-ranked statements were indicators that measured the Quality/extent of mitigating features, the Cost of Damaged Assets from previous flood incidents and Restoration Time for critical services in the area. Some of the collected views on the rankings are shared in Table 5-18.

Table 5-17. Physical Infrastructure Resilience Q-sort Factor Scores and Weights by Indicator.

No.	Statement	Factor 1	Factor 2	Weights per Statement			
		Score	score	Statement	Add 3	Normalise	x 100
1	Hazard Awareness (Utilities, Critical Service Providers)	3	2	2.815	5.815	0.121	12.114
2	Procedures/plans for hazard mitigation exist	2	1	1.815	4.815	0.100	10.031
3	Community-level Early Warning System (EWS)	0	3	0.556	3.556	0.074	7.407
4	Quality/extent of mitigating features	-3	1	-2.259	0.741	0.015	1.543
5	Training programme/system for DRR exist	1	0	0.815	3.815	0.079	7.948
6	Cost of damaged assets	-2	-1	-1.815	1.185	0.025	2.469
7	Loss of Essential Services (After Last Event)	-1	-2	-1.185	1.815	0.038	3.781
8	Age of structure	0	-3	-0.556	2.444	0.051	5.093
9	Safety design factors	1	0	0.815	3.815	0.079	7.948
10	Building Characteristics (Kactha, Pacca)	1	1	1.000	4.000	0.083	8.333
11	Mitigation standards (building codes)	2	2	2.000	5.000	0.104	10.417
12	Post-event damage system or mechanism	0	0	0.000	3.000	0.063	6.250
13	Length of time to conduct damage assessment	-1	-2	-1.185	1.815	0.038	3.781
14	Recovery Plan	0	0	0.000	3.000	0.063	6.250
15	Time needed for recovery	-1	-1	-1.000	2.000	0.042	4.167
16	Restoration time for full operation	-2	-1	-1.815	1.185	0.025	2.469
					48		100
	Kaiser-Guttman Criterion						

Eigenvalues	Factor 1 6.9763	Factor 2 1.5794	Factor 3 0.9304	Factor 4 0.8352
Explained Variance	44	10	7	5

Table 5-18. Respondent's comments on the choice of indicator statements in Factor 1. (Physical Infrastructure Resilience)

Highest Ranked	**Awareness of Hazard Risk (For utilities)** ***"Awareness compels people and organizations to take certain action before the beginning of a hazard to mitigate its effects or eliminate disaster risk and leave very little room for the negative impacts of a hazard… "*** **PRPKA1** ***"Awareness among service providers to the community is most important so as they may build structures away of any hazardous area preventing or mitigating the structural loss and safety of their infrastructure."*** **PRPAK2** ***"In the pre-phase of an event, when your community is aware of all those hazards which can affect them, they will be prepared and make their structure according to the upcoming hazard. That is why Hazard Awareness is most important."*** **PRPAKP5** ***"For the first indicator, we chose Hazard Awareness that may threaten the livelihoods because awareness comes first before any action."*** **PRPAKC2**
Lowest Ranked	**Quality/extent of mitigating features** *"I placed the other indicators like "Time needed for recovery" and "post-event damage system" in the less important category, but they are still more important than the quality of mitigating features. It is because these measures are coming in the post-disaster phase and can be used for plans and predictions, but the quality of a system that is not in place doesn't seem important at all."* **PRPAK5.** *"Quality/extent of mitigating features is unimportant because we don't have any such measures to note. For example, first, we must have a multi-hazard early warning system in place, then we can think about quality."* **PRPAKA1**

Factor 2 Early Warning Systems for Local Area

The remaining eight Q Sorts loaded onto Factor 2 but only explained 10% of the total variance. Factor 2 respondents comprised two Academics, three Practitioners and three Community members. This Factor engages with the discourse among the participants on having a locally based Early Warning System that can keep citizens informed while also linking with local utility and critical service providers to increase Hazard Awareness and contribute to preparedness and Mitigation Planning. Participants in this discourse ranked the Age of the Structure, Loss of Essential Services (After the Last Event), and time taken for Damage Assessment as the least important indicators for understanding local PI Resilience. Several supporting statements regarding the rankings are shared in Table 5-19 below.

Table 5-19. Respondent's comments on the choice of indicator statements in Factor 2. (Physical Infrastructure Resilience)

Highest Ranked	**Community Level Early Warning System (EWS)** ***"I've placed EWS is important because if there's an early warning in place, then there's a chance of less losses, and evacuation can be done timely."*** **PRPAKC3** ***"The most important indicator for physical resilience, according to my opinion, is "Early Warning System" because if a community is aware of the upcoming hazard, they will prepare themselves for evacuation or other necessary measures to avoid other negative consequences of a particular hazard."*** **PRPAKP3** ***"…putting a community-level early warning system at the top of the list for physical resilience is crucial because it ensures spotting proximity to dangers, enables prompt action, makes use of local knowledge and experience, fosters involvement and trust, and helps create resilient communities."*** **PRPAKP6**
Lowest Ranked	**Age of Structure** *"…[for this area] other indicators are more important than the age of the structure. The area has recently been built up over the last two decades, and when a disaster hits your community, and you face some damages, you will have to restore the damages. Many of the buildings in this area have been remade and are recent."* **PRPAKA4**

Weights for PI Resilience from the Q Sort Values

Table 5-17 uses the same method as in the previous two sections to derive the weights for Physical Infrastructure Resilience, with Hazard Awareness receiving 12.11 per cent, Structures Built According to Mitigation Standards at 10.41 per cent and Mitigation Planning at 10 per cent.

5.5.6 Community Capacity Index for Each Dimension

As developed during this step, the Community Capacity Index is shown in Table 0-19, ranked by weights and colour-coded by capacity. Table 5-20 shows the study participants' preferences for measuring community resilience.

Table 5-20. Community Capacity Index (Ranked Indicators with Weights)

Rank No.	Social Resilience Indicators	Weights	Economic Resilience Indicators	Weights	Physical Infrastructure Indicators	Weights
1	Local Leadership in DM	10.461	Hazard Risk Awareness (Business)	11.842	Hazard Risk Awareness (Utilities)	12.114
2	Community Participation in DRR	8.821	Wealth (Assets)	10.417	Hazard mitigation standards	10.417
3	Fair Access to Basic Needs	8.289	Preparedness Plan	9.759	Plans for mitigation	10.031
4	Community-Based DRR Plans	7.801	Income Status	8.224	Building Characteristics	8.333
5	Communication (social media)	7.624	Diverse livelihoods	7.675	Risk Mitigation Training Program	7.948
6	Community goals/priorities	6.871	Mitigation Measures/Strategies	7.018	Safety design factors	7.948
7	External support systems	6.738	Private Public Partnership (DRR)	7.018	Early Warning System (EWS)	7.407
8	Effective Civic Organizations	6.250	Government Relief	6.908	Post-event damage	6.250
9	Social Demography	5.940	Maintenance (economic infras.)	5.592	Recovery plans exist	6.250
10	Community Inclusiveness	5.807	Training Programmes for DRR	5.482	Age of structure	5.093
11	Community Shared Values	5.585	Risk Transfer (Insurance)	4.825	Time needed for recovery	4.167
12	Diverse Skill Set (Workforce)	5.408	System Failure	4.276	Probability of failure	3.781
13	Religious Beliefs & Norms	4.920	Severity of Failure	3.509	Length of time assessment	3.781
14	Mobility of People and Families	4.078	Household Support	3.399	Total Damaged assets	2.469
15	Local Culture and Norms	3.324	Recovery time	2.083	Restoration time (operations)	2.469
16	Household Structure	2.083	Post-event damage	1.974	Quality of mitigating features	1.543

Anticipatory Capacity =	39.361	Anticipatory Capacity =	41.119	Anticipatory Capacity =	39.043
Absorptive Capacity =	31.782	Absorptive Capacity =	39.693	Absorptive Capacity =	38.041
Restorative Capacity =	28.857	Restorative Capacity =	14.364	Restorative Capacity =	22.917

5.6 Index Formulation and Model Parameters (Step 6)

After completing Step 5, a consolidated list of indicators (with weights) was constructed from the results, as shown in Table 5-20. All three selected dimensions (Social, Economic and Physical Infrastructure Resilience) are listed and colour-coded in Table 5-20 by capacity (Anticipatory, Absorptive and Restorative). The ranked indicators show how the stakeholders in this study want to measure community resilience as key performance indicators; hence, any interventions being considered should target these indicators to improve overall community resilience. During the Q-Sorts, stakeholders choose to rank the most critical indicators in a forced quasi-normal distribution, with the most critical indicators placed to the right and the least important ones placed to the left. The scores of these indicators range from -3 (least important) to 3 (most important), as shown in Chapter 4. In addition to ranking the indicators in order of most important to those considered not important or least important, the Q-Sorts also generated weights which can be used to emphasise the importance of an indicator (or its associated capacity) as of higher priority than the others.

The scores provide the basis for allocating weights to each indicator. They can help researchers identify those indicators that can be left out or dropped if consistently ranked by stakeholders at the low end. If an indicator's total net score is zero, it indicates that most participants were neutral about that indicator on average. Neutral means they are indifferent to its use; the indicator set can be used but is not essential (from their perspective) to measure community resilience (for that dimension). Table 5-9, Table 5-15, and Table 5-17 show the raw scores and their calculated weights by dimension. In Table 5-20, the weights column indicates the weight of each indicator by dimension. Those indicators with a net score of 0 (neutral) are represented by the weight value of 6.250 (the calculated value after normalisation is applied). Any indicator with a Q-Sort score of less than 6.250 means it scored a negative number, that is, most participants ranked it unimportant. Accordingly, these indicators can be removed from the Index as they were considered unimportant for assessing resilience (by stakeholders interviewed in this study), as shown by the red dotted box in Table 5-20. Therefore, the remaining indicators are included in the Community Capacity Index (CCI) for measuring resilience in the case study. The revised CCI with the selected indicators was then shared with participants in the FGD for validation and feedback (for content and construct validity as described in Chapter 4).

5.6.1 Focus Group Discussion for Validation of the Community Capacity Index

The second validation FGD was arranged by the Peshawar Living Lab at the University of Peshawar (UoP). The primary purpose and objective of the FGD was to validate the indicators used in the Community Capacity Index. The FGD was attended by five participants: one academic from the University, two practitioners from the Provincial Disaster Management Authority, and two staff members from the AKF. All the participants had been interviewed in the Q-sort interviews. They were familiar with at least one of the resilience dimensions and the indicators used in the Q-sort exercise. The FGD was held in a conference room at the UoP (with projector facilities), and a presentation was delivered on the Q-sort Method, its application in the research, data collection, and the Community Capacity Index, as shown in Table 5-20. After the introduction, a discussion was held on each dimension (approx. 20 minutes each). Each discussion focused on the indicators with positive or zero scores, the reasons they were chosen, data sources and availability, and appropriateness for using those indicators to measure resilience in the case study context. The least essential indicators were also briefly discussed. Table 5-20 was used to explain the selection process, and the weights of each indicator were discussed.

Finally, the list of selected policies (from Step 4) was shared with the participants for their views on how those policies affected the community. After the discussion, feedback was sought from the participants on the Q-sort activity for indicator selection, the Community Capacity Index (Excel sheet and tables) and future applications. The FGD was scheduled for one hour, but an extended discussion on the availability of data and data sources exceeded the allocated time by forty minutes.

During the discussion portion of the FGD, participants examined the Index for each dimension and provided critical feedback on the priority indicators selected. The participants were not surprised by the rankings, except for the relatively low scores on Social Demography (in Social Resilience) and Restoration time (in Physical Infrastructure Resilience). Possible reasons for this were discussed: the homogenous population, the nature of infrastructure services in the local area, and the wording or language of the instrument. Some (n=2/5) of the participants suggested extending the CCI to include a few more variables, especially Social Demography and Community inclusiveness for Social Resilience, Maintenance and Training Programmes for Economic Resilience, and Age of Structures for Physical Infrastructure Resilience as shown by the purple dotted box in Table 5-20. These participants indicated that with the addition of these indicators, a more well-rounded and technical analysis of resilience can be done. The other participants agreed, and the necessary changes were made to the CCI, as shown in Table 5-21, Table 5-22, and Table 5-23 below.

Additionally, when discussing the most essential indicators per dimension, participants mentioned the problem of data availability and lack of data sources, especially for some of the indicators in the Social Resilience Index. Some mentioned that many indicators might have been designed for use in other contexts where data was more readily available from multiple sources. However, this was not the case in Pakistan, especially for the case study area. One of the participants mentioned a household survey was conducted in the area in 2019 that could fill some of the gaps.

After the discussion portion of the FGD concluded, the participants were asked to provide feedback on the Q-sort activity, the Community Capacity Index, and their experience with the Q-sort interview. All the participants replied that the activity was easy to understand and follow. Still, several (n=2/5) mentioned the problems with the wording and the language used on the cards to explain the indicators. For example, in both the ER and PI Q-sorts, the wording or language used to describe several indicators was considered for revision. Economic resilience terms translated into the local language (Urdu) may have influenced how these statements were ranked. For example, System Failure in Urdu can be translated as “Kharabi” or “Tabai”, meaning “loss of service” and “destruction”, respectively, terms that may be used in common usage for physical infrastructure but in retrospect are not usually used in conjunction with economic systems in general conversation. The wording and language issues highlighted the limitations of the pilot study conducted with a limited group who might have had a prior understanding of such terms.

Another vital suggestion from one participant was to include questions on the most critical indicators trends (or behaviour over time) in the Q-Sort Interviews. He suggested adding questions to the top three selected indicators on how the indicator was either increasing, decreasing, or staying the same. The extra information could help those respondents think clearly about the indicator and its nature and capture more information that could be useful for the modelling in the next phase. Additionally, some of the participants appreciated the adaptability of the process for accepting their feedback regarding the number of indicators to include (or exclude) in the CCI. Finally, when participants were shown the list of twenty-five policies narrowed down to four in the policy discussion, one asked if Q-Sorts could also be used to select policies among the participant groups in the study. They suggested including it in the Approach in future iterations.

In summary, the Artefact itself (i.e. Phase 1 of the Approach) was evaluated using the criteria mentioned in Chapter 3:

Goals

Most (n=3/5) of the Participants felt that the methods were practical and achieved the intended purpose of selecting indicators, with one participant suggesting using them for selecting Policy Scenarios. Some (n=2) felt that although the method could be used, more care would be needed, especially to contextualise the indicators to reflect local language use and terminology if the public or community members are involved. Accordingly, they felt some key indicators (in their opinion) could be missed or weighted down inadvertently and advised against dropping key indicators (like Social Demographics or Age of Structures from the Social Resilience and Physical Resilience Index, respectively) in future.

Environment

Most of the participants (n=3/5) expressed an interest in the use of Q-Sorts for Indicator Selection. They noticed it could be used for other uses where ranking was required and wanted to inquire about further information and training on the approach so it could be used in their work. The other two thought it would probably be better suited for expert-level respondents rather than with use in non-expert groups but recognised the value of understanding the perspectives of other non-expert groups. One participant inquired specifically about any digital tools that can be used to facilitate the sorting and ranking exercise.

Structure

Finally, the participants were asked about the Structure of the Artefact, its completeness, clarity, and level of detail. Almost all participants (n=4/5) remarked that the ranking exercise was easy to understand and use and could be adapted easily to other contexts. Most (n=3/5) remarked that the language and wording used in this case study could have been improved even though it was easy to use. They noted that although the measures on the back of the cards helped clarify the meaning of the indicators and the researcher's presence during the interview, both may have addressed some of these issues. Still, any ambiguity in the wording of an indicator will affect its selection and rank, especially among groups from diverse and non-technical backgrounds. More piloting before the data collection was suggested. For the level of detail, some (n=2/5) were satisfied with the indicators and their use (given the comments above) but suggested a graphic or diagram that could make the Index easier to understand (rather than the Excel sheet or Table form used in FGD presentation), while others (n=2/5) suggested adding questions on behaviour over time for the most critical indicators to increase the level of detail captured.

The second FGD helped validate the findings and methods used in the second stage of the data collection and provided constructive feedback on improving the Approach in future applications. Overall, using the Approach in this manner was received well, and most (n=4/5) of the participants expressed an interest in further participation in the next phase.

5.6.2 Validated Community Capacity Index

After the second validation FGD, the indicator lists for each dimension were updated to incorporate the feedback and suggestions. Since the indicators were based on a ranking scale from most important to least important, including the extra indicators did not pose a problem to the logic of including the most critical indicators relative to each other. Those indicators ranked 9 or 10 were still more important than those ranked 11 and below. Hence, the request from the FGD participants was considered consistent with the method used to select indicators for the CCI. Once the indicators were finalised, the weights for each were also revised. The weights of all dropped indicators were summed together and then divided by ten. This number was added to the remaining ten indicators to derive the weights, as shown in Table 5-21 below. Table 5-21 below also lists the direction of the effect of the indicator on the index (positive or negative), the link to the indicator in the library of indicators in the Appendix (the ones used in the study were localised to the context), and the potential data sources for the indicator as discussed with participants of the FGD and from the literature.

Table 5-21. Final List of Social Resilience Indicators.

No.	Social Resilience Indicators	Weights	Effect Direction	Linked in Library (see Appendix for measures)	Data source
1	Community Participation in DRR	11.36	+	Community Engagement	Expert opinion or field survey
2	Community-Based DRR Plans	10.34	+	Community Processes (Plans)	Expert opinion or PDMA
3	Communication (Social Media)	10.16	+	Clear communication	Census, 2017
4	Community goals/priorities	9.41	+	Community Goals (Efficacy)	PDMA or expert opinion
5	Fair Access to Basic Needs	10.82	+	Same	Expert opinion or field survey
6	Social Demography	8.48	+	Population Profile	Census, 2017
7	Community Inclusiveness	8.35	+	Same	Expert opinion or field survey
8	Local Leadership in DM	13.01	+	Social Cohesion	Expert opinion or administrative records
9	External support systems	9.27	+	Social Support	Expert opinion or field survey
10	Effective Civic Organizations	8.79	+	Social Networks	Expert opinion or field survey

Key:	Capacity Weight
Anticipatory Capacity	= 41.28
Absorptive Capacity	= 27.66
Restorative Capacity	= 31.07

Table 5-22. Final List of Economic Resilience Indicators.

No.	Economic Resilience Indicators	Weights	Effect Direction	Explanation	Data source
1	Hazard Risk Awareness (Businesses)	13.85	+	same	Expert opinion or field survey
2	Private Public Partnership for DRR	9.03	+	Communication Systems	Expert opinion or PDMA
3	Preparedness Plan	11.77	+	Preparedness and Training	PDMA
4	Mitigation Measures/Strategies	9.03	+	Procedures for Mitigation	PDMA
5	Training Programmes for DRR	7.492	+	Learnability/training	PDMA
6	Wealth (Assets)	12.43	+	same	PSLSM, 2019
7	Income Status	10.23	+	same	PSLSM, 2019
8	Diverse livelihoods	9.69	+	same	PSLSM, 2019
9	Maintenance (funds)	7.60	+	same	Expert opinion
10	Government Relief	8.92	+	same	PDMA

Key:	Capacity Weight
Anticipatory Capacity	= 51.17
Absorptive Capacity	= 39.94
Restorative Capacity	= 8.92

Table 5-23. Final List of Physical Infrastructure Resilience Indicators.

No.	Physical Infrastructure Indicators	Weights	Effect Direction	Explanation	Data source
1	Hazard Risk Awareness (Utilities)	13.93	+	same	Expert opinion or field survey
2	Risk Mitigation Training Program	9.77	+	Training in DRR	PDMA
3	Plans for mitigation	11.85	+	same	PDMA
4	Early Warning System	9.23	+	same	PDMA
5	Age of structure	6.91	-	same	Census, 2017
6	Hazard mitigation standards	12.24	+	same	Expert opinion or field survey
7	Building Characteristics (Kactha, Pacca)	10.20	+	same	Census, 2017
8	Safety design factors	9.77	+	same	Expert opinion or field survey
9	Recovery plans	8.1	+	same	PDMA
10	Post-event damage assessment	8.1	+	same	PDMA

Key:	Capacity Weight
Anticipatory Capacity	= 44.78
Absorptive Capacity	= 39.07
Restorative Capacity	= 16.14

5.7 Summary

Chapter 5 reported on the results of the interviews and FGDs conducted to understand the core resilience issues facing the BNB case study area concerning the hazard of urban flash flooding. At each data collection stage, an exploratory FGD was conducted to validate the information gathered and evaluate the method or technique used in the Approach for understanding and mapping the community system. The first exploratory FGD resulted in selecting three dimensions and four policies for use in the modelling phase. The second exploratory FGD reviewed the Community Capacity Index and considered the indicators used for measuring resilience in the context of the case study. Both FGDs provided critical feedback on the Artefact as used in the research's Systems Thinking and Mapping Phase. Next, Chapter 6 will examine how the System Design and Modelling research phase is applied and evaluated in the case study.

Chapter 6 Evaluation of System Design and Modelling

6.0 Overview

This chapter evaluates Phase 2: System Design and Modelling of the Participatory Approach to Modelling Community Resilience proposed in Chapter 4. In this chapter, a System Dynamics model of community resilience at the local levels is developed, tested, and used to run stakeholder-defined scenarios (SDS) to demonstrate different policy options. Once the model is developed, it will be used in a Validation Workshop to evaluate the whole Approach.

Table 6-1. Research Objectives and Methods

Research Objectives	Research Methods	Chapters
Objective 5: To validate the artefact as an approach to understanding community-based resilience dynamics using a case study	Case Study • In-depth Interviews (IDIs) • Focus Group Discussion (FGD) • System Dynamics Modelling (SDM)	Chapter 6: Evaluation of the System Design and Modelling (Phase 2)

Figure 6.1 shows the six steps in the System Design and Modelling phase as applied in the case study. The rest of the chapter is divided into individual sections for each step. Step 1 will apply the generic model developed in Chapter 4 to the case study and modify the model architecture to the identified community issues from Chapter 5. Step 2, Model Refinement, will describe how the model was improved with feedback and integrated with information from other sources. Step 3 tests the model to ensure it functions as designed and according to logic. Next, Step 4 shows the policy scenarios developed for the research. Next, step 5 covers the Validation Workshop with key stakeholders to evaluate the application of the Participatory Approach to Modelling. Eight participants were involved in the Confirmatory FGDs for Step 5. Finally, Step 6 mentions some Policy Recommendations from the research.

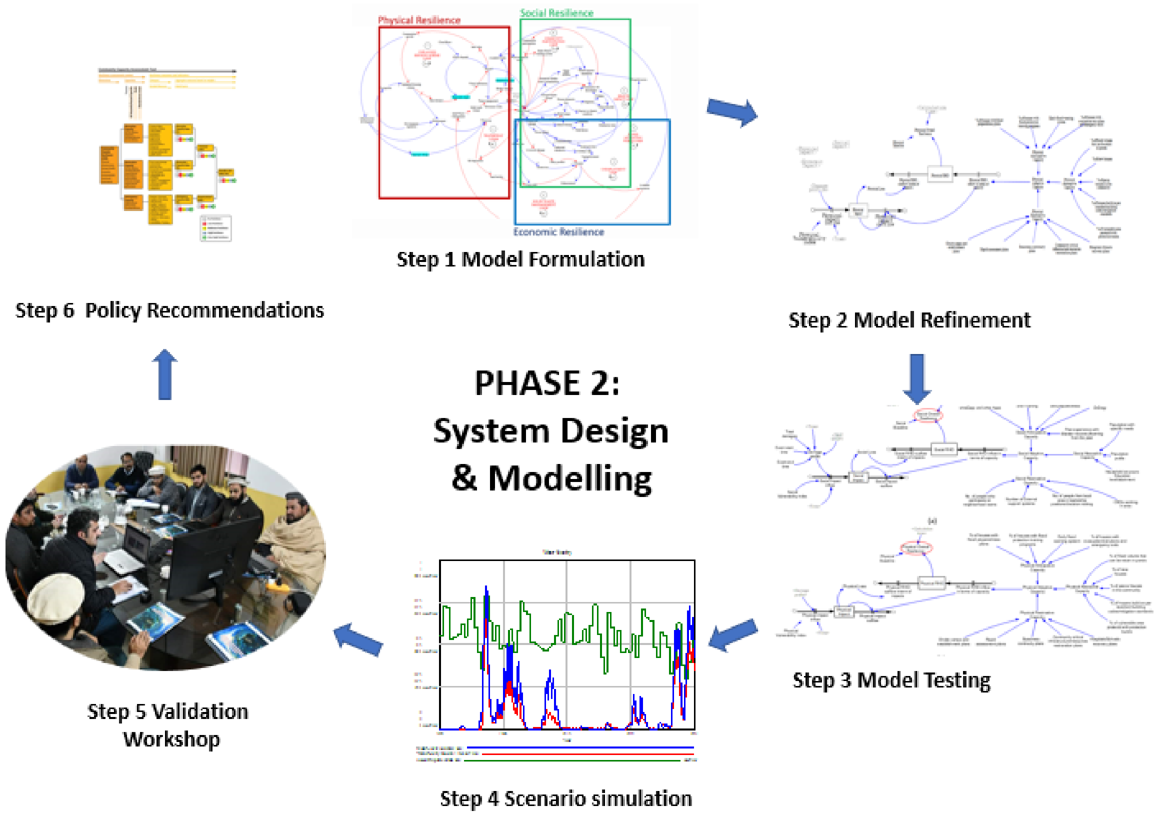


Figure 6-1. Steps in the System Design and Modelling Phase

6.1 Model Formulation (Step 1)

As shown in the previous chapter, flooding is a significant hazard for communities in the case study area. The CLDs developed in the research led to several insights into disaster risk management and policies that have been considered and implemented locally. The CLDs help identify the key dimensions that need to be modelled, and the Q sort help to determine the key indicators to include in the Community Capacity Index, hence providing the model's key parameters that can be quantified. In the conceptual model in Section 4.3.1, the impact from three interaction variables, i.e., hazards, exposure and vulnerability, are integrated into a damage profile. The damage profile changes the stock to produce a corresponding impact on the system. The auxiliary variables of start, stop, and time step in the formulation of the damage profile provide the flexibility to induce damage of different intensities and durations in the system. For example, for the simulation of Stakeholder Defined Scenarios (SDS), the impact of low, medium, and high intensities floods is produced by distributing flood damages over long, medium, and short durations events, respectively. The model can use inputs from discussions with experts who participated in the study to demonstrate the range of scenarios. In addition to the standard validity tests for models (Section 6.3), the current case study sought to validate the SD model and approach with stakeholders in two FGDs and is based on a combination of expert opinions, perspectives, and available historical or time series data. In future iterations, the SD model developed can be used with a broader set of primary and secondary sources for a more accurate representation of damages with purpose-built functions for exposure and vulnerability.

Figures 6.3 to 6.6 below demonstrate the overall resilience model where system performance (SP) under a particular disaster event is calculated from the change in the RHO stock. The 'RHO' stock represents changes in system performance in the diagrams, each dimension having its stock for SP. The inflow to this stock is based on the effect of adaptive capacity measure represented as "RHO inflow in terms of capacity". The inflows are counterbalanced by outflows based on adverse impacts calculated through the resilience dimension impact stock. Adaptive capacity is a function of three capacities: Anticipative, Absorptive and Restorative.

Figure 6-2 shows the stock and flow diagram for social resilience. The indicators of Social Resilience are determined by the Community Capacity Index developed in Chapter 5. For example, Anticipative capacity indicators such as community participation in disaster risk reduction (DRR) activities, community-based plans for DRR, community goals, and communications (social media use) play an essential role in this case study. The area's population profile (demography), community inclusiveness, and Fair Access to Basic Needs and Services indicators were considered for measuring the Absorptive capacity. The number of people from the area elected to leadership positions, effective civic organisations, and access to external sources like remittances are included for Restorative capacity.

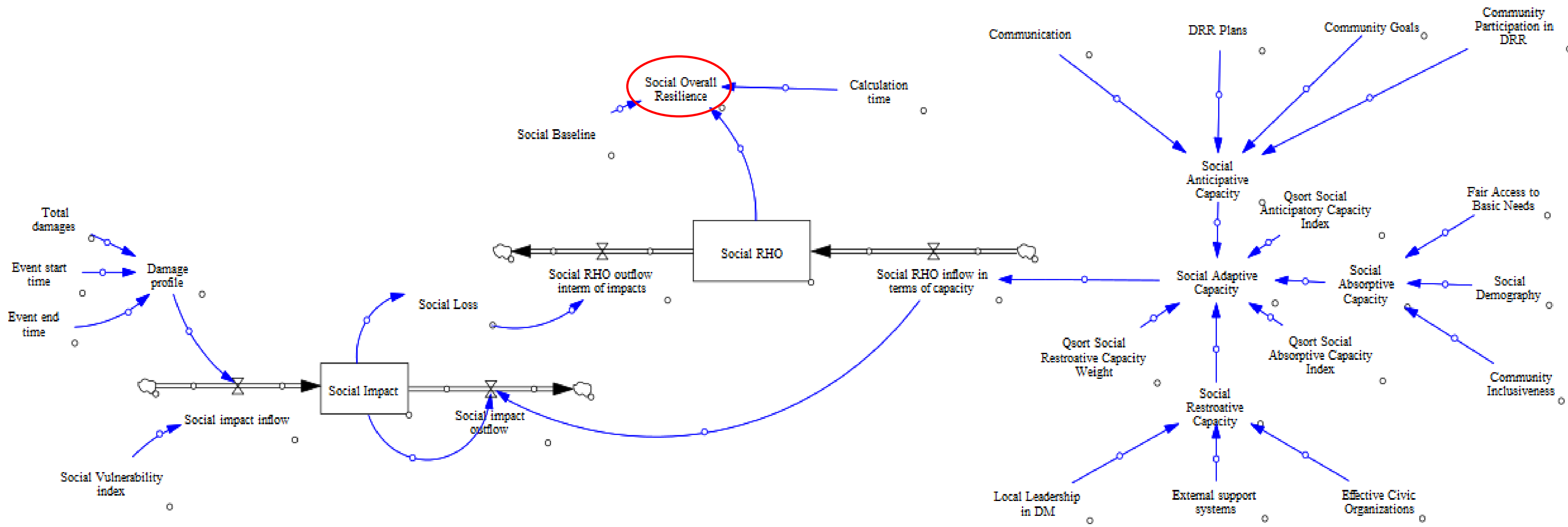


Figure 6-2. Social Resilience Model Structure.

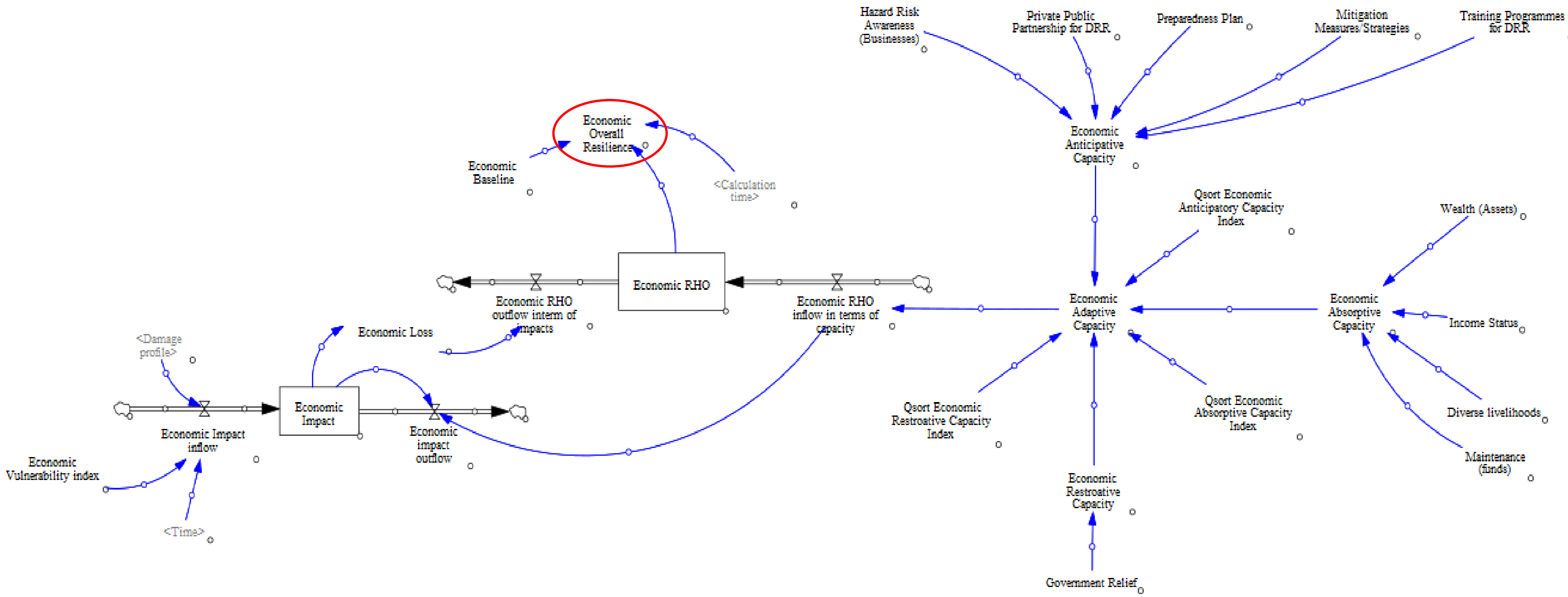


Figure 6-3. Economic Resilience Model Structure.

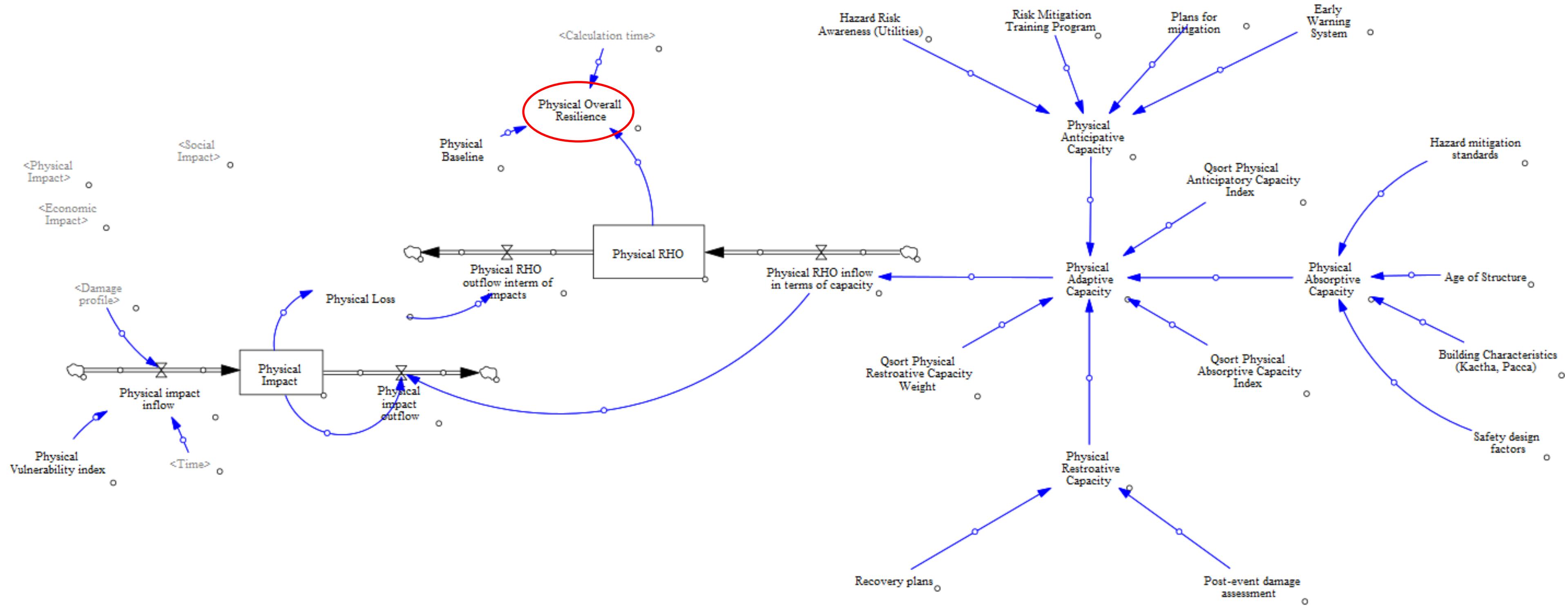


Figure 6-4. Physical Infrastructure Resilience Model Structure.

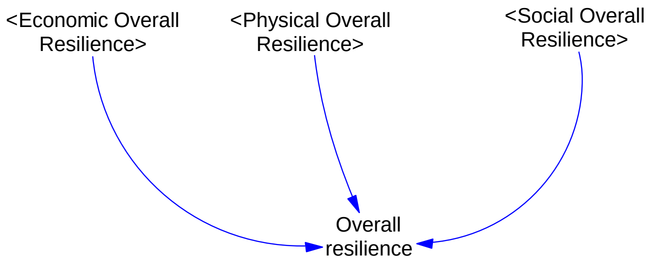


Figure 6-5. Overall Combined Community Resilience.

For Physical Infrastructure (PI) resilience, Figure 6-4 depicts the leading indicators of the PI capacities in the case study area. For the Anticipatory capacity of PI, indicators for hazard risk awareness, mitigation plans (to maintain flood defences, levees and rapid deployment of sandbags if needed), and connected to the early warning system were selected for inclusion in the model. In terms of Absorptive capacity, the age/type of structures and the percentage of houses built according to building code regulations and mitigation standards were used in the model (as selected by the participants). Finally, Restorative Capacity indicators for rapid damage/needs assessment and recovery planning were included in the model. Similarly, Figure 6-3 shows the stock and flows for economic resilience.

At the start of the simulation, system performance (SP) is checked by assuming an adverse impact (or the total damage) is equal to zero. Under this condition, the system should be in equilibrium as inflow equals outflow; therefore, zero change was observed in the 'RHO' stock. Under normal conditions (total damage = 0), the system utilises its resources to fulfil the basic needs of the communities. They use resources that are generally replenished from other sources to keep the system in equilibrium. At the onset of any disaster, more resources are utilised than replenished, reducing the system's resilience capacity. Thus, system resilience is linked with the SP (i.e., the value in the 'RHO’ stock). The following Equation can represent system resilience:

$$System\ resilience = 1 - \frac{RHO}{Base\ line\ performance * calculated\ time}$$

System resilience varies from zero to one, where one represents a 100% resilient system. The second term of the Equation governs change in system resilience. In case of no impact (total damage = 0), ‘RHO’ will be zero, and system resilience will be one, i.e. a 100% resilient system.

At normal conditions, total damage equals zero, RHO is zero and resilience is 100 per cent. With the introduction of a shock, the system resilience decreases from one due to adverse impacts. It reaches a minimum value (defined in the damage profile) and recovers due to the implemented restorative measures. For example, government relief after a disaster improves the system's restorative capacity and thus helps recovery (see Chapter 4 Figure 4.9 Resilience triangle and community capacities).

6.2 Model Refinement (Step 2)

Model refinement is a critical step in the research as it enhances the accuracy and realism of the model to represent the complex resilience issues in the case study. In the previous step, the generic system dynamics model of community resilience was adapted for three dimensions, with thirty indicators encompassing Social, Economic and Physical Infrastructure Resilience. The basic model can be used to model the main variables and some relationships identified in the Systems Thinking and Mapping Phase. In this step, researchers obtain feedback on the model from subject matter experts, stakeholders, or other researchers familiar with community resilience. They can provide valuable insights and perspectives on the model's structure, assumptions, and potential improvements. The Community Capacity Index developed earlier in Phase 1 operationalises resilience in the model and is explained in more detail in the next section.

6.2.1 Community Capacity Index

The Community Capacity Index developed in the previous Phase provides the model's parameters. Currently, the model is tested with data from three primary sources: 1) the Census conducted by the Pakistan Bureau of Statistics in 2017 (PBS, 2017), 2) the District Report on Peshawar City (GoP, 2017), and 3) the Pakistan Social and Living Standard Measurement (FBS, 2017). In addition to these sources, interviews and discussions with experts were used to confirm and refine the data according to their assumptions regarding trends (slope and direction).

Table 6-3 below shows the indicators chosen by the participants in the Q-Sort interviews and finalised for developing the Community Capacity Index (CCI) for Social Resilience. Table 6-3 also explains how that indicator is calculated or measured, the data source and a score based on the data source. The explanation column is based on the Library of Indicators and their measures as localised for this case study through the steps in Phase 1. For each indicator, a scoring criterion is also provided, ranging from Low (1-3), Medium (4-7) to High (8-10). The scoring criterion provides a guide for discussing how the variable can be quantified in the model. It is used with experts or stakeholders to gain a qualitative assessment of the variable's level so it can be included in the model calculations. Using the Low (1-3), Medium (4-7) and High (8-10) is easy to understand and convenient for stakeholders to use, and participants can quickly provide answers to queries from the research if required. Additionally, where data is available, a quick assessment can be made, and a score can be assigned between 0 and 10 to determine its value. For example, in Table 6-3 the indicator for Social Demography is Population Density, which can be found from the Census Data to be 35.37 people per acre, as shown in Table 6-2, compared to the other neighbourhoods in the BNB case study area and it can be given a score accordingly.

Normalisation example using data from Census (2017) (see Table 6-2)

Before this data can be used in the model, it must be normalised or standardised so it can be included in the Index,

x_normalized = (x - min) / (max - min)

(35.37-3.88)/(57.57-3.88) = .58

The trend for this variable is that population density is steadily increasing over time (same rate as population growth).

Since Population Density is negatively related to resilience, .58 is subtracted from 1 to get .41 (or 4.1 a score in Medium range).

Expert opinion is used when no data can be found for corresponding indicators. If the indicator is a constant value, it can be input into the model directly, or if a nonlinear relationship is expected, a Lookup curve can be used. Lookup or table function is commonly used in system dynamics modelling studies (Sterman, 2000, Peck and Simonovic, 2013, Inam et al., 2017b) to define nonlinear relationships or where there is no simple algebraic equation to define the relationship. Lookup functions provide the flexibility to control the shape, saturation points and slopes to represent the relationship between the two variables accurately.

Table 6-2. Village Councils (VC) and Budni Nalla Basin case study area population. (GoP, 2017)

Name of VC	Population	Average Household Size	Area (Acres)	Population Density	Flood Risk Level (Ali et al., 2022)
Budhni	13,300	7.37	1378	9.65	High
Kankola	20,792	8.5	1761	11.81	High
Larama	54,817	10.01	1192	45.99	High
Pakha Ghulam	59,077	8.25	2056	28.73	Med
Sardar Garhi	35,156	8.13	994	35.37	High
Mathra	25,590	7.92	2056	12.45	High
Dag	31,946	9.52	1990	16.05	High
Haryana Bala	25,479	8.91	1901	13.40	Low
Kafoor Dheri	39,869	9.63	10263	3.88	Med
Panam Dheri	18,434	9.56	2456	7.51	Med
Regi	19,425	8.95	982	19.78	Low
Shahi Bala	39,182	9.46	6174	6.35	High
Palosi	57,224	6.11	994	57.57	Med
Hassan Ghari	27,276	8	1960	13.92	High
Total	**467,567**	8.6	34359		

Tables 6-3, 6-4 and 6-5 provide the Social, Economic and Physical Infrastructure Resilience Index, respectively. The tables also show the scoring criteria as mentioned earlier, ranging from Low (1-3), Medium (4-7) to High (8-10) based on the data sources mentioned or expert opinion. All three tables also provide information on the weights used in the model. Due to the large number of variables, adding the weights in the model equation for each variable separately could prove cumbersome, so the weights are aggregated by capacity and directly input into the model. Assigning weights by capacity allows sensitivity analysis and other tests to be performed easily in the model testing phase.

Table 6-3. Social Resilience Index with measures and score.

No.	Social Resilience Indicators	Explanation Low (1-3), Medium (4-7), High (8-10)	Data source	Score
1	Community Participation in DRR	The level of community participation in DRR activities (volunteers, training etc.): Low (1-3), Medium (4-7), High (8-10)	Expert opinion or field survey	Low (1-3)
2	Community-Based DRR Plans	Existence of plans, updated and comprehensive: Low (no plans), Medium (plans exist), High (plans updated)	Expert opinion or PDMA	Low (1-3)
3	Communication (social media)	Smartphone use: Low (1-3), Medium (4-7), High (8-10)	Census, 2017	High (8-10)
4	Community goals/priorities	Community Awareness of DRR goals/priorities: Low (1-3), Medium (4-7), High (8-10)	Expert opinion or field survey	Low (1-3)
5	Fair Access to Basic Needs	Fair and equal access to basic services for all (poor, women, minorities); Low (1-3), Medium (4-7), High (8-10)	Expert opinion or field survey	Medium (4-7)
6	Social Demography	Population Profile: Population density High (1-3), Medium (4-7), Low (8-10)	Census, 2017	High (1-3)
7	Community Inclusiveness	Quality/level of engagement in DRR (poor, women, minorities); Low (1-3), Medium (4-7), High (8-10)	Expert opinion or field survey	Low (1-3)
8	Local Leadership in DM	Number of people from the local area in leadership positions: Low (none), Medium (local council, mayor), High (MNA/MPA)	Expert opinion or administrative records	Medium (4-7)
9	External support systems	Level of remittances, support from other sources: Low (1-3), Medium (4-7), High (8-10)	PSLSM, 2018, Expert opinion or field survey	Medium (4-7)
10	Effective Civic Organisations	Number of Civic Organisations: Low (1-3), Medium (4-7), High (8-10)	Expert opinion or field survey	Medium (4-7)

Key:	Capacity Weight		
Anticipatory Capacity	= 41.28		
Absorptive Capacity	= 27.66		
Restorative Capacity	= 31.07		

Table 6-4. Economic Resilience Index with measures and score.

No.	Economic Resilience Indicators	Explanation Low (1-3), Medium (4-7), High (8-10)	Data source	Score
1	Hazard Risk Awareness (Businesses)	The level of Hazard Risk Awareness among Businesses: Low (1-3), Medium (4-7), High (8-10)	Expert opinion or field survey	Low (1-3)
2	Private Public Partnership for DRR	Early Warning System (EWS) and communication for Businesses: Low (1-3), Medium (4-7), High (8-10)	Expert opinion or PDMA	Low (1-3)
3	Preparedness Plan	Existence of Business Continuity plans, updated and comprehensive: Low (1-3), Medium (4-7), High (8-10)	PDMA	Low (1-3)
4	Mitigation Measures/Strategies	Quality/extent of mitigation measures for Businesses: Low (1-3), Medium (4-7), High (8-10)	PDMA	Low (1-3)
5	Training Programmes for DRR	The level of Business community participation in DRR activities (training, drills, planning etc.): Low (1-3), Medium (4-7), High (8-10)	PDMA	Low (1-3)
6	Wealth (Assets)	Asset ownership level of households: Low (1-3), Medium (4-7), High (8-10)	PSLSM, 2019	Medium (4-7)
7	Income Status	Income level of households: Low (1-3), Medium (4-7), High (8-10)	PSLSM, 2019	Medium (4-7)
8	Diverse livelihoods	Additional income/sources of livelihood: Low (1-3), Medium (4-7), High (8-10)	PSLSM, 2019	Medium (4-7)
9	Maintenance (funds)	Funds spent on maintenance of Commercial building and infrastructure: Low (1-3), Medium (4-7), High (8-10)	Expert opinion	Low (1-3)
10	Government Relief	Amount of relief fund available: Low (1-3), Medium (4-7), High (8-10)	PDMA	Low (1-3)
Key:	Capacity Weight			
Anticipatory Capacity	= 51.17			
Absorptive Capacity	= 39.94			
Restorative Capacity	= 8.92			

Table 6-5. Physical Infrastructure Resilience Index with measures and scores.

No.	Physical Infrastructure Indicators	Explanation Low (1-3), Medium (4-7), High (8-10)	Data source	Score
1	Hazard Risk Awareness (Utilities)	The level of Hazard Risk Awareness among Utility providers: Low (1-3), Medium (4-7), High (8-10)	Expert opinion or field survey	Low (1-3)
2	Risk Mitigation Training Program	Existence of program, updated and comprehensive: Low (1-3), Medium (4-7), High (8-10)	Expert opinion or PDMA	Low (1-3)
3	Plans for mitigation	Existence of plans, updated and comprehensive: Low (1-3), Medium (4-7), High (8-10)	PDMA	Low (1-3)
4	Early Warning System	Early Warning System (EWS) and links to the community: Low (1-3), Medium (4-7), High (8-10)	PDMA	Low (1-3)
5	Age of structure	Age of Structures: Number of Buildings older than 2010: High (1-3), Medium (4-7), Low (8-10)	PDMA	Medium (4-7)
6	Hazard mitigation standards	Mitigation Standards: Number of Buildings according to Building Code: Low (1-3), Medium (4-7), High (8-10)	PSLSM, 2019	Low (1-3)
7	Building Characteristics (Kactha, Pacca)	Number of houses made from Mud or Adobe: High (1-3), Medium (4-7), Low (8-10)	PSLSM, 2019	Medium (4-7)
8	Safety design factors	Quality of mitigation/number of hazards considered in Building Codes: Low (1-3), Medium (4-7), High (8-10)	PSLSM, 2019	Low (1-3)
9	Recovery plans	Existence of Recovery plans, updated and comprehensive: Low (1-3), Medium (4-7), High (8-10)	Expert opinion	Low (1-3)
10	Post-event damage assessment	Existence of Post-Disaster Damage Assessment, updated and comprehensive: Low (1-3), Medium (4-7), High (8-10)	PDMA	Low (1-3)
Key:	Capacity Weight			
Anticipatory Capacity	= 44.78			
Absorptive Capacity	= 39.07			
Restorative Capacity	= 16.14			

6.3 Model Testing (Step 3)

System dynamics models are structure-behaviour-based models. The equations in the system dynamics model were developed based on a combination of theoretical frameworks, empirical data, and insights gathered from participants from community stakeholders. Theoretical frameworks used include the resilience triangle (Cimellero et al., 2010) and the model structure from Peck and Simonovic (2013). The model parameters were set according to indicators in the Community Capacity Index formed in Phase 1 Systems Thinking and Mapping and shown in Chapter 5. The empirical data for the indicators was collected from primary sources (Census data, previous literature, and expert inputs). This data provided the quantitative parameters used to calculate system performance, resilience and disaster impacts in the model. Engagement with community members and local experts was crucial throughout the model formulation and testing steps. Participatory modelling sessions helped validate assumptions, refine variables, and ensure the model's relevance to the specific context of the community under study.

Accordingly, Four tests were performed to assess the limits of the model's behaviour. The researcher also considered critical feedback from experts throughout the mode testing process. For example, in structure and behaviour testing, expert validation was used to test the assumptions on the parameters used in the study, specifically the development of the lookup curves and the weights assigned to each indicator in the model. One-on-one sessions with Subject Matter experts were used to consult on the historical consistency of the results.

For assessing the structure of the model, the generic model structure is adopted from published literature, which has been used in several case studies (Peck and Simonovic, 2013; Irwin et al., 2016). However, the indicators of those previous models were case-specific (objective) and not selected by participants (subjective) as done in this study. The CLDs and Q sorts from the previous Phase provide the basis for selecting the dimensions and indicators as parameters of the equations used in the model. Accordingly, due to the similar structure of the generic model used in this study, resilience is modelled using the appropriate equations for stocks, flows and auxiliary variables (Please see sections 4.3.1 for formulation details). Experts validated these parameter values and their behaviours at each step.

The researcher involved subject matter experts from the University of Peshawar (UoP) where needed throughout the System Design Stage. As it was developed, participants from the FGDs (senior staff of AKF and community members and academics from the UoP) were consulted on each model version. Once the basic structure was developed, the results from initial simulations were shared in one-on-one sessions and fortnightly meetings with experts and participants group online on Teams. Several simulations were run with changing parameters during these sessions, and the output graphs were discussed. These sessions ensured that simulations accurately reflected the reality of community capacities and indicators (and the appropriate weights) and their impacts on the community. Hence, an iterative testing procedure and a series of stakeholder meetings were carried out to refine the model structure and its associated behaviour and feedback.

After checking the model structure and behaviour through expert validation, additional tests were conducted as proposed in the system dynamics literature (Barlas, 1989; Sterman, 2000; Qudrat-Ullah and Seong, 2010) were used to test the model under different operating conditions. Calibration of the model involved adjusting parameter values to ensure that the model's output aligned with observed real-world data. The model was calibrated by comparing its outputs with historical disaster events in the community. For example, the model's predictions of total damages in the community (in total rupees) and recovery times (in days) were compared against documented outcomes of past disasters. Sensitivity analysis was conducted to understand how changes in parameter values affected model outputs. This helped identify the most critical parameters and refine their values for better accuracy. During the calibration process, continuous feedback from stakeholders (from the PLL and AKF) ensured that the model remained realistic and contextually appropriate. Adjustments were made based on their insights and experiences. Additional tests include dimensional consistency tests and reality checks. Dimensional consistency ensures correct model formulation through unit consistency (i.e., the left and right units of an equation are consistent). Dimension consistency checks model equations against the real system. All interacting equations of the model were subjected to dimension consistency using the Vensim unit check built-in tool and found correct.

Reality or automated validity checks check model input against expected behaviour. This test contains only model behaviour, not its structure. Therefore, it needs to be carried out after the structure validation from the experts. The Reality test checks the system's overall resilience against no flood. Under no flood condition, system overall resilience (i.e. integration of physical, social and economic resilience) should be equal to 1 or 100%. The reality check equation is written in Vensim as:

:$The\ Condition$: Total damages =0:OR: Vulnerability index = 0

:$IMPLIES$: Overall Resilience$t$= Overall Resilience$t-1$

The Equation temporarily sets the total damages and vulnerability index to zero and compares the resilience change over time. The expected behaviour is no change in system resilience against no flood and with zero vulnerability index. An error message is generated in case of any change in the system's overall resilience. Reality Check provides the opportunity to test models after each update. Regardless of model size, several equations can be written, and many simulations can be performed to check model behaviour, thus helping to build confidence in the model. By systematically developing, parameterizing, and calibrating the model in these ways, the researcher ensured that the model accurately reflects the dynamics of community resilience to disasters, providing a robust tool for understanding and improving resilience strategies.

6.4 Scenarios and Simulations (Step 4)

As mentioned in Chapter 4 Section 4.3.4, Stakeholder-defined scenarios (SDSs) are rooted in stakeholder engagement. Key individuals or groups who are affected by or impact the system are actively involved in the scenario-creation process. By involving stakeholders in defining flood scenarios, the modelling process becomes more inclusive and reflective of the community's unique challenges and aspirations. It helps bridge the gap between technical modelling and community engagement, ultimately leading to more effective flood resilience strategies and policies. The policy scenarios were developed to test the baseline capacities for the community-level simulation model and provide a basis for policy recommendations using the model.

The SDSs were parametrised within the model to represent the 4 different policies selected by the participants for scenario testing. As mentioned earlier, the interviews and FGDs in Phase 1 Systems Thinking and Mapping identified key policy interventions relevant to community resilience. These included policies such as emergency preparedness training, funds for preparedness and mitigation, debris clearance and retention pond construction.

Accordingly, during the model refinement and testing phase, empirical data from government reports, community surveys, and expert interviews provided baseline values for these policy-related parameters. For example, data on annual budget allocations for disaster preparedness and historical records of emergency training sessions could be found in the records with the PDMA and other government agencies working in the local area. Where direct data were unavailable, values were inferred from expert opinion, and academic studies and case studies from similar communities were used. During the first FGD and the one-on-one sessions during model refinement and testing, participants were asked how these policies might be operationalised in the model. For example, an increase in public awareness campaigns might be parameterized to lead to a specific percentage increase in community preparedness levels (Anticipatory Capacity) over a defined period. Additionally, as mentioned in the section on model testing, model calibration involves adjusting the parameters and equations in the model to ensure that its outputs align with real-world data. This ensures the model's accuracy and reliability are based on real-world expectations by using historical event analysis where the model's outputs (resilience triangle graphs) were compared with historical data from past disaster events in the community. This included data on response times, recovery rates, and community impacts. Parameters were adjusted iteratively to minimize the discrepancy between the model's predictions and historical data. For example, the rate of community recovery after a disaster might be adjusted to better match observed recovery times. Calibration of the model for the policy analysis was an iterative process involving repeated cycles of testing, adjustment, and validation. Each cycle improved the model's accuracy and reliability, accurately representing the dynamics of community resilience to disasters.

Through careful policy parameterisation and rigorous model calibration, the model could simulate the effects of various policy interventions on community resilience. The results reflected realistic scenarios validated against historical data and stakeholder insights. In summary, the process of parameterising policies and calibrating the model was thorough and data-driven, ensuring that the model outputs were accurate and actionable. This approach provided valuable insights into how different policy interventions could enhance community resilience to disasters.

The following scenarios were developed in conjunction with members of the AKF through individual consultation and review. From the discussion in the previous two FGDs, four policy interventions were identified as having the most impact on the case study community; 1) Funds for Preparedness and Mitigation; 2) Debris Removal; 3) Training and Awareness programs for the local community; and 4) Retention Ponds for long term security from flooding. These policies can directly impact the behaviour in the loops identified in the Merged CLD, and the Thematic Maps developed from it in Section 5.4 of the last chapter.

Policy 1 Funds for Preparedness and Mitigation

When considered as a whole, the system's main limitation from the community's perspective is Policy 1, which is Funds for Preparedness and Mitigation. Policy 1 is connected to the other identified policies in that our stakeholders from the AKF identified as a major factor in changing some of the behaviours in the overall system. This policy is discussed as a critical catalyst in the following three policies and is mapped in CLDs to explore some of the reasoning behind its application to change behaviour in those loops. Note these diagrams are a simplification for explaining one aspect of the behaviour in the system, and they are not isolated from the other loops. The complete impact of the policy across the system is presented in the merged CLD (Figure 5.7), which contains all the loops.

Policy 2 – Debris Removal

Participants identified the Waterway Loop as a crucial part of the flooding problem in the local area. As shown in Figure 6-6, the Waterway Loop depicts the reinforcing loop of frequent flooding, causing losses in local revenues and a lack of local funds for routine maintenance and debris removal. Performing routine maintenance and debris removal ensures the drainage capacity of the Waterway is optimum when rainfall bursts occur, and that the Waterway is not obstructed by debris or other blockages. Several other loops also contribute to this problem, including the solid waste management loop and the diversion works loop, where encroachments from highway construction contribute to reduced drainage capacity (see Figure 5.8 in Chapter 5). Providing funds from outside the local revenue stream when funds are low or scarce can save considerable money when drainage capacity is maintained, and hence the risk of flooding is lessened. This policy recommends that the government release a relatively small portion of funds in time to “top-up” local government funds so that routine maintenance and clearance work can be done to avoid the release of major payments when flood inundation occurs.

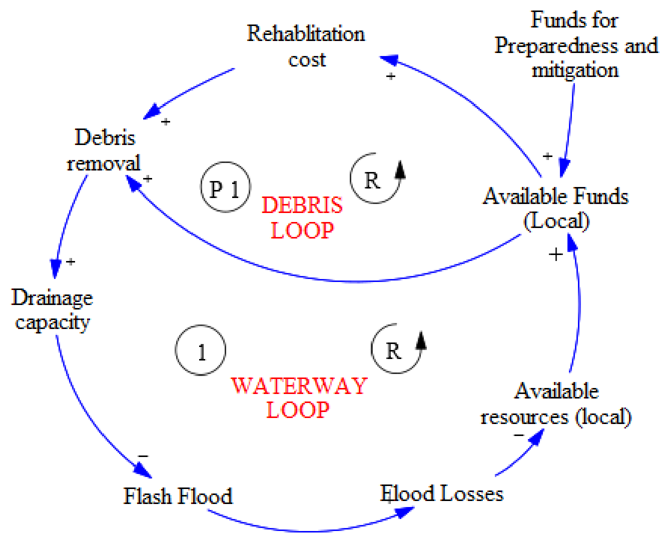


Figure 6-6. The Debris Clearance Policy.

Policy 3 – Training and Awareness

Another policy the participants wanted to explore was the impact of Training and Awareness on the local community, as shown in Figure 6-7. As an NGO, the participants in AKF noted that community participation in preparedness and mitigation activities is reduced when people suffer hardships (emphasis on economic issues), further compounding when a flood event occurs. On the other hand, a significant event can cause an influx of volunteers, but this does not translate to community participation. If funds are available, these volunteers can be trained in disaster risk reduction and preparedness, which will increase awareness of local hazards and how to deal with them. Increased awareness will increase community participation in hazard prevention, improve the community's preparedness, and reduce the impact of future floods. Awareness among the volunteers can result in greater awareness of the risks and solutions that reduce the impact of the hazards. This relatively low-cost policy can introduce innovation and self-reliance in the community, leading to opportunities like improved early warning systems, community-based plans (flood evacuation and recovery) and other local initiatives. Once again, this aims to spend relatively little money to prepare local communities for large-scale events.

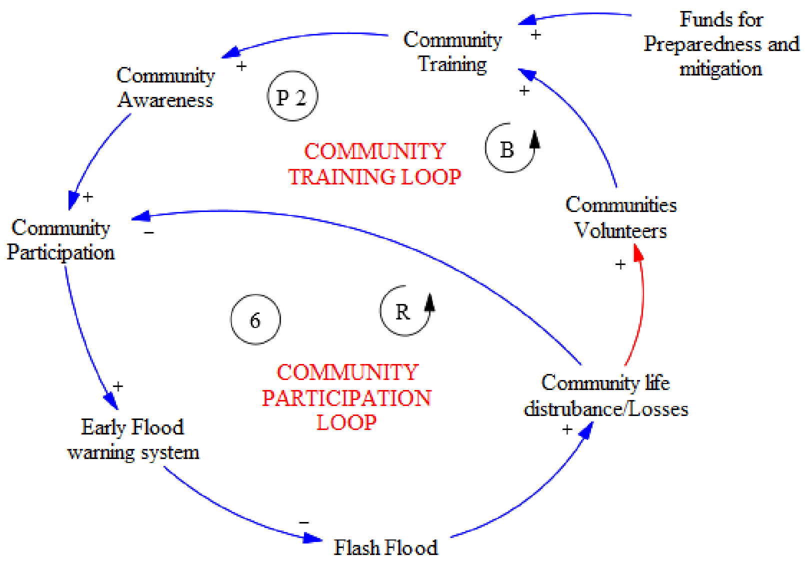


Figure 6-7. The Community Training and Awareness Policy.

Policy 4 – Retention Ponds

The fourth Policy on Building Retention ponds is considered a high-cost but high-impact policy as it can significantly reduce the surface runoff water and inundation levels in the case study area. Although effective, funding for such large-scale Mitigation Works is only possible when a major catastrophe leads to the loss of lives and heavy property damages. Unfortunately, the level of devastation provides the impetus for government funds to be released, as shown in Figure 6-8. The Retention Pond Construction Policy.. Even when funds are released, there is a significant delay between the approval of funds and the construction of the Retention Ponds, which can take up to a year to complete. Once completed, it significantly boosts the community's overall resilience as it can store a considerable amount of rainwater and reduce the speed of runoff into the Waterway, which is the primary cause of inundation. Additionally, due to physical space limitations, this Policy can only be employed once due to the relatively dense urban environment in the case study. Hence, Policy 1 is also a critical limiting factor for overall community resilience.

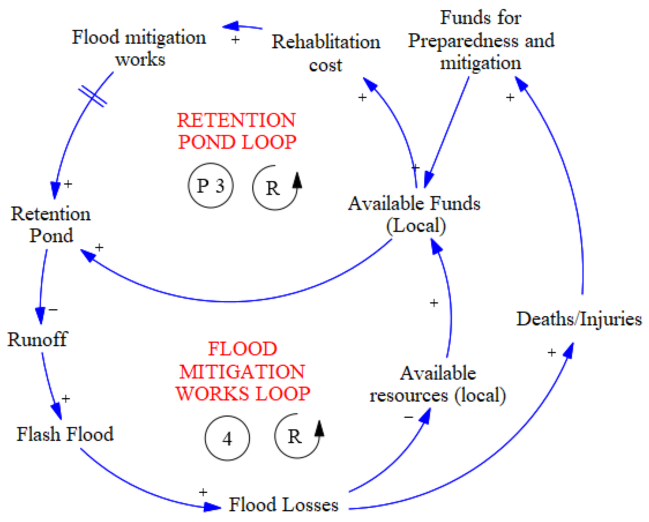


Figure 6-8. The Retention Pond Construction Policy.

The four policy interventions described above give a solid grounding to build scenarios to be tested and used in the model. These scenarios are based on conversations and input from stakeholders of the case study. Stakeholder-defined scenarios (SDS) are a valuable tool for modelling community resilience to floods because they incorporate the perspectives and insights of key stakeholders, including community members, emergency responders, local authorities, and experts (Albano et al., 2019). These SDS were then integrated into the system dynamics model to depict the abovementioned policy intervention scenarios.

The four SDS were run using Vensim PLE (V. 9.3.5) for community resilience at four different levels of flood intensity: no flood, low, medium, and high levels. Simulations were also run for baseline, where no policy or funds were applied for each flood level. The SDS that were run are shown in Table 6-6 below. The model was initially run using only single parameters and then combined with Policy 1 in providing funds for Preparedness and Mitigation, as it was reported in the interviews and the FGDs to be a policy that cross-connects and impacts all other policies. The participants in the validation FGD confirmed that due to limited resources, only one policy can be implemented at any one time, and it was unlikely that multiple policies be funded unless a major disaster occurs in the near future. The hazard levels for flooding in the model were selected for real-world applicability based on the literature, the data collected during the case study, and expert assessments. The SDS resulted in 33 unique sets of output combinations for testing in our research.

Table 6-6. Scenario simulations applied to Community Disaster Resilience and Intensity of Flood event

Run	Scenario	Flood Intensity	Policy Scenario	Relief/Response time
BC	S1	Normal no flood	No Policy (NP)	No Relief
BC	S2	Low-Intensity Flood (1-in-5)	No Policy (NP)	No Funds
1	S3	Low-Intensity Flood (1-in-5)	Retention Ponds	No Funds
2	S4	Low-Intensity Flood (1-in-5)	Retention Ponds	Normal Funds
3	S5	Low-Intensity Flood (1-in-5)	Retention Ponds	High Funds
4	S6	Low-Intensity Flood (1-in-5)	Debris Clearance	No Funds
5	S7	Low-Intensity Flood (1-in-5)	Debris Clearance	Normal Funds
6	S8	Low-Intensity Flood (1-in-5)	Debris Clearance	High Funds
7	S9	Low-Intensity Flood (1-in-5)	Community Training and Awareness	No Funds
8	S10	Low-Intensity Flood (1-in-5)	Community Training and Awareness	Normal Funds
9	S11	Low-Intensity Flood (1-in-5)	Community Training and Awareness	High Funds
BC	S12	Medium-Intensity Flood (1-in-10)	No Policy (NP)	No Funds
10	S13	Medium-Intensity Flood (1-in-10)	Retention Ponds	No Funds
11	S14	Medium-Intensity Flood (1-in-10)	Retention Ponds	Normal Funds
12	S15	Medium-Intensity Flood (1-in-10)	Retention Ponds	High Funds
13	S16	Medium-Intensity Flood (1-in-10)	Debris Clearance	No Funds
14	S17	Medium-Intensity Flood (1-in-10)	Debris Clearance	Normal Funds
15	S18	Medium-Intensity Flood (1-in-10)	Debris Clearance	High Funds
16	S19	Medium-Intensity Flood (1-in-10)	Community Training and Awareness	No Funds
17	S20	Medium-Intensity Flood (1-in-10)	Community Training and Awareness	Normal Funds
18	S21	Medium-Intensity Flood (1-in-10)	Community Training and Awareness	High Funds
BC	S22	High-Intensity Flood (1-in-100)	No Policy (NP)	No Funds
19	S23	High-Intensity Flood (1-in-100)	Retention Ponds	No Funds
20	S24	High-Intensity Flood (1-in-100)	Retention Ponds	Normal Funds
21	S25	High-Intensity Flood (1-in-100)	Retention Ponds	High Funds
22	S26	High-Intensity Flood (1-in-100)	Debris Clearance	No Funds
23	S27	High-Intensity Flood (1-in-100)	Debris Clearance	Normal Funds
24	S28	High-Intensity Flood (1-in-100)	Debris Clearance	High Funds
25	S29	High-Intensity Flood (1-in-100)	Community Training and Awareness	No Funds
26	S30	High-Intensity Flood (1-in-100)	Community Training and Awareness	Normal Funds
27	S31	High-Intensity Flood (1-in-100)	Community Training and Awareness	High Funds

[*]Scenarios = 3*3*3 + 4 Base case (BC) scenarios (one with each flood event with no policy and no Funds) = 31 Nos

As shown in Table 6-6 all four hazard levels were run for each policy in combination with Policy 1 Funds for preparedness and mitigation, as this policy was legislated to come into effect whenever a flood event occurs. Policy 1 has a direct impact on economic resilience and rehabilitation and recovery. Policy 2, Debris Clearance from the Waterway and Policy 4 on Construction of Retention Ponds impact Physical Infrastructure resilience and occur before the event; hence, they can be classified in preparedness and mitigation. Policy 3 on Community training and Awareness directly impacts the Social Resilience of the local community, which takes place before the event and primarily targets preparedness. According to our stakeholders, Policy 1 is at the normal level of Funds, and Policies 2 and 3 are relatively low cost and require little change to the current legislative environment or system. On the other hand, Policy 1 at the High Funds level and Policy 4 of constructing retention ponds are relatively high cost and require significant allocation of resources from provincial and central government sources.

6.5 Validation Workshop Results and Discussion (Step 5)

In this step, the model is shared with representatives from the major stakeholder groups for feedback and improvement. In addition, the final FGD/Workshop is also used as a Confirmatory FGD (CFGD) for Artefact Validation, as mentioned in Chapter 3 (Section 3.4 Artefact Validation). Therefore, the purpose of the Validation Workshop was to present the model of community resilience to stakeholders and gain feedback on the accuracy, usability, and reliability of the model and the Participatory Approach for Modelling Community Resilience used to generate the model.

For conducting a CFGD for validation, a small sample size of 5 to 10 participants is considered sufficient to test the artefact (Hevner et al., 2010). Since the case study focuses on one specific context and area, purposive sampling was used to select the participants from those who had already participated in the case study through interviews or consultation discussions for the modelling. Inviting previous participants ensured that the participants were familiar with the research and that more time was spent on artefact validation than on the introduction and context setting.

Accordingly, fifteen participants were requested by AKF and the PLL to attend the Validation Workshop at the same venue as the previous FGD at the University of Peshawar. The Workshop was then conducted with eight participants from the three stakeholder groups (seven apologies were received). The participants comprised three community members, two practitioners and three academics. The workshop used an observer (an academic from the UoP) to minimise personal bias, and the researcher participated as a facilitator/moderator.

The CFGD in this research lasted for two and a half hours (two one-hour sessions with a half-hour break in the middle).

The three academics attending the session were faculty members at the Centre of Disaster Preparedness and Management at the University of Peshawar. They were also members of the Peshawar Living Lab and were familiar with participatory approaches and the case study area. The two practitioners who attended the validation workshop were from the Disaster Operations Centre of the PDMA. The three community members were residents of the case study area, with two from the Al Khidmat Foundation NGO, and the third was a former Nazim (Mayor) of the case study area in 2008 when major flooding occurred. According to the stakeholder analysis in the case study, the participants' mix in the CFGD was a good representation for validating the artefact.

Additionally, the group's diversity meant that the different aspects of the artefact would be commented on in both technical and non-technical terms, thus providing richer feedback. The CFGD will allow each participant to provide feedback on the artefacts developed in the research. In this feedback discussion mentioned below, each respondent is identified by their participant code: R1 is Respondent 1, R2 is Respondent 2 and so on.

6.5.1 The Validation Workshop

Before the start of the Workshop, participants were introduced to the moderator and the observer for the FGD sessions. The observer was familiar with the research and was trained to alert the moderator and guard against any personal bias shown during the FGD sessions. The participants were then provided with a participant information sheet, a consent form, an interview guide (for Artefact validation), and a schedule of the sessions. The participant information sheet contained all the information regarding the research, as well as contact information of the researcher and the supervisor. The consent form had details about anonymity (in their responses), participation, and withdrawal from the research (if required). After all the participants had read the information sheet, they were allowed to ask any questions for clarification before the start of the workshop.

The Workshop began with a welcome message and an outline of the workshop schedule, clearly explaining the purpose and objectives of the two main sessions and the instructions for the smooth running of the FGDs in the workshop. The session schedule and outline are shown in Table 6-7. The research's introduction, background, and scope were shared, especially the Participatory Approach to Modelling Community Resilience.

Table 6-7. Outline of Validation Workshop.

Session	Title	Objective
1	Introduction to CDR Frameworks and Subjective Approaches to Measuring CDR	Awareness of the Problem
2	Case Study Briefing	Study Setting
3	Causal Loop Diagrams, Community Capacity Index, and the Policy Scenarios	Artefact Stage 1 for Systems Mapping
4	Break	
5	Model and Scenarios	Artefact Stage 2 for System Design and Modelling
6	Data Collection 2	Feedback and response
7	Debrief	Thanks, and future work

Following the introductory session, the moderator presented a short brief on the case study area and the community as defined in the research. The study setting was familiar to the audience, so after the brief, the participants were asked to introduce each other, their backgrounds, and their experiences in the area. In the next session, the findings of the Systems Thinking and Mapping phase were shared with the participants. There was further interest among the participants as all of them had participated in the data collection phase, either through a CLD or Q-Sort interview. The merged CLD and the Thematic Maps by Dimension, illustrating the feedback loops, were shared with the audience. Subsequently, the policy loops were discussed before going on to the Community Capacity Index derived from the process and the reasoning behind some of the indicator choices as provided in the qualitative data from the interviews and the previous FGDs.

Validation of Phase 1

As feedback on the System Thinking and Mapping Phase, the participants indicated that they were satisfied with the level of detail in the CLDs, including the feedback loops, and two (R4 and R6) suggested some amendments to the diagrams regarding the sequence and steps in some of the loops (Loops 4 and 9). Many (n=6/8, R1-R4, R7, and R8) of the participants asked for copies of the diagrams for their use. One participant (R3) asked if System Archetypes could have been used to understand the behaviour in the system and suggested they be incorporated in any future work. Finally, the Community Capacity Index and the selected indicators were reviewed and considered a satisfactory way to measure resilience in the systems, even though most (n=5/8, R2-R6) agreed there were still too many variables and insufficient data sources for some indicators in the Index. Similarly, comments were received regarding the set of "Euro-centric" (R4) and data-intensive indicators, the wording and language used. Few (n=3/8, R2, R3 and R5) requested more information on the aggregation method used in the Index and for normalising units. Nonetheless, all the participants agreed on the usefulness of having stakeholder-defined and selected indicators. After the session on Phase 1 was complete, there was a short break for tea and some refreshments before starting the Phase 2 System Design and Modelling session.

Validation of Phase 2

In the next session, the link between the Index and the model was explained, how the indicators were quantified and used and the use of expert opinion or stakeholder inputs into the model refinement phase through individual consultations. Subsequently, the model was presented to the participants, and each SDS and policy was presented to get feedback. Each policy scenario was evaluated separately to see the impact on each low, medium, and high hazard level's overall resilience. The three Adaptive capacities defined initially in Chapter 2 were the critical intervention variables to assess the overall resilience score for any given hazard level. The first set of diagrams in Figure 6-9 below represents the baseline scenario (or business-as-usual case) where no flood and no interventions occur. It shows the normal situation in our case study location. Each hazard level is then run as a base case for the community to indicate what would happen if no policies were implemented.

The first set of simulation runs was for the low-intensity flood (1-in-5 years) level, which showed several impacts across the physical, social, and economic resilience dimensions as shown in Figure 6-10. Of the three, economic resilience was the most impacted by the low flood event. Participants (R4, R6 and R7) confirmed that the flood primarily disturbed livelihood and commercial functions across the community, resulting in issues related to losses from days of work and the disruption of commercial activities. Noticeably, in the model, social resilience was not affected severely. One participant (R6) confirmed that most social facilities, like the mosque or hujra (community centre), remain functional in low flood events, as do schools and health facilities.

Similarly, physical infrastructure resilience is relatively high, with Policy 4 Retention Ponds and 2 Waterway Debris Clearance being very effective at absorbing the impact of the low-magnitude flood event. Community members in the interviews had remarked that after the 2008 and 2010 floods, most of the built-up area near the Waterway was rebuilt into Pakka (cemented) houses after suffering from damages and losses earlier in the decade, and this also would have contributed to overall physical infrastructure resilience. The participants also confirmed the change in building materials in 2008 (R5, R6 and R8). The impact on overall resilience was minor and releasing funds (Policy 1) at both levels would help the community recover much quicker.

When considering Policy 3 Training and Awareness, participants (R1, R2, R7, and R8) agreed that it could help residents deal with the flood locally but has a negligible impact on the community's social resilience. Some participants (3/9, R6, R7 and R8) suggested this is due to the hazard level and its consequences being limited to a smaller area and fewer people being mobilised for the response. All the participants agreed that retention ponds (Policy 4) and debris clearance (Policy 2) are very effective in dealing with low-level floods and significantly contribute to the overall resilience of the communities in the area. Both these policies prevent further erosion of the overall resilience by reducing the impact of regular flooding events and contribute to the long-run resilience of the community.

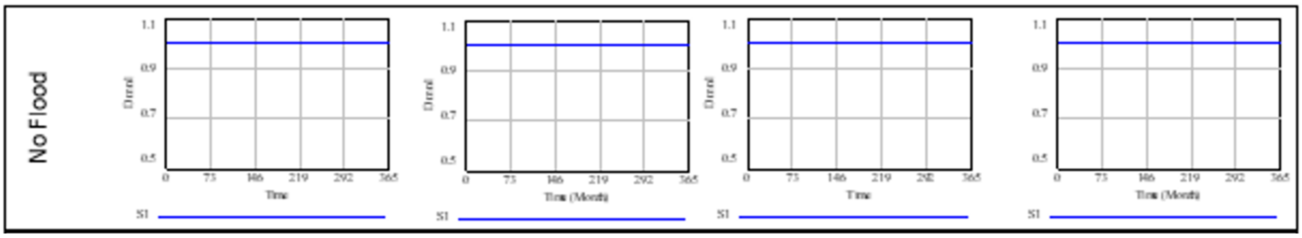
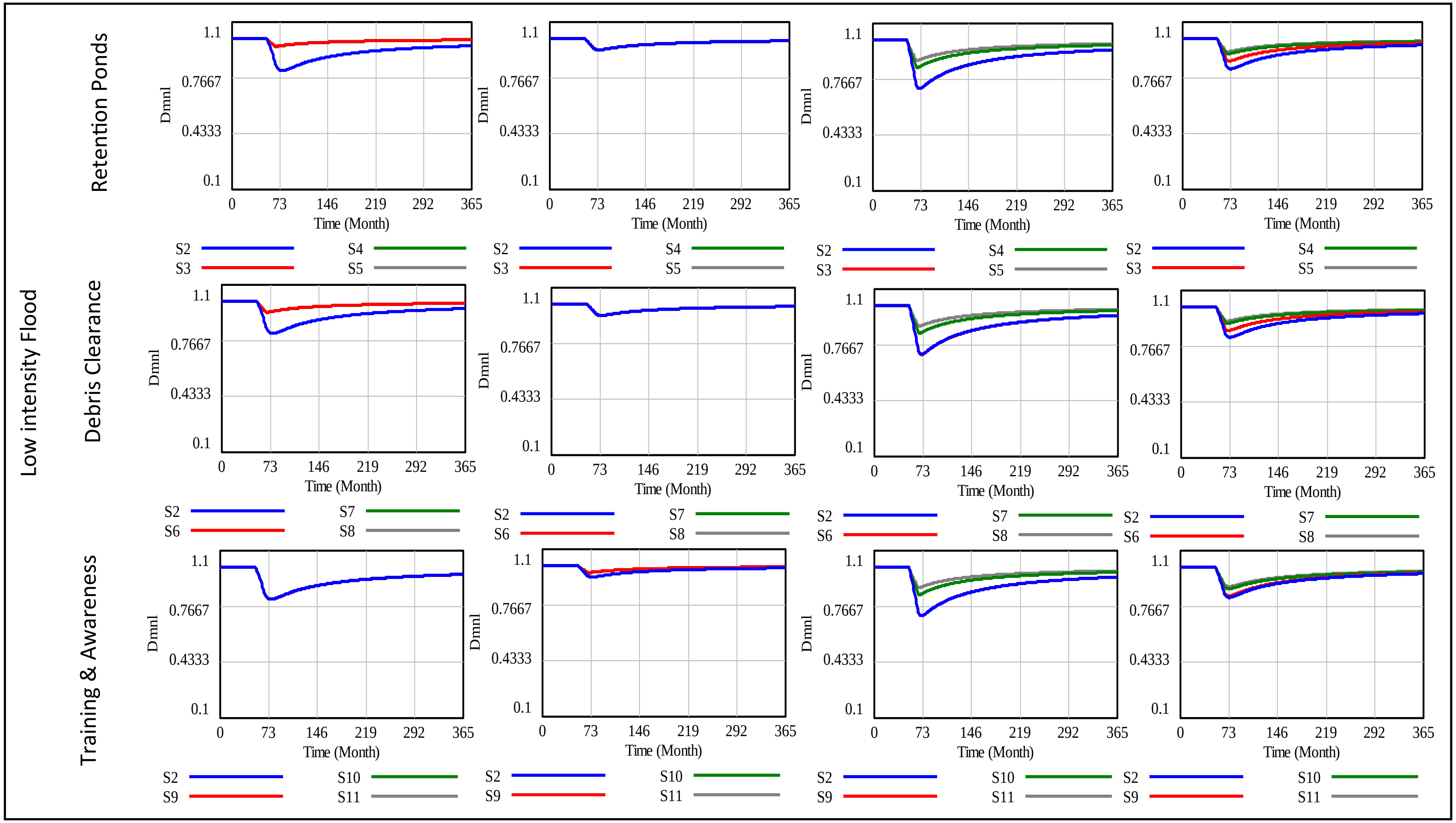


Figure 6-9. No Flood Scenario



a) Physical b) Social C) Economic D) Overall

Figure 6-10. Low Flood Intensity Scenario.

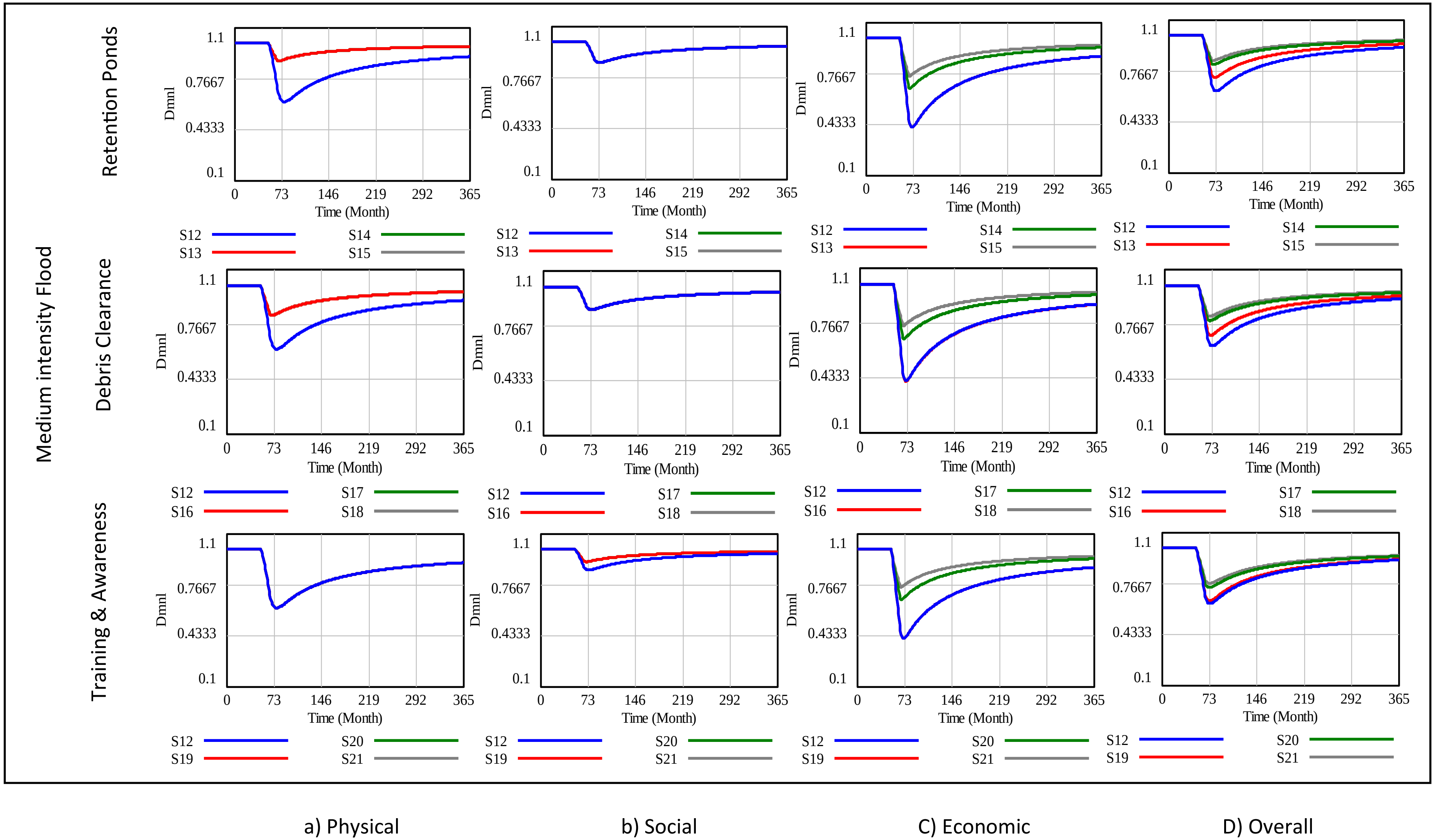


Figure 6-11. Medium Flood Intensity Scenarios.

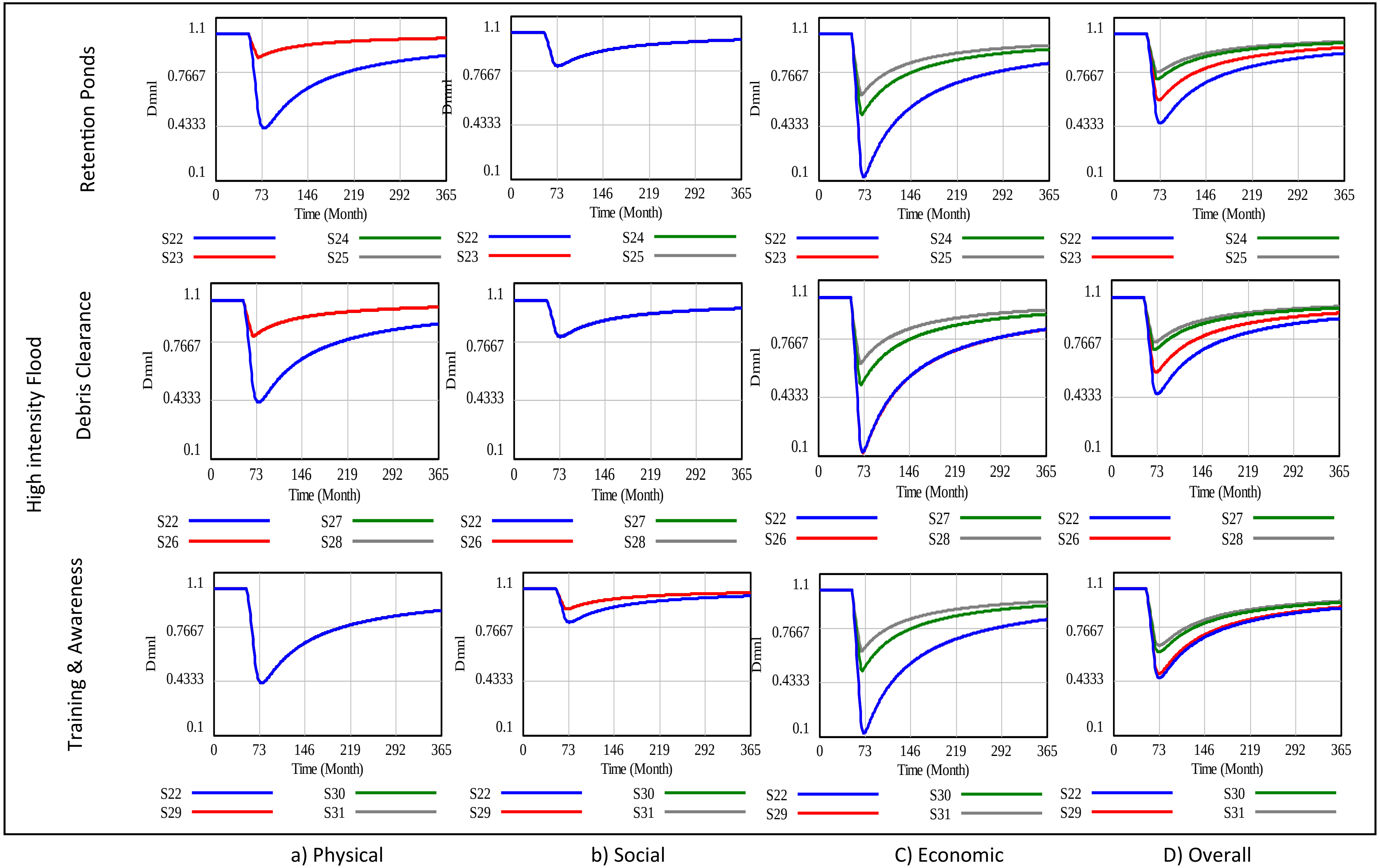


Figure 6-12. High Intensity Flood Scenario.

For the medium-level flood intensity (1-in-10 years), the SDS begins to indicate the possible limitations of some policies implemented in the case study area as shown in Figure 6-11. In this scenario, the retention ponds have done their job in absorbing much of the impact of the flooding, with the two participants from the disaster management authority (R4 and R5) indicating that the ponds are designed to absorb 1-in-10-year levels of flooding effectively. However, significant damage still results in the loss of physical infrastructure and economic resources. Similarly, conducting regular and timely debris clearance of the Waterway also absorbs some of the impacts of the flooding but not as much as the retention ponds. Both policies are effective, but to different degrees, with participants agreeing that Policy 2 is cheaper but effective in the short term and Policy 4 is significantly more expensive and long term. The same participants (R4 and R5) also pointed out that after flooding, the effectiveness of retention ponds may be reduced due to silt and debris and may also require a targeted silt-clearing activity such as Policy 2 does for Waterways to maintain effectiveness.

The Medium level hazard also significantly impacts the livelihoods and income of the community as the flash flooding affects the main commercial and industrial areas on both banks of the Waterway, causing considerable damage to local businesses and trades. As expected, the economic impact is considerably higher than the low flood case, and the timing and size of funds available from the Government play a significant role in recovery and overall resilience. Social resilience remains somewhat resilient as faced with a more substantial impact; locals rally around their community with greater participation among volunteers and local community-based organisations providing some initial support until support arrives from governmental and other external sources. Some participants (R6, R7 and R8) pointed out that Policy 3 can be more effective in this case as more volunteers and organisations who participated in the training can respond and recover in dealing with the flood locally and help coordinate the help and support from outside.

Finally, the high (1-in-100 year) flood intensity level shows that a major flood event will still have devastating consequences for the community in all three dimensions as shown in Figure 6-12. In Policy 4, despite the construction of the retention ponds, the sheer intensity and volume of flood waters easily exceeded the capacity of the ponds, resulting in significant damage to physical infrastructure. Practitioners and experts (R3, R4, R5, and R6) agreed that budget considerations for retention pond construction limit their capacity to absorb the flood waters. At the same time, community members (R6, R7 and R8) emphasised the corruption and misappropriation of funds playing a crucial role in limiting the effectiveness of built defences. Similarly, the high-intensity scenario shows that debris clearance has little effect on the overall flood levels. The Waterway is quickly filled at this hazard level, causing an overflow, followed by heavy inundation on both sides of the Waterway banks. The massive damage also results in considerable losses in livelihoods, assets (livestock and buildings), and agricultural and commercial output loss. High flood levels also severely impact social resilience as local resources are easily overwhelmed with dealing with the impacts. The devastating flood levels severely compromise local volunteers, and organisations take longer to organise, respond, and utilise any aid that might be provided. Additionally, social resilience is also reduced due to the impact on education (days off from school), mobility (access to health and other facilities) and adverse health outcomes, especially with water-borne diseases like malaria, dengue, and skin rashes taking a significant spike in the area (note we have coupled social and health indicators for simplicity in this model). Overall, the community takes longer to recover, and the timing and size of funds available play a crucial role in the recovery period of the community as it now takes much longer to return to pre-event resilience levels.

In this study, the Community Resilience model of Sardar Ghari VC showed the relative cost-effectiveness of Policy 4 over the long run and Policy 2 only in the short run. For a more long-term sustainable solution, Policy 4's construction of retention ponds would still require clearing debris and silt due to the frequent flood events in the area and the frequent dumping of industrial waste from the local industries. Hence, a combination of the two policies may be required, though at a higher cost. Policy 3's effectiveness can only be realised if a significant event occurs; hence, its contribution to preparedness for mega-flood events cannot be understated. Finally, Policy 1 suggests that early release of funds can help communities bounce back quicker and be better prepared for future hazards or shock events.

The scenarios modelled during the workshop were baseline scenarios developed with stakeholder input and can help improve the understanding of local capacities and the impact of shocks on the community's system performance. The model could be adapted to cover other dimensions, policies, or settings as required. Once the baseline scenarios have been established, like in this case study, the community disaster resilience model could be expanded to include further details by incorporating the feedback loops identified in the causal loops diagrams from Phase 1 Systems Thinking and Mapping in future work.

Workshop Feedback

Workshop participants provided valuable feedback on the potential value of the CDR modelling tool, especially for modelling different types and levels of hazards. Some (n=2/8, R1, and R7) participants suggested using it to model hazards like Dengue's impact and other health-related impacts such as epidemics. Some of the participants (n=3/8, R1, R2, and R4) appreciated the ability of the Modelling Approach to focus on multiple dimensions and multiple policies at the same time and not just one type of vulnerability or risk. Some (n=3/8, R3, R4, and R5) participants also asked about the approach's applicability to other locations and how the generic model can be adapted to different places, scales, and contexts. Participants were generally satisfied that the Modelling approach might be a reasonable starting point for modelling resilience at the local levels, with several (n=3/8, R3, R4, and R5) suggesting that additional data sources can also be used to improve the analysis.

Crucially, one participant (R4) pointed out that using such models at the local level may not be appropriate because many variables that have a bearing on the community (i.e., budgets, external funds, relief package sizes, etc.) are external variables. Locals have no decision-making powers regarding these policies; in this case, using the models for stakeholder engagement may increase frustration among stakeholders when they realise they cannot affect the outcomes. Other participants (R1, R2 and R3) expressed an interest in developing the Approach for the wider geographical area with more policy options that affect a larger population. A more comprehensive distributed model of the BNB case study may provide more insight into why flood risk is increasing in the area and link to the broader problem of rapid urbanisation in the area, lack of risk-sensitive urban planning and the long-term impacts of climate change on the communities living in the BNB area.

Artefact Validation

After the session, participants were asked to fill out the feedback questionnaire given to them earlier. The feedback questionnaire is shared in Appendix A. The feedback questionnaire for the Artefact used in the study was designed according to Prat et al. (2014), as indicated in Chapter 3 (based on Goals, Environment and Structure). The first section was on the background of the participants, followed by Section 2 on the use of Community Resilience

Frameworks. The third section asked about the effectiveness of the Approach used in the study, where participants were asked about the accuracy, reliability, and efficacy. Finally, they were asked about the application of the Approach in the case study, the participatory methods and the model used. The responses are summarised below.

Section 2 asked about the use of CDR frameworks among the participants. Most (n=5/8, R1, R2, R6, R7 and R8)) participants have not had experience using a Community Disaster Resilience framework for measuring community resilience at the local levels. Only three participants (R3, R4, R5) stated having used a framework before, the UNISDR City Resilience Scorecard piloted in Peshawar in 2018 (Jones et al., 2021a). The same three reported familiarity with the general literature on resilience measurement frameworks. When asked when they or their organisation would use a CDR framework, all three responded that it was used in post-work analysis, and none mentioned using it before or during an intervention. Next, they were asked about the use of CDR frameworks elsewhere in Pakistan that they might be aware of, to which most (n=5/8, R1, R2, R3, R4, and R5) responded that they had rarely seen its use in other parts of the country, and three (R6, R7 and R8) responded that they had not seen its use. The responses in this section indicated that CDR frameworks are not part of the regular work processes for most respondents, even those working on community resilience at the local levels, with less than half (n=3/8, R3, R4, and R5) having ever used them.

Section 3 was on participatory modelling and the use of simulations in community resilience research. Figure 6-13 summarises the responses in the section and shows that although there is an agreement on the need for more participatory methods or approaches in community resilience research, other non-participatory methods can also be used for the same purpose. The participants had a clear understanding that simulation modelling can be used for scenario testing and that it can be used for decision-making but were less confident of communities using the tools rather than decision-makers who had more technical know-how, expertise, and access to data.

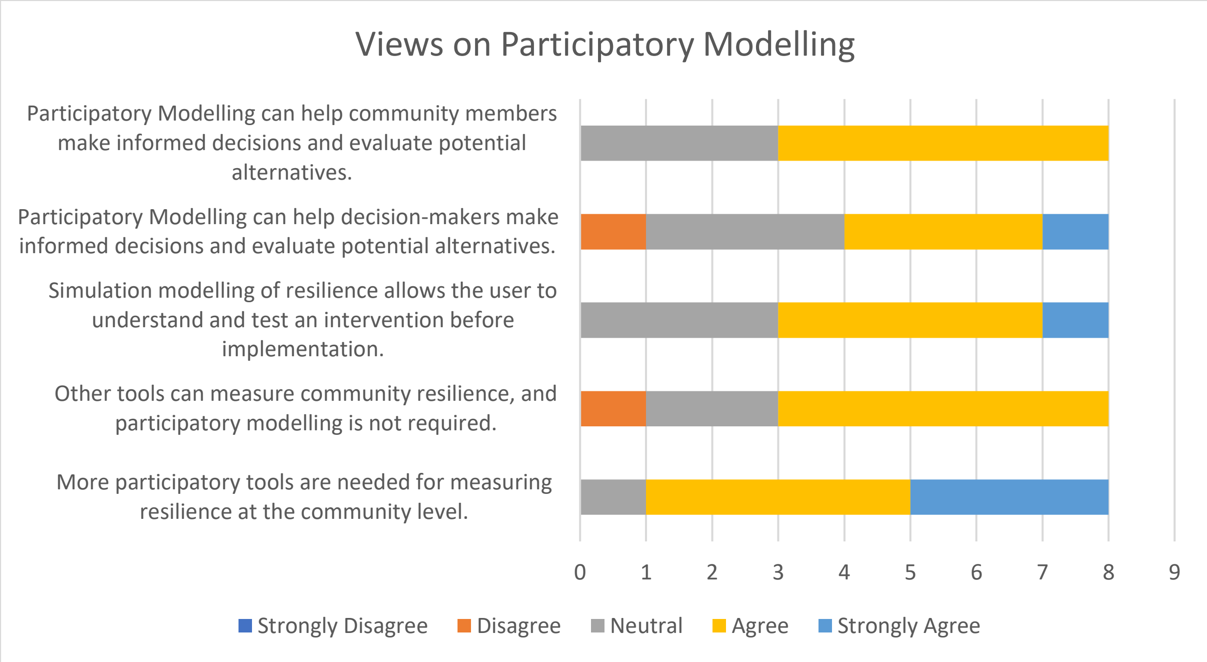


Figure 6-13. Participant Views on Participatory Modelling.

The following section asked about the effectiveness of using the Participatory Approach to Modelling Community Resilience in the Case Study. The first questions inquired about the accuracy of the information gathered by Approach in general – half of the participants (R1, R6, R7, and R8) strongly agreed with the accuracy of the information gathered, while most (n=3/8, R2, R3, and R4) of the rest reported that it was reasonably accurate and could be improved with minor changes – as shown in Figure 6-14. These numbers changed slightly when the same question was asked about the simulation model used in the Approach, with the number reporting accurate, with minor changes increasing, and one respondent (R3) indicating the need for significant changes, as shared in Figure 6-15. The significant changes were related to incorporating further dimensions and including feedback between them to allow for more realistic simulations of the problem. Next, Figure 6-16 shows the participants' responses on the strength of the Participatory Modelling approach used in the research.

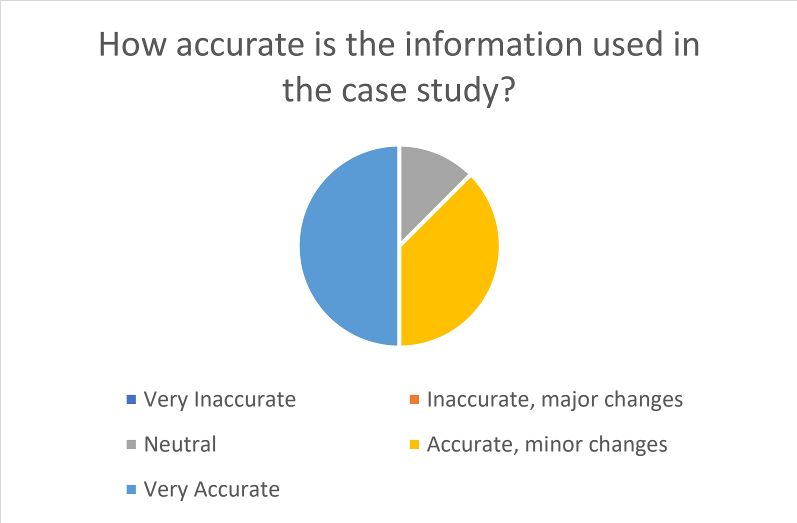


Figure 6-14. Accuracy of the Information gathered using the Participatory Approach.

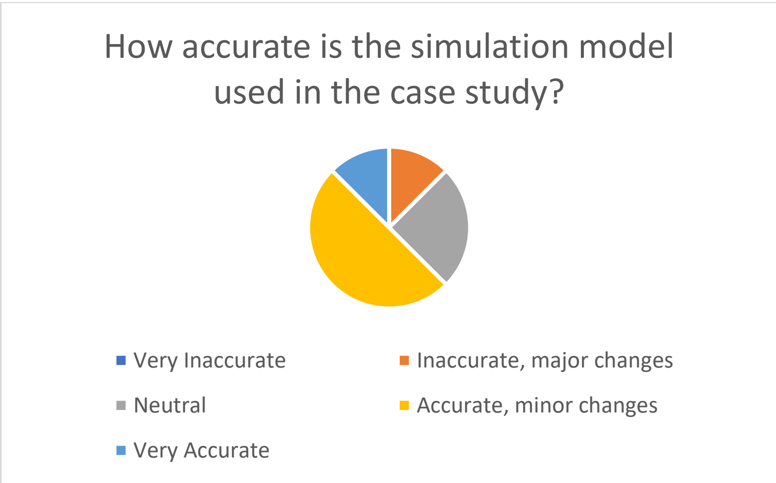


Figure 6-15. Accuracy of the Simulation Model used in the case study.

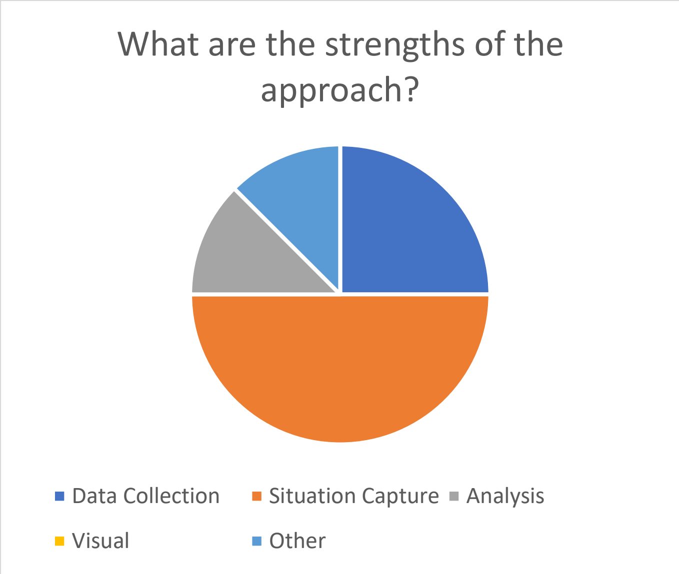


Figure 6-16. Strengths of the Modelling Approach.

The next set of questions asked the respondents about specific aspects of the Approach used in the case study relating to the methods and techniques. The participants were asked about the use of the participatory methods (CLDs and Q methods) in the case study – the majority reported their satisfaction with how the participatory methods were used, with slight differences between them (more strongly agreed with the use of CLDs). There was less agreement on the simulation model used, with one respondent (R3) indicating that it needed more work to be utilised effectively and providing suggestions after the workshop to do so. Questions were also asked about the policy scenarios used, the data collected during the case study, and the data analysis, as reported in Figure 6-17 below.

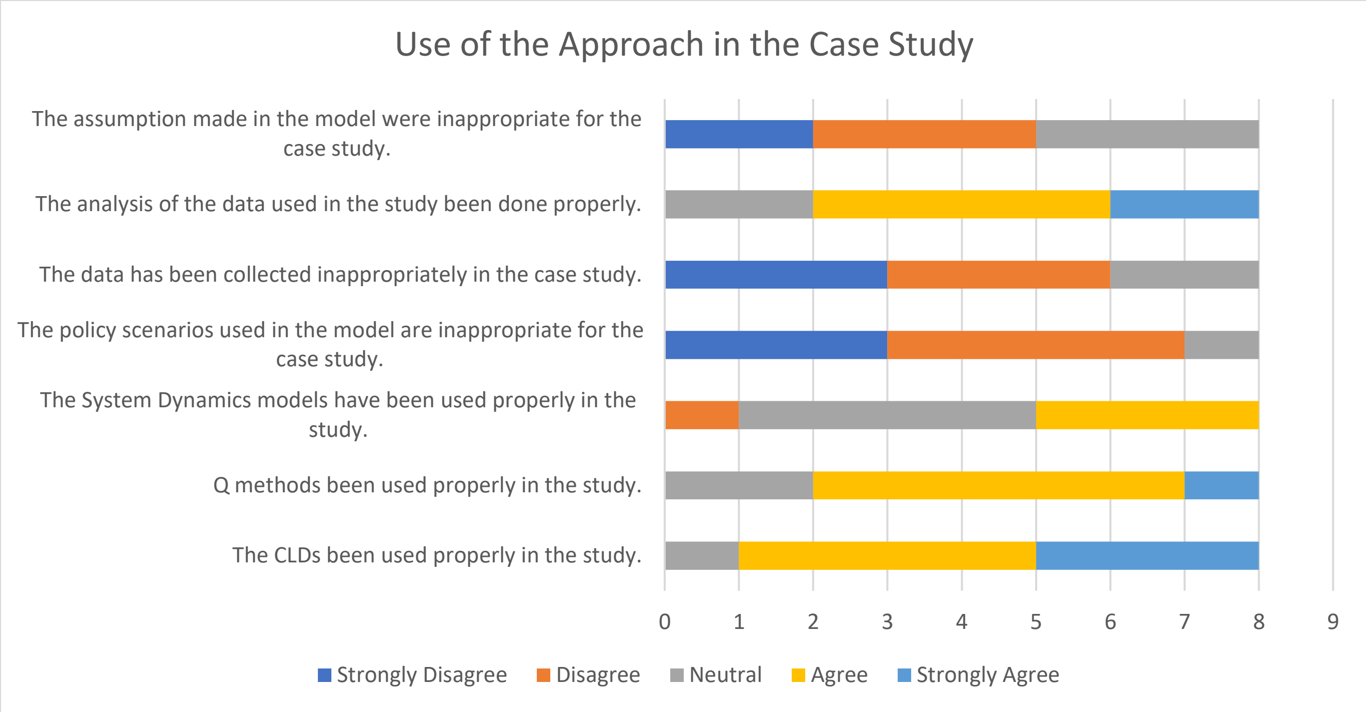


Figure 6-17. Use of the Participatory Approach in the Case Study.

Respondents were also asked if the assumptions used in the model were inappropriate for the case study, with most disagreeing, suggesting that the assumptions were well thought out and reasonable for use in the model. Respondents were next explicitly asked about how the Scenarios were chosen and modelled in the Approach and its applicability to the real world. More than half responded that the Scenario building process reflected real-world application but with minor changes needed, and one (R3) indicated significant changes were required before they could be related – as shown in Figure 6-18. Finally, the participants in the Validation Workshop were asked if any changes were needed in the Design and modelling process. Here, participants had different suggestions; one suggested more analysis be included (R2), two (R3 and R6) suggested more data was required in the model, and three (R1, R4, and R5) wanted integration with more graphical work that can make the approach more appealing and easier to use.

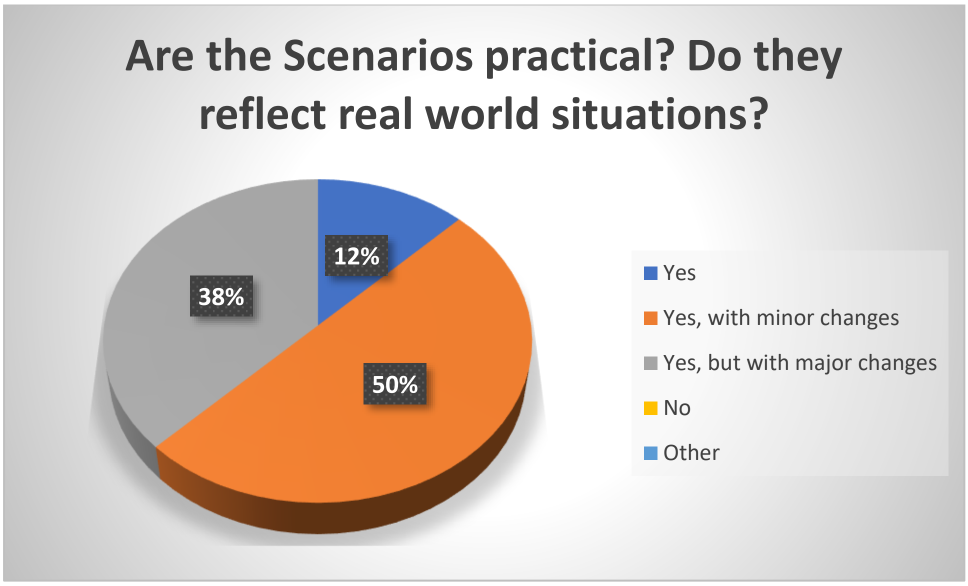


Figure 6-18. Applicability of the Scenarios in the Case Study.

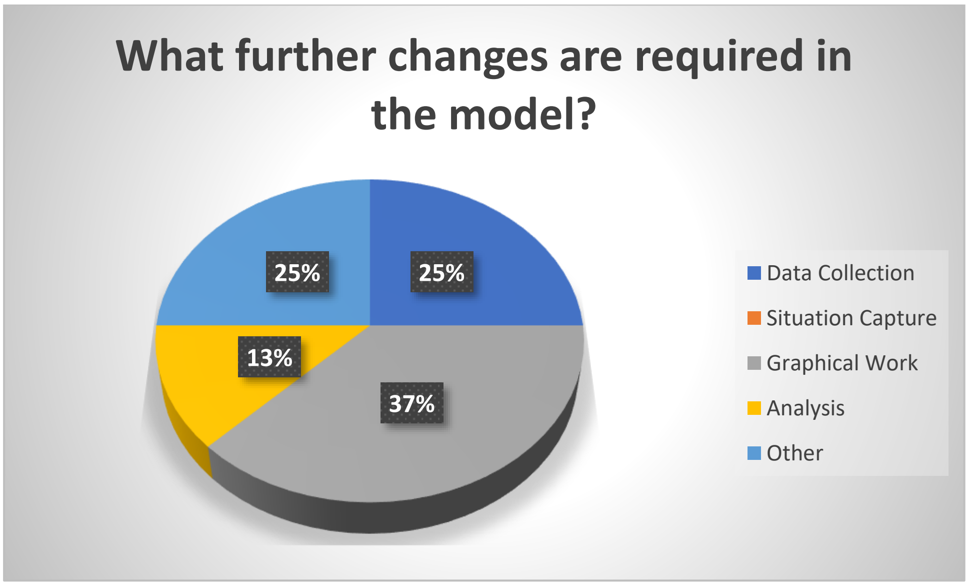


Figure 6-19. Changes needed in the model.

6.5.2 Validation Discussion

Goal

The goal criteria focus on whether the Artefact achieves its intended objectives and meets the defined goals and requirements (Prat et al., 2014). The purpose or goal of the research was to provide a more participatory approach to modelling resilience using subjective measures that address some of the gaps identified in the literature. The Participatory Approach to Modelling Community Resilience was developed to use subjective methods to measure resilience at the local levels. The Approach uses direct inputs from stakeholders, thus engaging them in the assessment process. Accordingly, a case study was conducted to evaluate the Artefact in field settings. As shown in the previous section, participants in the Validation Workshop have indicated that the Approach is comprehensive and needs only minor changes to make it more effective. For example, participants suggested more pilot testing of indicators (R1, R2, and R7) and using additional data sources (R3). As such, the Artefact has achieved its primary objective. The following two considerations are for its Validity and Generality.

The Validity of the overall Approach has been considered in the exploratory FGDs held throughout the research process in Phase 1 and then at the end of Phase 2. The validity of the Approach was evaluated in the case study by testing the Artefact's functionality with stakeholders in the exploratory FGDs and assessing whether it performs the intended tasks and functions as expected in the final CFGD. The Approach, as designed, was able to collect the necessary information, create an index to measure resilience and create a simulation model to engage local stakeholders in a discussion on policy interventions.

Finally, the generality of the Approach means its ability to be used in other contexts to achieve a similar goal. One of the core features of using subjective measures for measuring community resilience is its ability to be customised or contextualised according to local needs. The user feedback in the FGDs (R3, R4, R7 and R8) indicated their interest in using the Approach for other hazards (like Dengue) and to be used in a combined model for the whole

BNB area (total of fourteen neighbourhoods). Thus, according to the feedback from stakeholders (users), the Approach is relevant for use in other contexts, scales, and settings.

Environment

The environment criteria assess whether the Artefact suits the context and environment in which it will be deployed or utilised (Tremblay et al., 2010). This validation aspect was confirmed by ensuring that stakeholders from the three primary stakeholder groups (academics, practitioners, and community members) were involved in the validation process.

In the case study, significant interest was shown by the participants of the FGDs for the Approach, including a request for training (R1-R3, R7 and R8) by the UoP (academics) and AKF (community-based organisations). These participants particularly expressed an interest in using the subjective methods used in the research to gather information and develop user a defined Capacity Index. Hence, the Approach was relevant and applicable to the specific environment the participating individuals and organisations worked in such as Community Resilience Research and Social Work.

Structure

The structure criteria focus on the internal design and organisation of the Artefact, assessing its completeness, clarity, and level of detail (Prat et al., 2014). Most participants found the Participatory Approach designed in this research to be easy to follow, accurate in the information it collected and comprehensive enough to develop a model of the case study. A few (n=2/8, R3 and R5) of the participants did mention that the model itself requires some changes to make it more applicable. Hence, the completeness and the level of detail used in the Approach are addressed for the participatory part of the research (Phase I) and require improvement in the modelling part (Phase 2). Respondents (R3 and R5) mentioned that with a few adjustments to the Approach, it can be improved for use by stakeholders for discussion on scenarios. For example, R3 suggested adding system dynamics archetypes to the Approach will help understand the behaviour patterns in the community better and help in the modelling stage.

For clarity, it was mentioned that the wording and terminology used to describe the indicators in the statements could be improved. As this was translated into another language and tested in a small pilot, R1, R2, and R7 recommended using a professional translator and pilot with a wider audience to finalise the wording to address this shortcoming. Other than the wording of the indicators, participants found that the participatory tools were used effectively in the Approach.

6.6 Policy Recommendations (Step 6)

After compiling the feedback from participants, the following policy recommendations were made to the primary stakeholders of the case study:

- Lack of Funds (local government) for routine activities is the critical limiting factor for the community's resilience at Sardar Ghari.
- The availability of Funds depends on the community's economic resilience to Floods.
- Debris Clearance of the Waterway is an essential activity to maintain community resilience.
- Additional funds should be prioritised within the local government expenditure for Debris Clearance, or special provisions be made with Provincial Government authorities.
- Reserving Funds for Debris Clearance from internal and external sources and prioritising monitoring and law enforcement of the Waterway for the benefit of all community members.
- Funds should be generated internally through collection, donations and fines for those dumping solid waste into the Waterways.
- Other policy interventions like Training and Awareness for Volunteers may also be considered.
- Building Retention Ponds is a long-term strategy that should be considered for long-term resilience. Even with the approval and building of Retention Ponds, regular maintenance and Debris clearing must be performed.

Local community actors like the AKF can use these recommendations for Social Mobilisation and Awareness of the importance of Debris Clearance for all the community members (Businesses, Industry, Educational Institutions, and Housing Developers) and not just the responsibility of the local government or Irrigation department responsibilities. With greater awareness, citizens can monitor the level of debris in the Waterways by noting the presence of solid waste from local industries, housing construction and other encroachment activities. Citizens can work towards greater transparency and accountability within the community to ensure the Waterways are kept clear to prevent the regular cycle of flash flooding from sudden rainfall burst events.

6.7 Summary

This chapter evaluated the research's System Design and Modelling Phase. The six steps of the Phase were covered in each section of the chapter. The Approach and model were tested with stakeholder participants and found to be an effective method for exploring the impact of different interventions and their impacts on the main hazard faced at the community level. As suggested by participants, the model can be expanded to accommodate a wider area, and more significant policies and interventions can be modelled using the approach.

Based on the interest and support of the stakeholders participating in this study, a combined model of the other neighbourhoods along the Waterway is being developed to accommodate the communities' broader range of resilience problems. The model was based on data from recently published literature, expert opinion, and secondary sources (like Census data); it provided a basis for discussion and could be used to generate debate and consensus on developing disaster risk reduction interventions at the local levels. More inclusive approaches ensure that local voices are heard in the problem identification stage and will significantly improve intervention design. Studies have shown that such engagement at the community level can lead to more acceptance and better success in project implementation stages where the community feels ownership of the solutions and promotes resilience over the longer term (Clare et al., 2017, Jones et al., 2021b). The next chapter will provide the discussion and conclusion of this research.

Chapter 7 Discussion/Conclusion

7.0 Overview

The study's central aim was to propose a community-based approach to operationalise resilience measurement for understanding resilience at the local levels. This aim was addressed by developing a Participatory Approach to Modelling Community Resilience and evaluating the Artefact in a case study. This research achieved the aim by completing the five objectives identified in Chapter 1, as shown in Table 7.1 below.

Table 7.1 Research Objectives and Research Questions in the Research.

Research Objectives	Research Questions
Objective 1: Identify the initial library of indicators that local stakeholders can use to define and evaluate the resilience parameters of their community and its capacity to respond (anticipatory capacity), withstand (absorptive capacity), and recover (restorative capacity) from disasters or shocks	RQ1: What indicators can local stakeholders use to define and evaluate their resilience?
Objective 2: To propose a participatory approach to modelling and operationalise resilience measurement for understanding resilience at the local levels	RQ0*: "What methods and tools are required to allow local stakeholders to understand, measure and model resilience against disasters (or shocks) and explore what-if scenarios for leverage points that they can use for planning, advocacy and influencing policy to enhance their resilience?".*
Objective 3: To investigate a participatory approach for customising resilience parameters (dimensions, capacities, and indicators) which are relevant to the local context being considered	RQ2: What is a suitable participatory approach for the local stakeholders to customise resilience parameters according to their preferences and the local contexts?

Objective 4: To create a computational model that can compare the dynamic nature of resilience parameters and simulate the level of resilience in the community at the local level	RQ3: How can community resilience be modelled dynamically (over time) using resilience parameters?
Objective 5: To validate the above method and tools as an approach to understanding community-based resilience dynamics using a case study	

This chapter presents how each objective was achieved and some reflective learning that occurred while applying the systemic design approach. In this thesis, Chapter 2 provided a detailed literature analysis that was the foundation of the design of the Artefact. Chapter 4 provided details on the development of the Artefact based on the findings from Chapter 2 and stakeholder consultations. Chapters 5 and 6 evaluated the Approach developed in the research using a case study. Finally, Chapter 7 presents the **Conclusion and communication of the results** part of the Systemic Design methodology described in Chapter 3. Accordingly, this chapter covers the outcomes of each stage and how they contributed to answering the research questions and achieving the objectives stated for this study and provides the conclusion of the thesis and recommendations and future applications.

7.1 Objective 1: Identify an initial library of indicators

The first objective was to identify the initial library of indicators that local stakeholders can use to define and evaluate the resilience parameters of their community and its capacity to respond (termed anticipatory capacity), withstand (termed absorptive capacity), and recover (termed restorative capacity) from disasters or shocks. This research objective attempts to answer the following research question: "*What are the indicators that local stakeholders can use to define and evaluate their resilience?*".

The first part of the literature review considered the elements of community resilience as concepts that can be used to understand the ability of communities as systems to prepare, withstand and recover from disasters. Following a conceptual understanding of these terms, a systematic review of current Community Disaster Resilience (CDR) frameworks used in the literature was conducted.

The systematic literature review in Chapter 2 identified the key features and characteristics of CDR frameworks from the literature. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach was used to select and review 36 resilience frameworks. During the textual review of the articles, a matrix of indicators and measures was populated and clustered against six critical resilience dimensions (i.e., Physical, Health, Economic, Environmental, Social and Governance) into a library of 86 resilience indicators (composed of 360 measures) that can be used to operationalise a CDR framework according to the needs of the stakeholders. The review indicated that most of the articles selected use objective approaches to measure resilience, showing a gap for more frameworks using subjective or participatory approaches to measuring community resilience. Subjective or participatory approaches have been shown to improve the design and implementation of policies in public health, education and other settings, and similar applications in disaster risk reduction can also benefit communities. Additionally, most frameworks considered resilience a static outcome rather than a dynamic process that changes over time.

The first objective was achieved by developing a Library of Indicators that stakeholders could use to define how resilience is measured. Creating a repository of indicators allows community members to choose the indicators relevant to the local context for resilience assessment. This Library of Indicators was then used in the subsequent stages to operationalise the resilience measurement using subjective participatory methods identified in the review.

Dissemination: The research from this objective was presented at several workshops and seminars at the University of Salford, UK, for dissemination and feedback. The systematic review and findings were published in the International Journal of Disaster Risk Reduction, titled “Measuring Community Disaster Resilience at Local Levels: An Adaptable Resilience Framework” (Tariq et al., 2021c). This journal article was selected to be featured on ReliefWeb, a website for disseminating critical articles, reports, and documents of interest to humanitarians, run by the United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA).

7.2 Objective 2: Designing a Participatory Approach to Modelling Community Resilience

The second objective was to propose a participatory approach to modelling and operationalise resilience measurement to understand local resilience. This objective addresses the broader question linked to the main aim of the research, *"What methods and tools are required to allow local stakeholders to understand, measure and model resilience against disasters (or shocks) and explore what-if scenarios for leverage points that they can use for planning, advocacy and influencing policy to enhance their resilience?".*

As per the review conducted in this study, very few frameworks have used subjective assessment approaches to develop an adaptable, customisable CDR measurement approach that uses local community stakeholders' knowledge, expertise, and perspectives. Among resilience researchers, more effort is needed to develop and use approaches that allow for customisation to specific communities to measure their resilience. A CDR framework that addresses inclusivity and customisation can potentially help decision-makers choose the right interventions for the community (Jones, 2019)The review shows that most CDR frameworks are top-down in design and implementation. The lack of hybrid bottom-up approaches required the design of a new approach. The participatory and modelling approaches reviewed in the CDR frameworks in Chapter 2 provided the basis for the design of the Participatory Approach to Modelling Community Resilience proposed in Chapter 4 and evaluated in Chapters 5 and 6 in this research.

The design of the approach is based on CDR frameworks that have successfully addressed one or more of the gaps in CDR frameworks mentioned in the review previously. For example, the CoBRA and CCVA frameworks have participatory or subjective approaches to defining resilience but cannot consider resilience as a process over time (Adem et al., 2017, MacOpiyo, 2018). The TAMD framework has participatory approaches and the feature to track resilience over time but cannot simulate policy interventions for what-if scenarios in a simulation model (Anderson and Fisher, 2018). The CCAR, ResilSim, and COPEWELL frameworks can track resilience over time and use simulation models to test different policy options but are not designed for subjective input or use participatory approaches to define resilience parameters (Peck and Simonovic, 2013, Irwin et al., 2016, Links et al., 2017)

The research study proposes the Participatory Approach to Modelling Community Resilience at the local level. It uses participatory approaches to measure and model community resilience as a process over time and test stakeholder-defined policy interventions for discussion, consensus building, or generating awareness. Chapter 4 achieves this objective by providing the design of the Approach and the justification behind its development and use. Chapters 5 and 6 apply it in a case study for evaluation, and part of the improvement and reflective learning from the evaluation is discussed in Section 7.6 below.

Dissemination: As an overall objective encompassing the other three objectives, the dissemination activities and outputs from the design and use of the Approach are included in the appropriate sections below.

7.3 Objective 3: Participatory Approach for customising resilience parameters

Objective 3 of the research was to investigate a participatory approach for customising resilience parameters (dimensions, capacities, and indicators) relevant to the local context being considered. This objective aims to answer the research question, *"What is a suitable participatory approach for the local stakeholders to customise resilience parameters according to their preferences and the local contexts?"*.

The first phase of the Approach designed in this research is applied through six steps of the Systems Thinking and Mapping Phase (Chapter 5). These steps allow for problem identification, stakeholder analysis, interviews for Causal Loop Diagrams, Selecting Dimensions of Resilience, conducting Q-Sort interviews for Indicator Selection, and developing the Community Capacity Index for use in the System Design and Modelling phase.

The ST and Mapping Phase use Causal Loop Diagrams (CLDs) to capture stakeholders' perspectives and map the causes and consequences of hazards, including policies that may reduce these impacts. CLDs are used to identify and categorise the main variables and feedback loops in the community system and develop a consensus on what dimensions can be used to define the community's resilience problems.

Once the required dimensions are identified, Q-Sorts are used to rank and select indicators from the Library of Indicators for each dimension. The method enables stakeholders to engage in the process of resilience measurement by selecting which indicators should be used to evaluate resilience at the local level and, in the process, highlight what is important to measure from their perspectives. The Q-Sorts provide a mechanism for researchers to identify the patterns of opinions around measuring resilience among the stakeholder groups, including where consensus and disagreement exist. Using Q-Sorts is a subjective approach to selecting indicators for evaluating community resilience. It provides a quantitative method for determining statistically significant scores for indicator selection and a rich qualitative source for why those indicators were selected. The selected indicators are then compiled into a Community Capacity Index that can be used to measure community resilience and provide parameters for the System Design and Modelling Phase of the research.

Objective 3 was achieved in this research by designing the Systems Thinking and Mapping Phase (using CLDs and Q-Sorts) as participatory approaches that enable stakeholders to customise resilience parameters (dimensions, capacities, and indicators) relevant to the local context. A case study tested and evaluated the designed Approach (Objective 5).

Dissemination: The Systems Thinking and Mapping approach was presented at the 37th Annual System Dynamics Conference (Tariq, 2019) and in several workshops and seminars at the University of Peshawar, Pakistan; the University of Moratuwa, Sri Lanka; and the University of Salford, UK. Presenting the participatory methods used in the research led to collaborations with three different groups on publications: one for using Q-methods to develop a Physical Infrastructure Resilience Index for Disaster Management in Sri Lanka (Tariq et al., 2021a), one for developing an Environmental Resilience Index for urban planning in Malaysia (Tariq et al., 2022), and one for developing Thematic Maps from merged CLDs in Pakistan (Asif et al., 2023)Additionally, local partners in Pakistan requested training on the Artefact used in Phase 1 Systems Thinking and Mapping. A two-day training program was developed and delivered to 20 participants, consisting of academics (primarily postgraduate research students), social workers, and practitioners linked to the Peshawar Living Lab. Other academic partners requested similar training and delivered it to 15 and 12 participants in Sri Lanka and Malaysia.

7.4 Objective 4: Model and simulate resilience

The fourth objective of this research was to create a computational model that can compare the dynamic nature of resilience parameters and simulate the level of resilience in the community at the local levels. Objective 4 attempts to answer the research question, "*How can community resilience be modelled dynamically (over time) using resilience parameters?".*

Due to the complexity of socio-economic systems like the community and the dynamic nature of resilience, there has been an increasing interest in applying simulation modelling in disaster management (Mishra et al., 2019). This research used system dynamics modelling to simulate community resilience based on stakeholder inputs through the participatory Approach developed in Objective 2.

This objective was achieved by developing a System Design and Modelling Phase comprised of six steps to develop a computational model of resilience: Model Formulation, Model Refinement, Model Testing, Developing Scenarios, Model Use with Validation, and Policy Recommendations. Step 1 leads to the development of a generic system dynamics model of community resilience that conceptually reproduces the behaviour in the resilience triangle, the basic underlying theory behind quantifying community resilience in many of the CDR frameworks reviewed in Objective 1 (Cimellaro et al., 2010, Irwin et al., 2016). The generic model can then be refined according to the stakeholder-defined parameters generated from Phase 1 (Objective 2) of the research (Step 2). During Model Refinement and testing (Step 3), the indicators selected previously can be quantified with historical data, literature, or expert opinion. After refinement and testing, local experts and community members develop scenarios and validate the model in an FGD or a Group Model Building workshop (Steps 3 & 4). These stakeholders can guide developing scenarios in the model that can be shared with various stakeholders through Workshops, presentations, or other dissemination activities.

The System Design and Modelling Phase and the model were evaluated using a case study. The case study enabled testing the modelling approach in field settings with real-world resilience issues and actual stakeholders. Combining the participatory methods used in the previous Phase and the system dynamics modelling from this phase creates an innovative approach to modelling community resilience that addresses some of the gaps in CDR research identified in Chapters 1 and 2.

Dissemination: The System Dynamics model of Community Resilience was presented at the 25th Annual Sustainable Development Conference 2022 in Islamabad, Pakistan, and in several seminars at the University of Salford and the University of Peshawar. These presentations were delivered to diverse audiences, such as decision-makers, government representatives, academics, and disaster management practitioners.

7.5 Objective 5: Evaluation

Objective 5 was set out to validate the Artefact (Participatory Approach to Modelling Community Resilience artefact) using a case study. For this purpose, a community neighbourhood classified as a high-risk area for urban flooding was selected in the Northern part of Peshawar, Pakistan. The participants' selection and the artefacts' validation were conducted with the support of a local NGO working on community resilience issues such as social and health problems. The Artefact included the participatory methods and the simulation model of community resilience.

Application of the Approach in a case study enabled the researcher to test the subjective approaches to defining and evaluating resilience in field settings with stakeholders primarily defined across three primary stakeholder groups: Academics (experts), Practitioners (implementers), and Community Members (users). Nineteen interviews were conducted to develop CLDs for problem identification and dimension selection, and sixty-eight Q-sort interviews were conducted for indicators selection and Index development. Three exploratory FGDs with participants from each group were used during the case study to ensure the research outcomes from each phase had validity across three criteria: the goals of the Artefact, the environment in which the Artefact will be used, and the structure of the Artefact (Prat et al., 2014). Finally, the overall Approach was also validated in a CFGD with eight participants who assessed it and provided feedback on improving the process for future applications.

Dissemination: The case study results were presented in a seminar at the University of Salford, UK, and are being developed into a journal article for submission. The evaluation outcomes have led to several design improvements in the Artefact, which are mentioned in the next section below and will be applied in future research.

7.6 Participatory Approach to Modelling Community Resilience: Reflection

According to the review of CDR frameworks in Chapter 2, community resilience is inherently context-specific and requires a holistic approach to measurement across multiple dimensions and capacities. Furthermore, it recognised community resilience as a system of systems with interdependence and interlinkages and, hence, is particularly challenging to measure. At-risk communities suffering from the impact of repeated hazard events may have a high degree of complexity due to diverse stakeholders and complex vulnerabilities requiring innovative participatory approaches to capture these relationships (Herrera, 2018). Similarly, Beauchamp et al. (2019) report that any resilience assessment that ignores local priorities, their contexts, and the aspirations and motivations of local actors may misdiagnose resilience issues, resulting in missed opportunities to support communities with their existing goals, programs and strategies.

It is also important to realise that many researchers, and even some stakeholders, view community resilience as a normative concept, such as where it is “good” or preferred over other conditions, and this may not always be the case, especially for social scientists looking to gain insight and understanding of the deeper social issues affecting the community (Olsson et al., 2015). The consideration of resilience as a normative function may ignore the problems arising from conflict within the community and the role of agency, knowledge, and power within it (Inam et al., 2015, Ingalls and Stedman, 2016). It may lead to sub-optimal conditions for people living in that community if resilience is linked to recovering to a previous status quo which preserved any such inequalities in power dynamics before any event (Thorén and Olsson, 2018). Therefore, resilience researchers need a more nuanced understanding of what resilience means to some of the stakeholders in the community and whether it is a desirable state (Allen et al., 2019). Such nuance and insight are hard to capture in objective approaches and are often missing from stakeholders’ resilience conversations (Béné et al., 2019).

Participatory modelling approaches such as ST and SD modelling have a long history of using group model building to develop shared views of a system with complex feedback and interplay between multiple dimensions – an approach well suited to map out the different world views on resilience and how hazards impact a community (Herrera and Kopainsky, 2019). Participatory approaches among the diverse stakeholders can potentially engage these groups in the conversation about their community’s resilience. Sometimes, these engagements and conversations may be just as important a process as the resilience assessment itself (Beauchamp et al., 2019). System dynamics simulation models can be used in resilience assessment to understand behaviour within systems by helping understand the circular relationships that drive those behaviours (Links et al., 2017). For example, Herrera and Kopainsky (2019) use GMB sessions to develop Causal Loop Diagrams (CLDs) that can be used as boundary objects to engage stakeholders in food security and resilience. Similarly, Langellier et al. (2019) use Group Model Building sessions (GMBs) to explore health resilience across several communities in South America and how it can contribute to urban resilience using tools like Graphs over Time (GoT), CLDs and other “scripts” specially developed for health resilience assessment. Community-based Dynamics, as developed by Peter Hovmand (2014), enable community members to actively participate in the research process by engaging stakeholders in the conversation on issues like public health and obesity (Trani et al., 2019, Herrera and Kopainsky, 2020).

The Participatory Approach to Modelling Community Resilience at the local levels outlined in this research designed and tested a bottom-up, participatory approach for greater stakeholder engagement in the resilience measurement process. The Approach was evaluated using a case study, allowing researchers to test the Approach in field settings. The Case study allowed researchers to use interviews, focus groups, and GMBs to involve stakeholders in defining what resilience means to them and then asked them to select measures from a library of indicators to determine how resilience is measured, thus allowing customisation of the resilience assessment process according to their needs.

The case study and the FGDs provided several opportunities for feedback and suggestions for improving the 2 Phases of the Approach. Phase 1 conducted two rounds of data collection using interviews for CLDs and interviews for Q-Sorts in steps 3 and 5, respectively. Participant feedback suggested 19 interviews for developing CLDs were excessive for the flooding problem in the case study location. Accordingly, perhaps fewer interviews need to be conducted if the problems are less complex. Additionally, while developing the CLDs, it was suggested to use System Archetypes, such as Fixes that Fail and Shifting the Burden, which might find parallels in the case study and could be used to engage the stakeholders in discussions. In future work, System Archetypes will be explored in the Approach.

Another suggestion for improvement during data collection was for the Q-Sort interviews. When conducting the Q-Sorts, participants can be asked to provide additional information on the behaviour of the three most essential indicators they have selected over time. Asking for additional information ensures they think through their choice as they provide how the indicator is right now and how it will change in the future, providing information on behaviour for the modelling phase of the research. Furthermore, participants requested a visual or graphic representation of the Community Capacity Index that can be visually attractive and engaging. A diagram of the CCI was developed and will be included in future versions of the Approach – see Figure 7-1.

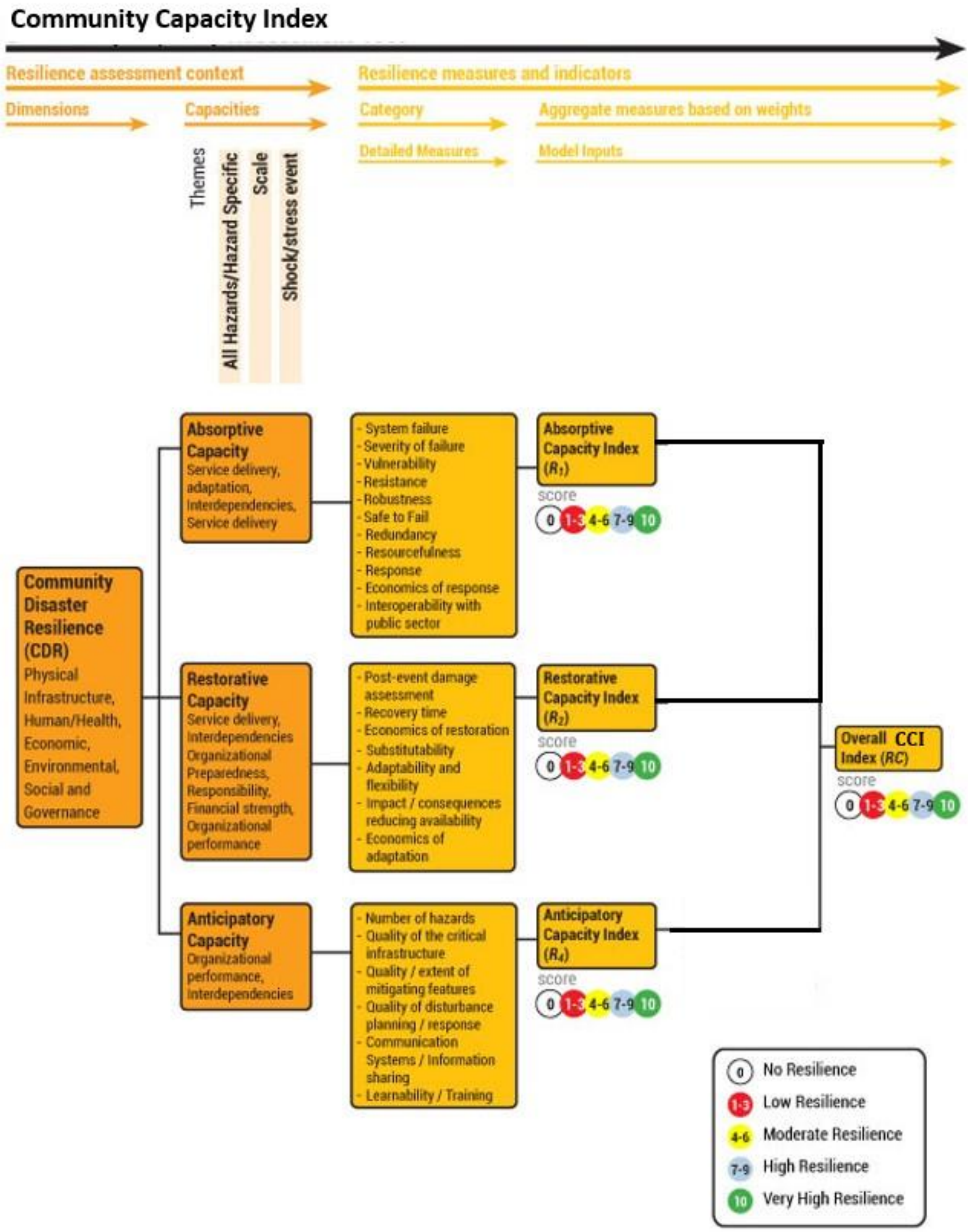


Figure 7-1. Community Capacity Index Tentative Diagram design.

Similarly, suggestions for improvement in Phase 2 required using more data sources relying less on qualitative information and conducting more FGDs or Group model-building sessions with stakeholder groups during the model refinement step. Unfortunately, due to the nature of the indicators in the Library of Indicators, most data will probably not be available in developing country contexts. They will have to be collected using a field survey. Hence, to improve the robustness of the model, conducting a random sample survey in the local area will address this criticism in future study applications. Furthermore, conducting more Group Model Building sessions will also make the model and the scenarios designed in the workshop more analytical. Extending the model for spatial analysis and developing an integration with the GIS application might also improve stakeholder engagement, especially when a larger geographical area is being considered for modelling. Additionally, thresholds were not considered for each of the dimensions, beyond which the ability of that dimension to recover or restore itself can be severely compromised. Adding thresholds can improve the validity of the model with respect to real word data. Finally, an Interactive Learning Environment (ILE) can be developed to increase the level of stakeholder engagement. An ILE can provide a Graphical User Interface (GUI) to make the model more user friendly and easy to use without the need for expert modellers. Including an ILE in the design stage will make the Particpatory Approach to Modelling Community Resilience more accessible and potentially improve the overall stakeholder engagement the process.

Accordingly, incorporating some of these aspects into the Participatory Approach to Modelling Community Resilience can improve the process, and further iterations might be tested in similar case studies in future work.

7.6 Conclusion

This study/research proposes a stepwise process for measuring CDR at local levels, which consists of two phases: 1) System Thinking and Mapping and 2) System Design and Modelling. The system thinking and mapping phase involves the engagement of local communities for qualitative modelling of the system and identification of the resilience issues faced by the community. This phase uses interviews, focus group discussions, causal loop diagramming and Q-Sorts to capture community resilience issues and specify the resilience dimensions to operationalise community resilience. At the System Design and Modelling phase, group model-building sessions and system dynamics simulation models are used to develop a working model of community resilience. In this phase, a system dynamics model is developed to demonstrate the resilience of the household sector for insights into the adaptive management of CDR at the local levels. The CDR model structure is simulated using expert opinion and data sets generated through the data collection part of the ST and Mapping Phase, as well as from the literature and data available from secondary sources.

This study addresses some limitations of previously developed resilience frameworks by integrating objective and subjective approaches to include stakeholders in resilience assessment by integrating their input into the model-building process. Using the more participatory, or subjective, Approach to co-creating resilience assessments ensures a more inclusive engagement with local stakeholders that enhances the model's ability to be customised, contextualised, and used for decision-making at the community level.

7.6.1 Contribution to Knowledge

This thesis has made the following contributions to community resilience measurement and modelling for disaster management:

1. Identifying a research gap in resilience frameworks: The literature review revealed a significant gap in current CDR frameworks, where most frameworks only used objective means to define and evaluate resilience. From the frameworks reviewed, only three used subjective means to define resilience, indicating a lack of frameworks that allow customisation to local contexts and conditions. In addition to customisation, most frameworks considered resilience as a snapshot or static concept and did not consider its temporal aspect. This research has addressed these shortcomings and provided a participatory approach to modelling community resilience as a multi-dimensional system changing over time.
2. The Library of Indicators for Index Formulation: The review also developed a Library of Indicators for resilience measurement. The research proposed its use as a database of indicators and measures from which stakeholders can rank and select indicators to develop an Index to measure community resilience. The Community Capacity Index (CCI), co-developed in this manner, reveals the perspectives and preferences of stakeholders regarding their resilience and how to measure it. The CCI can help local communities or decision makers to incorporate these indicators into their practice as Key Performance

Indicators to set community goals and priorities. For example, suppose the indicators contain references to plans, procedures and activities that are not found in the community yet are essential for resilience building. In that case, a key indicator has been identified to monitor for introducing change in the system. Helping communities become aware of resilience-building options can contribute to their overall resilience.

3. Q methods for Indicator selection: Q methods is a mixed methods approach using both quantitative and qualitative data and generates a rich data set on the patterns of opinion and perspectives within and among groups. This research proposed and tested the use of Q-Sorts for selecting indicators for resilience measurement and modelling. In addition to using the method for developing the CCI, the qualitative data collected during the Q-sort also provided cues on the behaviour of the indicators. To the best of the researcher's knowledge, there have not been any studies on using data from Q-methods to develop or refine SD models, and this study explores this potential.
4. Customisable SD model of community resilience: The research uses SD modelling to develop a generic stock and flow model that can be adapted to include multiple dimensions of community resilience when required by stakeholder feedback. The generic resilience model can function as a building block and be combined into multiple linked models for large-scale resilience assessment, such as multiple neighbourhoods along a river or canal. This makes the SD model flexible and adaptable to user requirements.
5. Developing an Approach for Community Engagement in the Resilience Assessment Process: The Approach developed and evaluated in this research can benefit practitioners and other stakeholders working on community resilience to disasters. The research provided a participatory approach to operationalising community disaster resilience, enabling communities (of place and practice) to participate and co-develop an Index for resilience assessment. The Approach (Community Capacity Index and Simulation model) can help identify the policies or interventions for disaster risk reduction that can lead to favourable outcomes for the community. Developing the Index can be an experiential learning experience for participants, especially gaining insight into the perspectives of other stakeholder groups. It may lead to consensus building concerning community action for resilience. For example, using participatory methods for resilience measurement can increase the learning of participants. In the case of community resilience, this includes a better understanding of the capacities and problems causing systemic vulnerabilities in

the community. By participating in the Approach, participants can gain insight into feedback between consequences and causes previously they hadn't connected. Helping communities to make the correct diagnosis can improve resilience. The Participatory Approach to Modelling Resilience was divided into two phases. Phase 1 uses relatively easy-to-learn and use methods so those skills can be transferable to participant stakeholders in the process, as witnessed by the requests from training from multiple sources during the research. Phase 2 of the research uses system dynamics modelling, requiring more technical knowledge to manipulate. Still, with some training, the generic Community Resilience model can also be adapted for use by stakeholders. Participants with technical skills or organisations with technical staff can be trained in its use.

6. Approaches that Facilitate Communication between stakeholders: The Approach proposed in this study can facilitate dialogue and communication between academics, practitioners and community members regarding resilience priorities, policies, and solutions. It can be used as a collaboration tool to support decision-making for interventions. It can be used to monitor and evaluate intervention progress, thus leading to transparency and accountability.

7.6.2 Challenges and Limitations

As with all Academic research, the study had several resource constraints, leading to limitations that must be considered. In addition to these resource constraints, the methods and techniques used in the research also provided their own set of assumptions and limitations that need to be mentioned.

Resource constraints and time limitations: The research was conducted during the COVID pandemic, which seriously limited the level and type of participatory activities that could be used in the limited timeframe of the study. Accordingly, the research design was adapted to limit the number of Focus Group Discussions and the Group model-building workshops used – both essential components in the design of the Participatory Approach. Additionally, the political instability in Pakistan and the devastating Floods in 2022 both posed additional challenges to the time available for data collection and the participation and engagement of stakeholders during the study.

Case Study Specificity: One of the limitations of using a single case study design is that the results of the evaluation cannot be generalised to a wider context. In this research, the Approach (the methods and techniques used) is developed to be adapted to any context required by the users (stakeholders). Using a second case study to evaluate the Approach in another context and setting (like another hazard) might have benefited the research. Unfortunately, the resource and time limitations mentioned above did not allow for an additional case study. Future work has been planned for conducting a similar study in another District in Pakistan to validate further the Approach developed in this study.

Data Availability: Gathering relevant and high-quality data for the case study was challenging, particularly at the local level. Most of the indicators and the measures used had no data sources available. Accordingly, proxies were used based on either expert opinion or extrapolations from existing data sets (for example, from Census data or administrative records). In developing country contexts like Pakistan, data on community resilience, historical events, demographics, and other variables are limited, leading to data gaps filled with expert opinion and stakeholder input. Additionally, tracking changes in community resilience over time often requires longitudinal data, which can be challenging to collect and maintain without sufficient stakeholder buy-in and resources. These inputs can potentially introduce errors and uncertainties in the model. Future applications of the Approach will consider using a survey to fill in some of the gaps in data availability.

Lack of Gender Balance in Data Collection: As mentioned in Chapter 3 Methodology, a significant limitation of this study is that most participants interviewed were male. This gender imbalance can lead to an underrepresentation of women's perspectives and experiences, particularly in areas where gender dynamics play a crucial role. The imbalance was due to the cultural and religious sensitivities of working in Pakistan, a conservative country. However, the main resilience problem identified in the case study impacted the community as a whole, and it was determined that there was little or no gender implications in the research. In other case studies, gender dynamics may play a significant role and hence, the stakeholder analysis would reflect the inclusion of more gender-focused organisations and groups. Future research should aim for a more balanced gender representation to ensure a comprehensive understanding of community resilience that includes the voices and experiences of both men and women.

Index Formulation: As mentioned in Chapter 4, developing an Index based on indicators from a Library of indicators developed and used in other contexts might lead to construct and content validity issues. Keeping these validity issues in mind, the researcher sought additional feedback from experts at the different stages of the research to assess the validity of the Index developed in the study. These were addressed by stakeholder validation and expert vetting but were still open to interpretation by different stakeholders.

Model Formulation and Refinement: The generic SD model of community resilience does not contain Thresholds beyond which the ability of a system to recover or restore itself can be severely compromised. In the next iteration of the model used in the Approach, asking participants to define such thresholds might help develop more realistic models. Additionally, the basic model provides a baseline of community disaster resilience that can be used to create more detailed models with full use of the feedback captured in the CLDs developed in the study. Finally, participatory system dynamics models can become complex, making them challenging for stakeholders and community members to understand fully. This complexity can hinder effective participation and collaboration in the modelling process. Ensuring meaningful engagement of community members and stakeholders in the participatory modelling process is difficult. Building trust, facilitating discussions, and encouraging active participation required significant effort indicating a higher skill level for the researcher to use the Approach effectively.

Despite these limitations, this research on participatory modelling of community resilience is a significant contribution to disaster and resilience studies for the development of subjective resilience assessment frameworks. The researcher has tried to mitigate some of these challenges through careful planning, strong local partnerships, appropriate training, ethical considerations, and effective communication with stakeholders. The study's outcomes can offer insights and guidance for future research and real-world applications of participatory modelling for community resilience.

7.7 Future Research

The basic system dynamics model structure developed in the study can replicate resilience dimensions such as health, economic, environment, physical and their sub-sectors to build a comprehensive community resilience model. The present model can be recalibrated to focus on different hazards or be expanded to cover additional dimensions in the present case study area. Alternatively, the Approach itself can easily be adapted to suit different contexts and settings in other locations if required. Evaluating system resilience against different disaster events demands a comprehensive spatially distributed system developed by integrating all resilience dimension dimensions in the next phase of this research project. The future form of the model will produce spatial and temporal maps of community resilience against different disaster events and individual assessment of a resilience dimension for adaptive management. Furthermore, the Participatory Approach to Modelling Community Resilience can be extended to the broader geographical area of the BNB case study in Peshawar and incorporate a Spatial System Dynamics model. Accordingly, two additional research studies are planned in the future:

1) Spatial System Dynamics Modelling of Community Resilience of the BNB area: This research will extend the analysis in this study to include the other Village Councils (VCs) in the BNB case study area to develop a spatial system dynamics model that extends the generic SD community resilience model developed here into spatial analysis that includes all nine of the high flood-risk VCs in the BNB area.
2) Nowshera Riverine Flooding Case Study: The second case study will use the learning from this research to evaluate the next iteration of the Participatory Approach to Modelling Community Resilience at the local levels in the Nowshera District, one of the most affected areas in the Floods of 2010 and 2022. The System Thinking and Mapping Phase has already begun (August 2023). In addition, a field survey will be included to fill any data gaps that may result from the new Community Capacity Index developed for Nowshera. It is expected to be finished by December 2023.

7.8 Summary

This research provides a basis for developing an adaptable CDR framework, which could result in blending the benefits of both subjective and objective approaches and adopting a more mixed or hybrid approach, as both have a role to play in the resilience assessment process (Maxwell et al., 2015). For example, the application of the Participatory Approach to Modelling Community Resilience used in this research uses subjective approaches to define and evaluate resilience using a library of indicators from the literature. The ability to adapt and customise the adaptable community resilience framework to suit the needs of local stakeholders was seen as a crucial benefit of using the methods in this research for a more participatory and subjective approach to resilience assessment that may help Disaster Risk Reduction planning and intervention design.

Finding wider use for such combined subjective-objective approaches may improve problem identification regarding critical vulnerabilities and leveraging local knowledge and experience to address Disaster Risk Reduction (DRR) issues (Jones, 2019). Additionally, such combined approaches have been used effectively to map resilience at the local level in frameworks like CoBRA (UNDP, 2014) and TAMD (Brooks et al., 2013) and have also proven helpful as a means of assessing the impact of interventions and holding those intervening in the community, whether government or non-government organisations, accountable for their actions (Jones, 2019).

Hence, the Approach developed here is designed to address some of the needs of the community resilience stakeholders by tapping into their knowledge, opinions and beliefs and using that to co-create tools that may aid them in developing fit-for-purpose resilience measurement tools that may help them in the every-day decision-making processes of their jobs. The adaptable CDR framework seeks to complement the existing decision-making structures. It offers itself as an additional support tool within the risk assessment process that may inform decision-makers of the resilience issues of the local community. It is envisioned that the adaptable CDR framework may help to bridge the gap between decision-makers and key stakeholders like disaster management authority staff, local government officers, and community members to potentially achieve a more equitable form of resilience assessment where stakeholder viewpoints are shared among the groups and were tracking the progress of local, national, and international commitments may improve the overall resilience of the community.

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APPENDIX A:

Library of Indicators and Measures for adaptable CDR framework

Tables SIS 1-6

Table SIS 1: List of indicators and measures for Physical Resilience

Table SIS 2: List of indicators and measures for Human/Health Resilience

Table SIS 3: List of indicators and measures for Economic Resilience

Table SIS 4: List of indicators and measures for Environmental Resilience

Table SIS 5: List of indicators and measures for Social Resilience

Table SIS 6: List of indicators and measures for Governance Resilience

Table SIS 1: List of indicators and measures for Physical Resilience

No.	Sub-dimensions	Capacity	Indicator/Measure
1	Buildings	Anticipatory	Awareness: Ecosystem monitoring and protection
2	Buildings	Anticipatory	Early Warning System: An early warning system exists, and covers multiple hazards
3	Buildings	Anticipatory	Learnability/training: Educational Attainment of households in community
4	Buildings	Anticipatory	Learnability/training; DRR Training and exercises for households in community
5	Buildings	Anticipatory	Quality/extent of mitigating features: Level of preparedness of households in the community
6	Buildings	Anticipatory	Quality/extent of mitigating features: Quality of range land/green spaces/land management
7	Buildings	Anticipatory	Recovery plan exists: Climate change impacts are covered (long-term)
8	Buildings	Anticipatory	Recovery plan exists: Single hazard covered or Multiple hazards covered?
9	Buildings	Anticipatory	Response plans exist: Single hazard covered or Multiple hazards covered?
10	Buildings	Anticipatory	Response plans exist: Climate change impacts are covered (long-term)
11	Buildings	Anticipatory	Recovery plan exists: Plans are up to date/regularly updated
12	Buildings	Anticipatory	Training system exist: Number of trainers/qualification of trainers
13	Buildings	Anticipatory	Training system exist: How many climate related hazards is covered by training
14	Buildings	Anticipatory	Training system exist; How many hours of training is performed/quality of training/content and materials
15	Buildings	Anticipatory	Training system exist: Frequency of training/Last training was within a year
16	Critical Facilities	Anticipatory	Communication: Backup system for communication and information sharing exist
17	Critical Facilities	Anticipatory	Communication: Communication and information sharing system exists/Awareness of and using Early Warning System
18	Critical Facilities	Anticipatory	Learnability/training: DRR Training and exercises for staff of Critical Facilities
19	Critical Facilities	Anticipatory	Quality/extent of mitigating features: Level of preparedness (Evacuation plan, disaster kit etc.)
20	Critical Facilities	Anticipatory	Recovery plan exist: At Community Level: Climate change impacts are covered (long-term)
21	Critical Facilities	Anticipatory	Recovery plan exist: At Community Level: Single hazard covered or Multiple hazards covered?
22	Critical Facilities	Anticipatory	Recovery time: At Community level: Does a recovery plan exist? How many hazard types does it cover?
23	Critical Facilities	Anticipatory	Recovery time: At Community level: Time needed to recovery? How many days/weeks/years expected till recovery of the system to pre-event level?
24	Critical Facilities	Anticipatory	Response plans exist: At Community Level: Climate change impacts are covered (long-term)
25	Critical Facilities	Anticipatory	Response plans exist: At Community Level: Single hazard covered or Multiple hazards covered?

26	Critical Facilities	Anticipatory	Response plans exist: At Community Level: Plans are up to date/regularly updated
27	Lifeline Systems	Anticipatory	Awareness: Number of hazards assessed as threats to asset or network
28	Lifeline Systems	Anticipatory	Communication: Communication and information sharing system exists/Awareness of and using Early Warning System
29	Lifeline Systems	Anticipatory	Equipment and procedures for hazard mitigation exist: Climate change impacts are covered (longterm)
30	Lifeline Systems	Anticipatory	Equipment and procedures for hazard mitigation exist: Resources/Finances/Equipment for hazard mitigation in place
31	Lifeline Systems	Anticipatory	Equipment and procedures for hazard mitigation exist: Single hazard covered or Multiple hazards covered?
32	Lifeline Systems	Anticipatory	Equipment and procedures for hazard mitigation exist: Legislation in place/Procedures are documented
33	Lifeline Systems	Anticipatory	Equipment and procedures for hazard mitigation exist: Legislation up to date/Procedures are regularly updated/revised
34	Lifeline Systems	Anticipatory	Communication: Plans/procedures/equipment for communication and information sharing between Critical Infrastructure operators and public sector exist
35	Lifeline Systems	Anticipatory	Recovery time: At Critical Infrastructure service level: Does a recovery plan exist? How many hazard types does it cover? Does it link to other Critical Infrastructure?
36	Lifeline Systems	Anticipatory	Recovery time: At Critical Infrastructure service level: How long till you operations restored? And at what levels/
37	Buildings	Absorptive	Damages: Percentage of change from base state after event
38	Buildings	Absorptive	Damages: Insurance costs
39	Buildings	Absorptive	Resistance: Age of structure: % houses built after threshold year (after building codes/standards)
40	Buildings	Absorptive	Resistance: Built according to hazard mitigation standards: % houses built according to hazard mitigation standards
41	Buildings	Absorptive	Resistance: Probability of failure (last event): % houses damaged (all types) with damaged structure (<threshold%) in last event
42	Buildings	Absorptive	Resistance: Probability of failure (last event): % houses without utilities (electricity/water/gas etc.) after last event
43	Buildings	Absorptive	Resistance: Safety Design factors: % of houses built according to building code
44	Buildings	Absorptive	Resistance: Type of structure (materials): materials used/roof type (building stock)
45	Buildings	Absorptive	Severity of Failure: loss/damages for certain hazards and hazard levels (Damage Curves - Residential Units)
46	Buildings	Absorptive	Severity of Failure: Total time that households left without any Critical Infrastructure services / No. Critical Infrastructure services
47	Buildings	Absorptive	System Failure: Loss for certain hazards level
48	Buildings	Absorptive	System Failure: Cost of damaged assets (Households/Residential)
49	Buildings	Absorptive	System Failure: hours/days of no economic activity or lost productivity (Private Sector)
50	Buildings	Absorptive	System Failure: Time that households/buildings are not able to serve its intended function
51	Critical Facilities	Absorptive	Resistance: Safety Design factors - Built according to building code

52	Critical Facilities	Absorptive	Resistance: Probability of failure (last event): % Buildings (all types) with damaged structure (<threshold%) in last event
53	Critical Facilities	Absorptive	Severity of Failure: loss for certain hazard levels
54	Critical Facilities	Absorptive	Severity of Failure: Total time that Critical Facilities left without any Critical Infrastructure services/ No. Critical Infrastructure services
55	Critical Facilities	Absorptive	Severity of Failure: Total time that Government Organizations (not healthcare) left without any Critical Infrastructure services/ No. Critical Infrastructure services
56	Critical Facilities	Absorptive	Severity of Failure: Total time that Health Care facilities left without any Critical Infrastructure services/ No. Critical Infrastructure services
57	Critical Facilities	Absorptive	System Failure: Costs of damaged assets
58	Critical Facilities	Absorptive	System Failure: Loss for certain hazards level (Damage Curves - Commercial/Industrial Units)
59	Critical Facilities	Absorptive	System Failure: Loss for certain hazards level (Damage Curves - Healthcare Units)
60	Critical Facilities	Absorptive	System Failure: Cost of damaged assets of Health care units: context dependent
61	Critical Facilities	Absorptive	System Failure: Time that health care is not able to serve its intended function: context dependent
62	Lifeline Systems	Absorptive	Asset backup exists: Duration of backup facility/How long is backup available?
63	Lifeline Systems	Absorptive	Asset backup exist: How quickly can backup services be offered/After how much time is backup available?
64	Lifeline Systems	Absorptive	Damages: Cost of reputation loss
65	Lifeline Systems	Absorptive	Damages: Cost of restoration of Critical Infrastructure service
66	Lifeline Systems	Absorptive	Damages: Loss due to possible penalties from violating service level agreements with buyers
67	Lifeline Systems	Absorptive	damages: Loss of income during restoration of Critical Infrastructure service
68	Lifeline Systems	Absorptive	Maintenance: Costs of Critical Infrastructure assets after hazard (cleanup cost)
69	Lifeline Systems	Absorptive	Maintenance: Amount spent on maintenance of Critical Infrastructure assets structure (amount/time period)
70	Lifeline Systems	Absorptive	Maintenance: Regular maintenance of Critical Infrastructure assets is performed
71	Lifeline Systems	Absorptive	Maintenance: Regular maintenance of the asset is performed/On time maintenance is performed according to plan
72	Lifeline Systems	Absorptive	Maintenance: Maintenance plan exist/Up to Date/Frequency of updating
73	Lifeline Systems	Absorptive	Resistance: Aging of Critical Infrastructure assets
74	Lifeline Systems	Absorptive	Resistance: Aging of Critical Infrastructure networks
75	Lifeline Systems	Absorptive	Resistance: Resources allocated for upkeep/depreciation of structure
76	Lifeline Systems	Absorptive	Resistance: Probability of failure at certain hazard levels
77	Lifeline Systems	Absorptive	Resistance: Probability of failure within Critical Infrastructure network

78	Lifeline Systems	Absorptive	Resistance: Critical Infrastructure Assets backup exist/No. of Critical Infrastructure Assets in Network (Energy/Gas)
79	Lifeline Systems	Absorptive	Resistance: Critical Infrastructure Assets backup exist/No. of Critical Infrastructure Assets in Network (Telecom)
80	Lifeline Systems	Absorptive	Resistance: Critical Infrastructure Assets backup exist/No. of Critical Infrastructure Assets in Network (Transport)
81	Lifeline Systems	Absorptive	Resistance: Critical Infrastructure Assets backup exist/No. of Critical Infrastructure Assets in Network (Water)
82	Lifeline Systems	Absorptive	Resistance: Critical Infrastructure Service replacement exist/No. of Critical Infrastructure Services (Residential)
83	Lifeline Systems	Absorptive	Resistance: Probability of failure (last event): % Buildings (all types) without electricity after last event
84	Lifeline Systems	Absorptive	Resistance: Vulnerability assessment of Critical Infrastructure assets exist (No. of hazards covered/No. of assets covered)
85	Lifeline Systems	Absorptive	Resistance: Vulnerability assessment of Critical Infrastructure Network exist (No. of hazards covered/No. of asset networks covered)
86	Lifeline Systems	Absorptive	Resistance: Safety design standards for respective hazards are applied - How many relevant standards is applied?
87	Lifeline Systems	Absorptive	Resistance: Safety design standards for respective hazards are applied - How many climate related hazards it covers?
88	Lifeline Systems	Absorptive	Severity of failure: loss of Critical Infrastructure service for certain hazard levels
89	Lifeline Systems	Absorptive	Substitutability: At Critical Infrastructure service level: Replacement of service is possible: Financially Possible
90	Lifeline Systems	Absorptive	Substitutability: At Critical Infrastructure service level: Replacement of service is possible: Technically Possible
91	Lifeline Systems	Absorptive	System Failure: Costs of damaged Critical Infrastructure assets
92	Lifeline Systems	Absorptive	System Failure: Loss for certain hazards level (Damage Curves - Key Critical Infrastructure Units Energy)
93	Lifeline Systems	Absorptive	System Failure: Loss for certain hazards level (Damage Curves - Key Critical Infrastructure Units Telecom)
94	Lifeline Systems	Absorptive	System Failure: Loss for certain hazards level (Damage Curves - Key Critical Infrastructure Units Transportation)
95	Lifeline Systems	Absorptive	System Failure: Loss for certain hazards level (Damage Curves - Key Critical Infrastructure Units Water)
96	Lifeline Systems	Absorptive	System Failure: Service/Function loss for certain hazards level
97	Lifeline Systems	Absorptive	System Failure: Time that Critical Infrastructure is not able to serve its intended function
98	Lifeline Systems	Absorptive	System Failure: Time that Critical Infrastructure is not able to serve its intended function (how many Critical Infrastructure services in total not functioning?)
99	Lifeline Systems	Absorptive	System Failure: Number of Critical Infrastructure assets fully damaged (beyond repair)
100	Lifeline Systems	Absorptive	System Failure: Number of Critical Infrastructure assets partially damaged
101	Lifeline Systems	Absorptive	System Failure: Number of Critical Infrastructure assets with a [over] certain percent (%) or range of damages
102	Lifeline Systems	Absorptive	System Failure: Time that infrastructure unit is not able to serve its intended function
103	Buildings	Restorative	Economics of restoration: Deforestation/erosion protection

104	Buildings	Restorative	Post-event damage assessment: Mechanism in place for rapid assessment
105	Critical Facilities	Restorative	Adaptability: Adaptation plan exists/Up to date
106	Critical Facilities	Restorative	Adaptability: Adaptation plans based on community/expert consultation? Plans based on sound economic analysis?
107	Critical Facilities	Restorative	Economics of restoration: At community level: Hazardous materials storage and cleanup cost
108	Critical Facilities	Restorative	Post-event damage assessment: At community level: how long does it take for damage assessment?
109	Critical Facilities	Restorative	Post-event damage assessment: At community level: Is there a post-event damage system or mechanism in place?
110	Lifeline Systems	Restorative	Adaptability and flexibility: At Critical Infrastructure service level: Business Continuity Plan exist?
111	Lifeline Systems	Restorative	Adaptability and flexibility: At Critical Infrastructure service level: Critical Infrastructure have ability to change while maintaining or improving functionality
112	Lifeline Systems	Restorative	Adaptability and flexibility: At Critical Infrastructure service level: Decisions to adopt adaptation based on market forces/Increased business due to adopting new adaption options
113	Lifeline Systems	Restorative	Adaptability and flexibility: At Critical Infrastructure service level: Do Adaptation plan exists? Any changes in Business Continuity plan after last event?
114	Lifeline Systems	Restorative	Adaptability and flexibility: At Critical Infrastructure service level: Impact/consequences: New building facilities are built according to higher standards/codes
115	Lifeline Systems	Restorative	Adaptability and flexibility: At Critical Infrastructure service level: Impact/consequences: Relocation of economic activities within the area? Outside of the area?
116	Lifeline Systems	Restorative	Adaptability and flexibility: At Critical Infrastructure service level: Quick adoption of alternative strategies is possible
117	Lifeline Systems	Restorative	Adaptability and flexibility: At Critical Infrastructure service level: Responding to changing conditions in time is possible
118	Lifeline Systems	Restorative	Economics of restoration: At Critical Infrastructure service level: Loss of income during restoration period
119	Lifeline Systems	Restorative	Economics of restoration: At Critical Infrastructure service level: Maintenance costs after hazard (cleanup costs)
120	Lifeline Systems	Restorative	Economics of restoration: At Critical Infrastructure service level: Reputation costs/Insurance costs
121	Lifeline Systems	Restorative	Economics of restoration: At Critical Infrastructure service level: The amount used to restore operations or business activity
122	Lifeline Systems	Restorative	Post-event damage assessment: Mechanism in place for rapid assessment of Damaged Critical Infrastructure network? How many networks covered?
123	Lifeline Systems	Restorative	Post-event damage assessment: At Critical Infrastructure level: % change from base level after event (functionality loss)? For each critical infrastructure
124	Lifeline Systems	Restorative	Time needed to recovery of Critical Infrastructure service

Table SIS 2: List of indicators and measures for Human/Health Resilience

No.	Sub-dimensions	Capacity	Indicator/Measure
1	Healthcare System	Anticipatory	Awareness: level of awareness of the Healthcare system to hazard risks
2	Healthcare System	Anticipatory	Preparedness: Main hospitals have a disaster plan; No. of hazards covered by plan
3	Healthcare System	Anticipatory	Preparedness: % of Healthcare units (clinics, health units and dispensaries) linked to plan
4	Healthcare System	Anticipatory	Preparedness: Arrangements for temporary hospitals and treatments during event (in area of interest)
5	Healthcare System	Anticipatory	Preparedness: Arrangements with alternative hospitals and care clinics during event (out of area of interest)
6	Healthcare System	Anticipatory	Preparedness: Main hospitals have alternative power generation for X hours
7	Healthcare System	Anticipatory	Early Warning System: Health units aware of and using the service
8	Healthcare System	Anticipatory	Training and exercises: No. Healthcare personnel trained for DRR/No. of Healthcare personnel
9	Healthcare System	Anticipatory	Training and exercises: No. of Drills or Exercises conducted in past year, if any: No. personnel involved in the drills or exercise
10	Healthcare System	Absorptive	Damages: Cost of damaged assets of Healthcare units: In last disaster
11	Healthcare System	Absorptive	Damages: Cost of damaged assets of Healthcare units: In current (ongoing) disaster (estimated): representing direct measure of disaster/hazard and also dynamics
12	Healthcare System	Absorptive	System Failure: Time that Healthcare is not able to serve its intended function: In last disaster
13	Healthcare System	Absorptive	System Failure: Time that Healthcare is not able to serve its intended function: In current (ongoing) disaster (estimated)
14	Healthcare System	Absorptive	Severity of failure: loss for certain hazard levels: In last disaster
15	Healthcare System	Absorptive	Severity of failure: loss for certain hazard levels: In current (ongoing) disaster (estimated)
16	Healthcare System	Absorptive	Resistance: Age of structure: Built before or after a certain threshold (e.g. pre 1970 build before major changes to building standards and code)
17	Healthcare System	Absorptive	Resistance: Safety Design factors: Built according to current building code
18	Healthcare System	Absorptive	Resistance: Safety Design factors: Built according to current hazard mitigation standards
19	Healthcare System	Absorptive	Maintenance: Amount spent on upkeep of key buildings in the health system
20	Healthcare System	Restorative	Post-event damage assessment: Is there a post-event damage assessment system or mechanism in place? How does the community assess its health units/system damages? Is the community able to conduct a post-event damage assessment? how long does it take?

21	Healthcare System	Restorative	Post-event damage assessment: % change from base level after event (functionality loss)
22	Healthcare System	Restorative	Recovery time: At community level: Does a recovery plan exist? How many hazard types does it cover? Time needed to recovery? How many days till recovery of the health system to pre-event level?
23	Healthcare System	Restorative	Economics of restoration: Costs of restoration of health system
24	Healthcare System	Restorative	Economics of restoration: Maintenance costs after hazard (cleanup costs)
25	Healthcare System	Restorative	Economics of restoration: Reputation costs/Insurance costs
26	Healthcare System	Restorative	Economics of restoration: Loss of income during restoration
27	Healthcare System	Restorative	Adaptability and flexibility: Any changes to process and procedures since last event?
28	Healthcare System	Restorative	Adaptability and flexibility: Any equipment or personnel changes in health system after last event?
29	Household health	Anticipatory	Awareness: Level of awareness at HH level of hazard risks
30	Household health	Anticipatory	Awareness: % population reached through awareness/risk communication program
31	Household health	Anticipatory	Preparedness: Household to Community level Disaster plan?
32	Household health	Anticipatory	Preparedness: Is there an up-to-date evacuation plan and % of HH covered in the plan? % of community have disaster kits at home?
33	Household health	Anticipatory	Early Warning System: % of HHs covered by/linked to system
34	Household health	Anticipatory	Early Warning System: % of people aware of system? % of people registered with the system. % of people with mobile phone App?
35	Household health	Anticipatory	Learning/training: Household members trained for DRR, first aid
36	Household health	Anticipatory	Learning/training: No. of Drills or Exercises conducted in past year, if any:
37	Household health	Anticipatory	Learning/training: No. of HH members with secondary level education or higher
38	Household health	Absorptive	Damages: Cost of damaged assets In last disaster
39	Household health	Absorptive	Damages: Cost of damaged assets in current (ongoing) disaster (estimated): representing direct measure of disaster/hazard and also dynamics
40	Household health	Absorptive	Resistance: Time that household is not able to serve its intended function in last disaster
41	Household health	Absorptive	Resistance: Time that household is not able to serve its intended function in current (ongoing) disaster (estimated)
42	Household health	Absorptive	Resistance: % HH requiring food/cash assistance
43	Household health	Absorptive	Resistance: % severe acute malnutrition rates
44	Household health	Absorptive	Severity of Failure: loss for certain hazards and hazard levels in last disaster

45	Household health	Absorptive	Severity of Failure: loss for certain hazards and hazard levels in current (ongoing) disaster (estimated)
46	Household health	Absorptive	Resistance: % houses built after threshold year
47	Household health	Absorptive	Resistance: materials used
48	Household health	Absorptive	Resistance: Roof type
49	Household health	Absorptive	Resistance: Built according to building code
50	Household health	Absorptive	Resistance: Built according to hazard mitigation standards
51	Household health	Absorptive	Maintenance: Amount spent on maintenance of structure
52	Household health	Absorptive	Access to Healthcare: How easy/hard it is to access Healthcare resources? Physical access and Cost
53	Household health	Absorptive	Access to Healthcare: How easy/hard it is to access Healthcare resources? Difference across ethnic, language, gender or disability
54	Household health	Absorptive	Household Structure: Unemployment rate (at community level)
55	Household health	Absorptive	Household Structure: No. of people within household employed
56	Household health	Absorptive	Household Structure: % income spent on housing
57	Household health	Absorptive	Household Structure: % income spent on transportation/commute
58	Household health	Absorptive	Household Structure: Types of transport available to the Household; costs
59	Household health	Absorptive	Household Structure: % people with limited Main (Risk Communication) language proficiency
60	Household health	Absorptive	Household Structure: Household members with disability
61	Household health	Restorative	Post-event damage system: Mechanism for household in place? How does the community self-report economic infrastructure damages and economic loss? Is the community able to conduct a post-event damage assessment? how long does it take?
62	Household health	Restorative	Recovery plan: household recovery time % change from base level after event (functionality loss)
63	Household health	Restorative	Recovery plan: At community level: Does a recovery plan exist? How many hazard types does it cover? Time needed to recovery? How many days till recovery of the HH system to pre-event level?
64	Household health	Restorative	Economics of Restoration: The amount used to restore HH activity as before event
65	Household health	Restorative	Economics of Restoration: Loss of income during restoration
66	Household health	Restorative	Economics of Restoration: Insurance costs
67	Household health	Restorative	Economics of Restoration: Maintenance costs after hazard (cleanup costs based on last event)
68	Household health	Restorative	Adaptation: Change in household behavior after event

Table SIS 3: List of indicators and measures for Economic Resilience

No.	Sub-dimension	Capacity	Indicator/Measure
1	Economic system	Anticipatory	Awareness: Community level: % of businesses in the area who know about the potential hazards they might face
2	Economic system	Anticipatory	Awareness: Individual business level: Awareness of the number of hazards that may threaten their operations
3	Economic system	Anticipatory	Equipment and procedures for hazard mitigation exist: % of businesses with hazard mitigation plans
4	Economic system	Anticipatory	Equipment and procedures for hazard mitigation exist: % businesses with annually updated plans
5	Economic system	Anticipatory	Equipment and procedures for hazard mitigation exist: % businesses who have spent money on Business Continuity plan
6	Economic system	Anticipatory	Equipment and procedures for hazard mitigation exist: Inclusion of resilience in economic development plans
7	Economic system	Anticipatory	Communication Systems/information sharing: Plans of communication and information sharing between businesses and public sector exist
8	Economic system	Anticipatory	Communication Systems/information sharing: Communication system for communication and information sharing between businesses and public sector exist
9	Economic system	Anticipatory	Communication Systems/information sharing: Is there community level Early Warning System (EWS)? % business integrated into the EWS?
10	Economic system	Anticipatory	Communication Systems/information sharing: Backup of communication system for communication and information sharing exist
11	Economic system	Anticipatory	Learnability/training: Does a Training program/system for DRR exist?
12	Economic system	Absorptive	System Failure: Cost of damaged assets
13	Economic system	Absorptive	System Failure: Time that Economic system is not able to serve its intended function
14	Economic system	Absorptive	Severity of Failure: loss for certain hazard levels
15	Economic system	Absorptive	Resistance: Probability of failure; %business the failed in past hazard event/total number of businesses in area
16	Economic system	Absorptive	Resistance: Age of structures: Average age of economic infrastructure; % built after (key DATE)
17	Economic system	Absorptive	Resistance: Safety Design factors: % economic infrastructure built according to building code
18	Economic system	Absorptive	Resistance: Safety Design factors: % economic infrastructure built according to hazard mitigation standards
19	Economic system	Absorptive	Maintenance: Amount spent on maintenance of economic infrastructure/the number of businesses that spend more than X $ on maintenance (threshold level)
20	Economic system	Absorptive	Resistance: Diversity of industries
21	Economic system	Absorptive	Resistance: No. of banks in local area

22	Economic system	Restorative	Post-event damage assessment: Is there a post-event damage system or mechanism in place? How does the community self-report economic infrastructure damages and economic loss? Is the community able to conduct a post-event damage assessment? how long does it take?
23	Economic system	Restorative	Post-event damage assessment: % change from base level after event (functionality loss)
24	Economic system	Restorative	Recovery time: At community level: Does a recovery plan exist? How many hazard types does it cover? Time needed to recovery? How many days till recovery of the economic system to pre-event level?
25	Economic system	Restorative	Economics of restoration; Costs of restoration: The amount used to restore operations or business activity
26	Economic system	Restorative	Economics of restoration: Costs of restoration: Hazardous materials storage and cleanup cost
27	Economic system	Restorative	Economics of restoration: Loss of income during restoration
28	Economic system	Restorative	Economics of restoration: Maintenance costs after hazard (clean up costs)
29	Economic system	Restorative	Economics of restoration: Reputation costs
30	Economic system	Restorative	Economics of restoration: Insurance costs: Access to insurance; Type of insurance owned
31	Economic system	Restorative	Economics of restoration: Impact/consequences of reducing availability: Relocation of economic activities within the area? Outside of the area?
32	Economic system	Restorative	Economics of adaptation: Adaptation plan exists? Up to date? Revised?
33	Economic system	Restorative	Economics of adaptation: Changes in building codes OR New investments/facilities are built according to higher standards/codes
34	Economic system	Restorative	Economics of adaptation: Decisions to adopt adaptation based on market forces; Reputation is increased due to implementing adaption options
35	Economic system	Restorative	Economics of adaptation: % Businesses adopting new adaption options and costs of those options

Table SIS 4: List of indicators and measures for Environmental Resilience

No.	Sub-dimensions	Capacity	Indicator/Measure
1	Environmental System	Anticipatory	Awareness: Ecosystem monitoring and protection: System for monitoring ecosystem in place?
2	Environmental System	Anticipatory	Awareness: Ecosystem monitoring and protection: Laws/regulations for protection of natural resources/biodiversity
3	Environmental System	Anticipatory	Quality/extent of mitigating features: Water supply; Number and Types of Water supply sources; supply source (eg. Wells, pipes) protected from hazards?
4	Environmental System	Anticipatory	Quality/extent of mitigating features: Quality of rangeland/land management; No. of functional Natural Resource Management/Rangeland committees
5	Environmental System	Anticipatory	Communication Systems/information sharing: Water conservation programs, boil water advisories, bottled water initiatives implemented
6	Environmental System	Anticipatory	Communication Systems/information sharing: Other conservation programs, environmental advisories, initiatives implemented
7	Environmental System	Anticipatory	Learnability/training; Environmental agencies training/awareness activities, programs in local area
8	Environmental System	Absorptive	System Failure: Cost of damaged environmental assets (including natural resources)
9	Environmental System	Absorptive	System Failure: Time that Water supply is not able to serve its intended function
10	Environmental System	Absorptive	System Failure: Water supply functionality threshold e.g. % age of residential buildings without access to water
11	Environmental System	Absorptive	System Failure: Water supply functionality threshold e.g. % age of critical lifeline system buildings without access to water
12	Environmental System	Absorptive	System Failure: Natural resource use policy and management: Availability and accessibility of resources
13	Environmental System	Absorptive	System Failure: Natural resource use policy and management: Protection of wetlands and watersheds
14	Environmental System	Absorptive	System Failure: Natural resource use policy and management: Land use policy and management (from resource use perspective)
15	Environmental System	Absorptive	Severity of Failure: loss for certain hazard levels (thresholds for different hazards)
16	Environmental System	Absorptive	Resistance: Safety Design factors: Hazard mitigation strategies: Impact of wildlife conservation
17	Environmental System	Absorptive	Resistance: Safety Design factors: Hazard mitigation strategies: Impact of reforestation activities
18	Environmental System	Absorptive	Resistance: Safety Design factors: Hazard mitigation strategies: Impact of Green spaces initiatives

19	Environmental System	Absorptive	Resistance: Development/existence of alternative and secondary drinking water sources
20	Environmental System	Absorptive	Resistance: Maintenance: Expenditure on maintenance of natural resources
21	Environmental System	Absorptive	Resistance: Biodiversity index: Biodiversity count (flora/fauna)
22	Environmental System	Absorptive	Resistance: Biodiversity index: Species health (flora/fauna)
23	Environmental System	Absorptive	Resistance: Natural defenses: Acreage of natural buffers
24	Environmental System	Absorptive	Resistance: Natural defenses: Extant of natural tree cover
25	Environmental System	Restorative	Post-event damage assessment: Environmental/Ecological Impact assessment mechanism exists?
26	Environmental System	Restorative	Recovery time: Water: Reestablish safe drinking water supplies in 1 day
27	Environmental System	Restorative	Recovery time: Environmental recovery: Time to Clean up pre-event levels
28	Environmental System	Restorative	Economics of restoration: Cleanup/restoration costs
29	Environmental System	Restorative	Economics of restoration: Deforestation/erosion protection costs
30	Environmental System	Restorative	Economics of restoration: Adaptation planning and implementation costs

Table SIS 5: List of indicators and measures for Social Resilience

No.	**Sub-dimension**	**Capacity**	**Indicator/Measures**
1	Social beliefs/culture/faith	Anticipatory	Social beliefs/culture/faith: Local cultural beliefs/norms that contribute to resilience: Cultural and historical preservation of DRR methods
2	Social beliefs/culture/faith	Anticipatory	Social beliefs/culture/faith: Local cultural beliefs/norms that contribute to resilience: Existing cultural and behavioral norms for DRR
3	Social beliefs/culture/faith	Anticipatory	Social beliefs/culture/faith: Local religious beliefs/norms that contribute to resilience: Current religious practice and world view on DRR
4	Social beliefs/culture/faith	Anticipatory	Social beliefs/culture/faith: Local religious beliefs/norms that contribute to resilience: Faith based engagement activities for DRR
5	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Community engagement: Community engagement strategy
6	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Community engagement: Political participation
7	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Collective decision-making process
8	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Community competence: Information and communication pre, during and post disaster
9	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Community competence: Knowledge of local risk or perceptions
10	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Community competence: Past experience with disaster recovery/learning from the past
11	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Community engagement: Involvement in public affairs
12	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Community goals: Community perception/awareness of goals, priorities
13	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Community processes: Collaboration frameworks
14	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Community processes: Collaborative problem solving and decision making
15	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Community processes: Planning (community plans)
16	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Frequency of strategy, goal and priorities setting
17	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Social Media use: % of people using Tweets, facebook, whatsapp and other Apps

18	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Social Media use: No. of messages generated from area in last incident
19	Social mechanism/competence/values	Anticipatory	Social mechanism/competence/values: Speed with which messages travel through official and unofficial channels
20	Training and exercises	Anticipatory	Training and exercises: No, of people trained for DRR, first aid, No. training programs initiated in the local area
21	Training and exercises	Anticipatory	Training and exercises: No. of Drills or Exercises conducted in past year, if any:
22	Social equity and diversity	Absorptive	Social equity and diversity: Community inclusiveness and equality: Ethnic equality and involvement in diverse groups
23	Social equity and diversity	Absorptive	Social equity and diversity: Community inclusiveness and equality: Gender norms and equality
24	Social equity and diversity	Absorptive	Social equity and diversity: Community inclusiveness and equality: Involvement and equality for people with special needs
25	Social equity and diversity	Absorptive	Social equity and diversity: Fair access to basic needs and services for all: Access to education for all ethnic groups
26	Social equity and diversity	Absorptive	Social equity and diversity: Fair access to basic needs and services for all: Access to health and well-being for all ethnic groups
27	Social equity and diversity	Absorptive	Social equity and diversity: Fair access to basic needs and services for all: Access to resources (livelihood) for all ethnic groups
28	Social mechanism/competence/values	Absorptive	Social mechanism/competence/values: Community shared values and attitudes: Place of attachment and sense of community/pride (community connectedness)
29	Social mechanism/competence/values	Absorptive	Social mechanism/competence/values: Community shared values and attitudes: Shared beliefs and values
30	Social mechanism/competence/values	Absorptive	Social mechanism/competence/values: Community shared values and attitudes: Traditional coping mechanisms
31	Social structure	Absorptive	Social structure: Household structure: Education level/attainment
32	Social structure	Absorptive	Social structure: Household structure: Health Status
33	Social structure	Absorptive	Social structure: Household structure: Socioeconomic Status
34	Social structure	Absorptive	Social structure: Mobility of people and families: Access to transport
35	Social structure	Absorptive	Social structure: Mobility of people and families: Land and home ownership
36	Social structure	Absorptive	Social structure: Mobility of people and families: Street connectivity

37	Social structure	Absorptive	Social structure: Social demographics: Population density and growth
38	Social structure	Absorptive	Social structure: Social demographics: Population profile
39	Social structure	Absorptive	Social structure: Social demographics: Population with specific needs
40	Social capital	Restorative	Social capital: Social cohesion: Community led leadership: No. of people from local area in leadership positions/decision making; No. of local ethnic/religious/social groups represented in decision making
41	Social capital	Restorative	Social capital: Social cohesion: Connection between groups/societal systems
42	Social capital	Restorative	Social capital: Social cohesion: Social trust: % of people trusting the local government/authority in risk communication/messaging
43	Social capital	Restorative	Social capital: Social networks: Connectedness: Network analysis to map social connectedness
44	Social capital	Restorative	Social capital: Social networks: Connectedness: No. and type of organizations in which people are engaged
45	Social capital	Restorative	Social capital: Social networks: Effective civic organization
46	Social capital	Restorative	Social capital: Social networks: Social support system/mechanism
47	Social capital	Restorative	Social capital: Social networks: Volunteerism: No. of people who participate on neighborhood teams (e.g. community Emergency Response Teams etc..)
48	Social capital	Restorative	Social capital: Social networks: Volunteerism: No. of volunteer hours per capita
49	Social capital	Restorative	Social capital: Social support: Number of External support systems
50	Social capital	Restorative	Social capital: Social support: Number of Shared assets and collective experiences
51	Social capital	Restorative	Social capital: Social support: Social support system/mechanisms available to community
52	Social capital	Restorative	Social equity and diversity: Diverse Skill Set (Diverse workforce): Access to diverse skills/workforce
53	Social capital	Restorative	Social equity and diversity: Diverse Skill Set (Diverse workforce): Diversity of skills and trained personnel
54	Social mechanism/competence/values	Restorative	Time taken to recover social functionality of social system
55	Social mechanism/competence/values	Restorative	Time that Social unit is not able to serve its intended function: In current (ongoing) disaster (estimated)
56	Social mechanism/competence/values	Restorative	Time that Social unit is not able to serve its intended function: In last disaster

Table SIS 6: List of indicators and measures for Governance Resilience

No.	Sub-dimension	Capacity	indicators/measures
1	Governance	Anticipatory	Awareness of potential hazards: Local hazards, vulnerabilities and risks. Have these been fully investigated in the context of the plan and are plans based on local scenarios of what is likely to happen, and such of its consequences that can be envisaged?
2	Governance	Anticipatory	Awareness of potential hazards: Government organizations/agencies aware of climate hazards/climate change
3	Governance	Anticipatory	Quality/extent of mitigating features: Comprehensive, all-hazards planning. Is the emergency plan capable of dealing with all the hazards that are important in the local area and can it be adapted to unlikely or as yet unknown hazards?
4	Governance	Anticipatory	Quality/extent of mitigating features: Integration of plans. Is the emergency plan compatible and integrated with plans held by other levels of government and critical facilities (hospitals, industry, infrastructure, etc.)?
5	Governance	Anticipatory	Quality/extent of mitigating features: Connections to monitoring services. Is the civil protection service adequately connected to scientific monitoring services that provide timely information on hazardous phenomena (meteorological, hydrological, oceanographic, seismic, volcanic, etc.)?
6	Governance	Anticipatory	Quality/extent of mitigating features: Evacuation plans. Is evacuation adequately dealt with in the emergency plan and are potential evacuees aware of the need to evacuate and the procedures involved?
7	Governance	Anticipatory	Quality/extent of mitigating features: Emergency plans. Are they written, current and fully in place?
8	Governance	Anticipatory	Quality/extent of mitigating features: Links to critical facilities. Is emergency planning and management encouraged and supported in critical facilities such as local hospitals, airports, hazardous industries, infrastructure companies, etc.?
9	Governance	Anticipatory	Quality/extent of mitigating features: Integration with emergency plans. Have the procedures for safeguarding and maintaining the operation of critical facilities been fully integrated into emergency plans?
10	Governance	Anticipatory	Quality/extent of mitigating features: Specialised functions. Do plans and procedures adequately take account of specialized functions
11	Governance	Anticipatory	Quality/extent of mitigating features: Business continuity management (BCM). Have plans been formulated and implemented to ensure that there is continuity of essential services when disaster strikes?
12	Governance	Anticipatory	Communication Systems/information sharing: Dissemination, testing and updates. Is the plan known to its participants, has it been tested by table top or field exercises and is it regularly updated?
13	Governance	Anticipatory	Communication Systems/information sharing: Is it capable of displaying, interpreting, using and acting upon predictive information?

14	Governance	Anticipatory	Communication Systems/information sharing: Ability to warn citizens in advance of impending hazard impacts. Is a system for this in place and does it reach all those citizens who need to be informed?
15	Governance	Anticipatory	Communication Systems/information sharing: Ability to communicate between services (interoperability). One of the leading reasons why emergency responses are poor is inability to create and maintain robust, effective communications between different services that are working on the same disaster.
16	Governance	Anticipatory	Communication Systems/information sharing: Protocols and standardization procedures.
17	Governance	Anticipatory	Communication Systems/information sharing: Redundancy and robustness of equipment and methods.
18	Governance	Anticipatory	Communication Systems/information sharing: Power and reach of communications. Can all services, units and key workers who will need to be contacted during an emergency be reached with existing communications methods? Does the communications equipment have full geographical coverage and, if appropriate, will it extend adequately into underground tunnels or high buildings?
19	Governance	Anticipatory	Communication Systems/information sharing: BCM links. Have business continuity links been set up with local companies? In
20	Governance	Anticipatory	Communication Systems/information sharing: Mass media links. Does the civil protection service have a spokesperson and are there adequate links with local (and perhaps regional and national) mass media?
21	Governance	Anticipatory	Learnability/training: Culture of training, safety and professionalism. Is enough weight given to education and training in order to fashion a culture of professionalism?
22	Governance	Anticipatory	Learnability/training: Academic impetus. Does the civil protection system have good links with academic institutions in terms of research, education and training?
23	Governance	Anticipatory	Learnability/training: Common or national training programme. Is there a national curriculum or programme for training emergency planners, managers and responders? Is there a standard or set of guidelines?
24	Governance	Anticipatory	Learnability/training: Consensus on what to teach. In developing, promoting or supporting courses, is there an adequate consensus on what to include in the curriculum?
25	Governance	Anticipatory	Learnability/training: Professional associations. Are civil protection staff enrolled in, or encouraged to join, appropriate national or international professional associations?
26	Governance	Anticipatory	Learnability/training: Professional emergency managers. Are local personnel in the emergency planning and management field trained to an adequate professional standard?
27	Governance	Absorptive	System Failure: Response System: Leadership. Is there clarity about who is in charge in the case of emergencies of different kinds and sizes?
28	Governance	Absorptive	System Failure: Response System: Emergency operations centre. Is the EOC functioning (or are there multiple EOCs?)
29	Governance	Absorptive	System Failure: Response System: Ability to command and control operations on site.

30	Governance	Absorptive	System Failure: Response System: 24 operation. Is the service available when needed regardless of the time of day and day of the week?
31	Governance	Absorptive	Severity of Failure: No. of services not functional/for how long?
32	Governance	Absorptive	Resistance: Response System: Degree of articulation of the system. Is the system developed in such a way as to fulfil the needs of the population and respond well to different kinds of emergency?
33	Governance	Absorptive	Resistance: Response System: Local emergency resources. Are these fully known, available, understood and utilized appropriately?
34	Governance	Absorptive	Resistance: Evacuation routes and shelters. Have routes and shelters been designated, and where necessary signposted? Have the shelters been supplied with appropriate resources or have arrangements been put in place to supply them when they need to be activated?
35	Governance	Absorptive	Resistance: Response System: Incident command system (ICS) or alternative command and control protocol.
36	Governance	Absorptive	Resistance: Response System: Provisions and procedures. Critical facility protection procedures fully developed for emergency operations centres, decision-making centres (if these are separate), hospitals and clinics, vital administrative services, infrastructure, rest centres and sources of assistance to the population
37	Governance	Absorptive	Resistance: Volunteer organizations. Are volunteer services of relevance to civil protection fully integrated into official structures?
38	Governance	Absorptive	Resistance: Resources (structures, equipment, competencies and manpower)
39	Governance	Absorptive	Resistance: Support: Political and institutional support; Administrative support.
40	Governance	Absorptive	Resistance: Support: Culture and attitudes
41	Governance	Restorative	Post-event damage assessment: Recovery plans and procedures: Rapid damage assessment teams
42	Governance	Restorative	Post-event damage assessment: Recovery plans and procedures: Surge planning for delivery of stockpiles
43	Governance	Restorative	Recovery time: Time required for resumption of normal services
44	Governance	Restorative	Recovery time: Response to emergencies
45	Governance	Restorative	Economics of restoration: Accountability
46	Governance	Restorative	Economics of restoration: Cost of restoration of services
47	Governance	Restorative	Economics of restoration: Cost of adaptation plans

Appendix B: Participant Information/Consent Sheet and Questionnaires

B.1 Participant Information Sheet

B.2 CLD Interview Questionnaire

B.3 Q-Sort Interview Questionnaire

B.4 Validation Workshop Questionnaire

B.1 Participant Information Sheet and Consent Form

STUDY TITLE: Community-Level Measures for Social Resilience

INTRODUCTION

We invite you to participate in a research study by Mr. Hisham Tariq on developing a stakeholder-defined index of community resilience indicators. This research will give us knowledge that would benefit the research work at the University of Salford, UK and the University of Peshawar, Pakistan.

First, we want you to know that participating in the research is voluntary. You may choose not to take part, or you may withdraw from the study at any time. Before you decide to participate, please take as much time as you need to ask any questions and discuss this study with the researcher or anyone contacting you on his behalf. Thank you.

THE RESEARCH STUDY

1. Research Protocol

You will participate in an interview as part of a research study to explore aspects of community resilience concerning Social Resilience. You will be asked questions about your background and about selecting indicators that can best measure Social Resilience. This interview should take approximately 30 to 45 minutes of your time.

2. Risks/ Discomforts

Since we will keep your responses confidential, we perceive little to no foreseeable risks to participating in this Study. However, your participation is entirely voluntary. You may skip over any questions for any reason, and you may stop at any time. Your responses will be confidential, and your name will not appear in our final products. Any data used is constructed to preclude identifying participants.

3. General or Participant Benefits

Participants are generally not paid for participating in these research studies.

4. Problems or Questions

If you have any problems or questions about your rights as a research participant or about any research-related concern, please contact:

Local Partner in Pakistan: Dr Mushtaq Ahmad Jan, Assistant Professor, Centre of Disaster Preparedness and Management, University of Peshawar, Pakistan Tele.: +92-346 939 7774 Email: mushtaq@uop.edu.pk	Supervisor of the Researcher in the UK: Prof. Terrence Fernando Director, THINKLab 7th Floor, Maxwell Building, University of Salford, Manchester M5 4WT, UK T: +44(0) 0161 295 2914 Email: t.fernando@salford.ac.uk
Participant's Consent I have read the explanation about this research study and have been allowed to discuss it and ask questions. I hereby consent to take part in this study. Signature of Participant Date	

B.2 Interviews and Focus Group Discussion Guide for Developing CLDs

Focus Group Discussion Schedule

FGD Sheet 1 Hazard Risk Matrix

In the Hazard Risk Matrix exercise, the participants are asked to list the number of hazards the community faces locally and rank them according to the likelihood of occurrence and the magnitude of impact on the people, livelihoods, physical infrastructure, and residential houses.

	Variable Scores (Low=1, Medium=2 and High=3)					
Natural Hazard (List)	A: Likelihood of Event	B: Impact on population	C. Impact on livelihood	D Impact on Physical Infrastructure	E: Impact on homes	Total Risk Score = A(B+C+D+E)
X						
Y						
.						
.						
.						
Z						

FGD Sheet 2 Analysis of hazards and stresses

What to ask about hazards and stresses?

• What is the typical frequency and duration of this hazard or stress occurrence? Is it seasonal? Has it changed over time, for example, due to climate change or other trends?
• What is the speed of onset of the hazard or stress? Are there any warning signs? Are there established early warning systems?
• Are there any underlying causes of the hazard or stress? Does the community understand them, or know how to address them?
• Which groups within the community (livelihood groups, social groups, geographical groups, people with disability, etc) are most affected and how?
• Which community or individual assets, property, or services are affected (for example infrastructure, services, markets, crops, savings, land) and how?
• How do different groups typically respond immediately after the hazard occurs (are there contingency plans, safe areas, emergency resources, response organizations, etc)?
• Based on the issues raised, what opportunities and capacities are available, or could be strengthened to improve peoples' disaster preparedness?

Hazard Priority 1:	Issues and vulnerabilities	Capacities and opportunities for resilience
Frequency, Duration, Seasonality, Trends		
Warning signs, Early Warning		
Groups affected		
Assets and services effected		
Immediate response		

Interview Guide for Developing Causal Loop Diagrams		
Specific dimensions/topics	Questions	Suggested probes
Introduction/background	1. Please indicate what are your designations /departments that you belong to and describe the nature of your role in the organisation as well as your main responsibilities and duties. 2. How long have you worked in this organisation? How long have you worked in Disaster Management (DM)? 3. Did you work in DM during the recent disaster period? Where exactly and for how long?	Ask about living in the community for community members.
Resilience Problems and Issues	4. Can you confirm that the [Selected Hazard] is the main resilience issue facing [Community name]?	- Hazards Identified in Area: 1) Flooding 2) Earthquake 3) Storms 4) Epidemics 5) Other Write the Main Hazard Identified on Post-it and place it in the centre of the Chart.
Direct Causes	5. What are the main direct causes of the [Selected Hazard]? What are the main indirect causes of the [Selected Hazard]?	Write the causes Identified on post-it notes and place them on the Chart to the left of the Main Hazard Identified. List as many direct and indirect causes as the respondent provides – do not prompt. Use several columns to indicate 1st Order, 2nd Order and 3rd Order causes if needed.

		Include link polarities between identified causes in the diagram.
Direct Causes	6. What are the main direct consequences of the [Selected Hazard]? What are the main indirect consequences of the [Selected Hazard]?	Write the consequences Identified on post-it notes and place them on the Chart to the right of the Main Hazard Identified. List as many direct and indirect consequences as the respondent provides – do not prompt. Use several columns to indicate 1st Order, 2nd Order and 3rd Order consequences if needed. Include link polarities between identified consequences in the diagram.
Feedback Processes	7. What are the primary feedback processes in the diagram?	Explore and probe for links between the Consequences and Causes for any feedback processes.
Policies (Short Term)	8. What short-term policies can be adopted to solve this resilience problem?	
Policies (Long Term)	9. What long-term policies can be adopted to solve this resilience problem?	
Hurdles	10. What are the main hurdles to the success of these policies?	

Interview Guide for Q-Sort Exercise

Focus Group Discussion Guide for Social Resilience Expert Panel		
Specific dimensions/topics	Questions	Suggested probes
Introduction/background	1. Please indicate what are your designations /departments that you belong to and describe the nature of your role in the organisation as well as your main responsibilities and duties. 2. How long have you worked in this organisation? How long have you worked in Disaster Management (DM)? 3. Did you work in DM during the recent disaster period? Where exactly and for how long?	Ask about living in the community for community members.
Place Cards of Indicators (with explanations and example measures) on the table along with Q-Sort Table Chart		
Social resilience Indicators	4. Please arrange the indicators below according to their importance for inclusion in assessing a community's social resilience.	Observe the placement of Cards on the Q-Sort Table Chart.

The Three Most Important Indicators	5. Please explain why you chose these three Indicators as the most important.	Ask about each in turn and note the reasoning behind the selection.
The Three Least Important Indicators	6. Please explain why you chose these three Indicators as the least important.	Ask about each in turn and note the reasoning behind the selection.

Artefact Validation Workshop Guide

Focus Group Discussion Guide for Validation Workshop		
Specific dimensions/topics	Questions	Suggested probes
Section 1: Respondent Background		
Introduction/background	1. Please indicate what are your designations /departments that you belong to and describe the nature of your role in the organisation as well as your main responsibilities and duties.	
	2. How long have you worked in this organisation? How long have you worked in Disaster Management (DM)?	Ask about living in the community for community members.
	3. Did you work in DM during the recent disaster period? Where exactly and for how long?	
Section 2: Using Community Resilience Frameworks		
	4. Have you or your department/community used a resilience framework, tool, model, or scorecard for measuring resilience?	a) Yes, many times b) Yes, once c) No d) I don't know/not sure If used? Name of other tool(s) used:___________
	5. To your knowledge, how often are the CDR frameworks used before designing DRR interventions in Pakistan?	a) Never b) Rarely c) Frequently d) Always
	6. If yes to Q1, then When do you or your organisation utilise CDR frameworks or similar tools?	a) In planning stages. b) Before starting the project. c) During the work happening on site (as-is improvement analysis)

		d) Post-work analysis (use lessons learnt for future projects)
Section 3: Effectiveness of Participatory Approach to Modelling Community Resilience		
	7. Community Resilience can be effectively measured in other ways; participatory resilience modelling is not required. Do you agree with the statement?	a) Agree b) Highly agree c) Disagree d) Highly disagree
	8. Participatory resilience models produce realistic scenarios and can be applied to real-life situations and projects for process improvement.	a) Yes b) Yes, but after approval by experts. c) No d) It depends
	9. What are the strengths of the Participatory approach?	a) Data collection techniques b) As-is situation capturing c) Graphical work d) Analysis performed e) Other: ______
	10. How accurate is the CDR model?	a) Accurate b) Accurate, need minor changes c) Inaccurate d) Need major changes e) Other (please elaborate)
	11. Are the what-if scenarios practical?	a) Yes b) Yes, but after minor changes c) Yes, but after studying the process is more detail d) No e) Other (please elaborate)

Section 3: Continued

		Rating				
No.		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

11.	More participatory tools are needed for measuring resilience at the community level.					
12.	Other tools can model community resilience, and participatory modelling is not required.					
13	Participatory Modelling can help decision-makers make informed decisions and evaluate potential alternatives.					
14.	Participatory Modelling can help community members make informed decisions and evaluate potential alternatives.					

Section 4: Use of the Participatory Approach in the Case Study

		Rating				
No.	Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
15.	Has the use of participatory tools like CLDs been utilised properly in this Case Study					
16.	Has the use of participatory tools like Q methods been utilised properly in this Case Study					
17.	Has the use of modelling tools like System Dynamic Modelling been utilised properly in this Case Study					
18.	Has the data been collected in an appropriate way to					

	understand the resilience issues					
19.	Data analysis was performed Professionally.					
20.	Assumptions made during the creation of the SD model are practical, and they will not affect the working of the model in real-life scenarios.					
21.	Some other tools could have been used to measure resilience similarly.					
22.	The simulation model requires further changes before replicating it in real-life scenarios.					

Section 5: Suggestions

23. How do you think this model can further be improved? Please discuss.

Appendix C: Additional Q-Sort Analysis

Communities increasingly need tools that can help them assess the environmental risks they face to understand better their own capacities in mitigation, preparedness, response, and recovery to hazard events and shocks. Community Resilience is a key policy objective of local authorities, but unfortunately, it is challenging to know what Community Resilience means and how it can be measured. Most of the research in CDR focuses on tools that are top-down in nature and are not customisable to user requirements. As mentioned, this research proposes a more inclusive and novel technique to achieve consensus among diverse stakeholders on definitions, objectives, and indicators for measuring CDR. This study uses Q-methods to contextualise a resilience index for CDR. The Community Capacity Index (CCI) can be useful for local governments and communities to measure their own resilience on their own terms. The CCI can be used as a boundary object for discussion and consensus building, ensuring that the resilience issues raised correspond to the metrics used for assessment. This ensures that the indicators used are important and relevant to meet their requirements.

The concept of CDR, how it is defined and measured, can be used as a boundary concept among academics, practitioners and disaster management professionals from diverse fields (i.e., social, economic, health, technological and ecological backgrounds) to encourage discussion among different stakeholders working towards similar goals but from different perspectives (Huggins et al., 2015). Multiple definitions of resilience have been proposed and debated in each discipline, with many different approaches to defining and measuring it (Endress, 2015). Accordingly, planning for community resilience is complex. It requires an inter-disciplinary approach that captures the different dimensions of resilience, such as the community's physical, economic and social resilience (Tariq et al., 2021c).

Boundary objects in the context of measuring community resilience are tools, concepts, or artefacts that communicate and collaborate among different groups or stakeholders involved in assessing and enhancing community resilience (Baggio et al., 2015). They are especially useful when multiple disciplines, organisations, or community members come together to understand and improve resilience (Keating and Hanger-Kopp, 2020). Boundary objects help bridge gaps in knowledge, language, and perspectives, facilitating effective communication and cooperation (Bixler et al., 2021). In this research, the Community Capacity Index is used as a boundary object to provide a common structure for assessing and measuring resilience from the perspective of stakeholder groups (academics, practitioners, and community members) in our BNB case study area. Different stakeholders can use these tools to evaluate resilience from various angles, such as social, economic, environmental, and infrastructure resilience (Tariq et al., 2021a). Boundary objects have been identified as useful in resilience research when encouraging collaboration and cooperation across disciplinary siloes (Marchal et al., 2023).

Due to the diversity of stakeholders involved in resilience assessment, there are often differing views on what consists of resilience at the community level and what dimensions can be included within it (Jones and Tanner, 2017). Hence, significant debate exists between academics, practitioners, and other community stakeholders on how community disaster resilience and its dimensions are conceptualised, defined, and evaluated, especially for decision-making at different levels (Clare et al., 2017). Resilience assessment frameworks and tools need to capture some of this debate by allowing for greater customisation by using a more subjective approach to understanding the nature and objectives of the different resilience dimensions. Therefore, developing context-specific CDR assessment tools can add value and benefit to those involved in creating resilient communities.

The Q methods approach to ranking and selecting indicators for resilience assessment used in this research has been applied in two studies published on Physical Infrastructure (PI) Resilience and Environmental Resilience (ER), respectively. In the first study, Tariq et al. 2021 conducted several Q methods workshops on PI Resilience with 84 participants drawn from practitioners, academics and experts working on different aspects of resilience. The initial set of 317 measures was reduced to 128 and divided into three community capacities: Anticipatory, Absorptive and Restorative. The Physical Infrastructure Capacity Index (PI-CI) was then finalised to encompass 38 indicators that were ranked in order of importance by the participants. In the second study, Tariq et al. 2022 conducted ten interviews among academics and practitioners working on the urban resilience of Kuching City in Sarawak, Malaysia to determine the best way to measure ER. An initial set of 57 measures from the review was reduced to 25. In both studies, the PI-CI and the Environmental Resilience Capacity Index (ER-CI) were used as boundary objects for discussion and consensus building, ensuring that the metrics used in the assessment are important and relevant to meet their requirements. The PI-CI and ER-CI can be useful to local governments and communities to measure their resilience and potentially help intervention design.

This research uses a similar approach and methodology to capture the various opinions and perspectives of community members, practitioners and academics working on CDR at the local levels in the BNB case study area in Pakistan. As in Tariq et al. (2021a) and (2022), this study also uses the Library of Indicators developed in Chapter 2 (and published in Tariq et al. (2021c). In this research, Q sort ranking for each dimension is done to form a community-level capacity assessment tool that can help measure community resilience at the local. The Community Capacity Index (CCI) is proposed as a tool for understanding some of the debate and achieving consensus between diverse groups working on the same resilience issues or problems by finding the common (and diverging) patterns of indicator selection. This section looks at some of the Q-Sort results that were left out of the analysis in Chapter 5 due to length of the overall manuscript.

Qualitative Assessment of Ranks by Group and Additional Statistical Analysis

Measuring Social Resilience

33 respondents participated in the Social Resilience Q sort interviews and were asked to rank 16 Social Resilience indicator statements in order of importance from most important to the least. Each participant ranked the 16 indicators statements by themselves individually and were only assisted in the process by the researcher when requiring clarifications regarding the meaning and content of the indicator statement on the Q sort cards placed before them. *Table 0-1* below shows the average Q sort ranking by each stakeholder group and the combined average ranking overall.

Table 0-1. Social Resilience Indicator Statements ranked by importance to the participating stakeholder groups.

No.	Indicator Statement	Acad. Ranking	Community Ranking	Prac. Ranking	Overall
1.	Social Demography	7	13	6	10
	Local Leadership in Decision Making (DM)	1	2	5	2
3.	Household Structure	12	11	13	14
	Mobility of People and Families	11	10	9	13
5.	External support systems	4	9	9	7

	Effective Civic Organizations	7	3	10	6
7.	Community Participation in Disaster Risk Reduction	2	1	1	1
	Community goals/priorities	9	4	2	4
9.	Community Shared Values and Attitudes	5	12	7	9
	Community-Based DRR Plans	6	5	4	4
11.	Communications (social media)	5	2	3	3
	Fair Access to Basic Needs	7	7	4	5
13.	Community Inclusiveness	8	8	8	8
	Diverse Skill Set (Workforce)	3	6	12	6
15.	Religious Beliefs & Norms	9	10	8	11
	Local Culture and Norms	10	10	11	12
Note when number repeats - it is because the total score was the same.					

The average rankings from the Q sorts indicate the relative importance of measuring Community Participation, Local Leadership in Decision Making and Communication (media use) for all the groups combined. Meanwhile, Household Structure and composition, mobility of people, and local cultural norms were considered as least important to understand the social resilience capacity of the BNB area. Among the Academics group, preference for Local Leadership in Decision Making was emphasised as the most important indicator to measure while Household structure was the least important. A large majority (n=9) of the Academics mentioned the role of political participation and electing local representatives from the affected areas as a critical component of influencing the allocation of expenditures for preparedness and mitigation measures, like flood walls, retention ponds and waterway clearance. It was noted in the interviews that several political parties are active in the Sardar Ghari area, including the regional headquarters of a main political party, as well as having a former elected representative from the area in the previous provincial parliament (2017-2023).

For the Community Members, Community Participation in Disaster Risk Reduction was ranked as the most important indicator as a majority (n=7) indicated the importance of involvement of the community in decision making and awareness of preparedness, mitigation and other activities were crucial for social resilience. On the other hand, social demography was considered as the least important from their point of view with several (n=4) stating that population profile does not necessarily translate into more resilient communities as indicated by the relatively higher education and employment levels in the Sardar Garhi area while still being one of the most vulnerable and high-risk areas for flooding in the BNB area. Finally, the Practitioner group also ranked Community Participation as the most crucial indicator for determining social resilience while determining that Household Structure and composition was the least important of all the indicator statements. It was surprising to the researcher on why Household Structure and Social Demography ranked relatively low in the rankings, despite being included in several of the CDR frameworks reviewed in the literature in Chapter 2. This low ranking could be because of the relative importance to the participants of the other indicators, or the context of the densely populated Sardar Ghari area.

In addition to the rankings shown in *Table 0-1* above, statistical analysis of the Q sorts was conducted to provide deeper insight to the viewpoints of the participants. *Table 0-2* below shows the Pearson Correlation Coefficient in matrix form between the Q sorts of the participants. In the matrix, a high number indicating agreement or similarity and a low number or negative indicating disagreement or dissimilarity in the in the Q sorts. A 100 indicates a perfect match and is only possible for the same Q sort, as indicated by the green values along the diagonal of the matrix where the participant is correlated with themselves. The red cells indicate negative values and show a marked difference between the participants rankings. In the next step, the Correlation Matrix is subjected to factor analysis to find the highly correlated groupings in the data which form clusters of perspective or opinion that generate consensus and disagreement on how to measure Social Resilience.

Table 0-2. Correlation between Social Resilience Q sorts.

Participant	SRPAKA1	SRPAKA3	SRPAKA4	SRPAKA5	SRPAKA6	SRPAKA7	SRPAKA8	SRPAKA9	SRPALA10	SRSLA1	SRSLA3	SRSLA4	SRPAKC1	SRPAKC2	SRPAKC3	SRPAKC4	SRPAKC5	SRPAKC6	SRPAKC7	SRPAKC8	SRPAKC9	SRPAKC10	SRPAKC11	SRPAKP1	SRSLP1	SRSLP2	SRSLP3	SRSLP4	SRPAKP5	SRPAKP6	SRPKPM1	SRPKPM4	SRPKPM10
SRPAKA1	100	45	63	-23	8	55	13	43	10	50	-23	13	55	60	28	45	63	-13	18	18	3	63	5	3	75	20	40	40	63	3	38	30	8
SRPAKA3	45	100	25	-33	50	15	28	10	55	-3	10	-20	25	45	-40	10	43	13	35	35	40	8	8	15	25	-25	13	33	25	5	-30	43	3
SRPAKA4	63	25	100	-23	18	63	20	38	-8	48	-38	50	60	65	50	50	60	28	48	-28	23	50	43	8	48	28	35	53	63	-10	15	33	-23
SRPAKA5	-23	-33	-23	100	-25	-3	20	40	3	23	48	18	30	-40	-3	5	0	28	-18	-15	-20	-5	-57	35	10	-10	-10	5	-35	28	33	30	23
SRPAKA6	8	50	18	-25	100	-10	43	0	45	-13	13	-13	-5	38	-30	-5	-10	-25	25	30	10	0	10	-3	5	-40	-10	15	-5	10	-10	5	43
SRPAKA7	55	15	63	-3	-10	100	18	53	3	75	-33	23	53	40	38	20	53	10	25	-15	8	20	35	15	25	23	35	48	43	-8	-8	43	10
SRPAKA8	13	28	20	20	43	18	100	-5	30	28	8	35	18	45	-20	20	20	15	13	-8	-10	20	-8	63	23	5	65	23	18	0	5	33	20
SRPAKA9	43	10	38	40	0	53	-5	100	0	38	15	23	63	18	18	8	38	25	-3	-3	13	28	-38	3	25	-33	-13	28	15	-8	10	33	30
SRPALA10	10	55	-8	3	45	3	30	0	100	-8	35	-53	13	3	-35	13	13	-10	8	57	-8	-10	-10	18	25	-45	-8	28	-23	20	-18	55	25
SRSLA1	50	-3	48	23	-13	75	28	38	-8	100	-28	13	28	38	48	50	55	-15	38	-23	-38	28	20	38	48	50	45	33	43	40	40	30	38
SRSLA3	-23	10	-38	48	13	-33	8	15	35	-28	100	-25	5	-43	-35	-8	-23	25	-13	5	-10	13	-57	18	0	-30	-25	15	-43	0	5	35	15
SRSLA4	13	-20	50	18	-13	23	35	23	-53	13	-25	100	48	35	30	23	20	55	8	-50	30	30	8	18	3	18	40	23	35	-28	5	10	-43
SRPAKC1	55	25	60	30	-5	53	18	63	13	28	5	48	100	20	8	35	38	40	-10	-23	30	25	-8	-8	35	-20	10	33	15	-15	10	55	-28
SRPAKC2	60	45	65	-40	38	40	45	18	3	38	-43	35	20	100	28	35	70	3	50	-3	23	53	18	40	33	23	65	33	85	13	18	25	5
SRPAKC3	28	-40	50	-3	-30	38	-20	18	-35	48	-35	30	8	28	100	45	48	13	48	-20	-3	35	38	18	30	50	33	38	57	15	45	0	0
SRPAKC4	45	10	50	5	-5	20	20	8	13	50	-8	23	35	35	45	100	48	8	40	-20	-35	38	20	23	60	28	38	33	35	40	43	40	-10
SRPAKC5	63	43	60	0	-10	53	20	38	13	55	-23	20	38	70	48	48	100	33	63	3	25	50	5	60	53	35	57	55	83	30	28	55	-3
SRPAKC6	-13	13	28	28	-25	10	15	25	-10	-15	25	55	40	3	13	8	33	100	23	-35	55	10	-5	38	-10	-5	20	38	18	-38	-30	38	-50
SRPAKC7	18	35	48	-18	25	25	13	-3	8	38	-13	8	-10	50	48	40	63	23	100	5	18	25	45	50	28	43	28	68	55	45	5	38	5
SRPAKC8	18	35	-28	-15	30	-15	-8	-3	57	-23	5	-50	-23	-3	-20	-20	3	-35	5	100	-5	0	-15	-3	33	-30	-25	28	-13	15	-13	10	35
SRPAKC9	3	40	23	-20	10	8	-10	13	-8	-38	-10	30	30	23	-3	-35	25	55	18	-5	100	-15	18	-5	-35	-25	0	15	28	-30	-38	10	-40
SRPAKC10	63	8	50	-5	0	20	20	28	-10	28	13	30	25	53	35	38	50	10	25	0	-15	100	-28	35	68	45	45	50	63	-3	53	33	-8
SRPAKC11	5	8	43	-57	10	35	-8	-38	-10	20	-57	8	-8	18	38	20	5	-5	45	-15	18	-28	100	-23	-10	30	13	20	20	-5	-30	-13	-23
SRPAKP1	3	15	8	35	-3	15	63	3	18	38	18	18	-8	40	18	23	60	38	50	-3	-5	35	-23	100	25	38	68	43	45	30	20	48	18
SRSLP1	75	25	48	10	5	25	23	25	25	48	0	3	35	33	30	60	53	-10	28	33	-35	68	-10	25	100	33	30	53	38	23	55	35	15
SRSLP2	20	-25	28	-10	-40	23	5	-33	-45	50	-30	18	-20	23	50	28	35	-5	43	-30	-25	45	30	38	33	100	53	25	53	23	43	0	-20
SRSLP3	40	13	35	-10	-10	35	65	-13	-8	45	-25	40	10	65	33	38	57	20	28	-25	0	45	13	68	30	53	100	23	73	-3	28	20	-5
SRSLP4	40	33	53	5	15	48	23	28	28	33	15	23	33	33	38	33	55	38	68	28	15	50	20	43	53	25	23	100	38	10	-3	70	-5
SRPAKP5	63	25	63	-35	-5	43	18	15	-23	43	-43	35	15	85	57	35	83	18	55	-13	28	63	20	45	38	53	73	38	100	8	33	18	-10
SRPAKP6	3	5	-10	28	10	-8	0	-8	20	40	0	-28	-15	13	15	40	30	-38	45	15	-30	-3	-5	30	23	23	-3	10	8	100	48	30	33
SRPKPM1	38	-30	15	33	-10	-8	5	10	-18	40	5	5	10	18	45	43	28	-30	5	-13	-38	53	-30	20	55	43	28	-3	33	48	100	-3	25
SRPKPM4	30	43	33	30	5	43	33	33	55	30	35	10	55	25	0	40	55	38	38	10	10	33	-13	48	35	0	20	70	18	30	-3	100	-15
SRPKPM10	8	3	-23	23	43	10	20	30	25	38	15	-43	-28	5	0	-10	-3	-50	5	35	-40	-8	-23	18	15	-20	-5	-5	-10	33	25	-15	100

In applying q-sorts for analysis, Watts and Stenner (2012) recommend conducting a centroid factor analysis (CFA) that can reveal the ideal q-sort, called factor array, for each factor found significant. To apply CFA, the researcher needs to select the total number of factors that are found to be statistically significant. Additionally, they also suggest a rule of thumb of having a least one factor for every 5 to 6 participants which in this case is 5 factors. In this study, Ken Q analysis allowed the data to be checked till seven factors as recommended by Brown and Rhoades (2019), beyond which it is computationally difficult to assess using the current limitations of the software. In this study, all seven centroid factors were initially found to be statistically significant using the first test - the Kaiser-Guttman criterion, i.e., Eigenvalues greater than 1 as shown in *Table 0-3* Unrotated Factor Matrix (Zabala and Pascual, 2016). To double check the significance, Watts and Stenner, (2014) recommend using Cattell's Scree Plot diagram alongside the Kaiser-Guttman criteria to confirm the number of factors where the line changes slope as shown in *Figure 0-1* below. The Plot Diagram indicates a slope change after the second factor indicating that only two factors are significant for inclusion in the analysis.

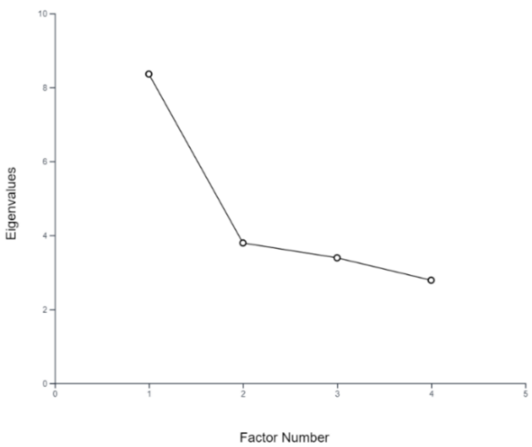

Figure 0-1. Scree Plot for Factors in Social Resilience.

Both the Kaiser-Guttman and Cattell's Scree Plot are used by Q methods researchers as simple rules of thumb for determining the number of factors used for the CFA analysis as these are generated automatically by the software for initial analysis. In case of discrepancy between them, Watts and Stenner (2012) recommend two additional tests for consideration: Brown's Factor Loadings test and Humphrey's rule. Both these tests are considered more thorough by Watts and Stenner (2012) and require additional calculations of the significant factor loading value and the standard error for the case study.

Table 0-3. Unrotated Factor Matrix.

Participant	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
SRPAKA1	0.67	0.3061	0.0585	-0.2161	-0.2791	-0.0298	-0.502
SRPAKA3	0.1887	0.3994	0.6622	-0.2026	0.2989	-0.0956	-0.1476
SRPAKA4	0.851	-0.0514	0.3042	-0.1268	-0.3381	0.0361	0.0434
SRPAKA5	-0.0052	0.3026	-0.2876	0.7624	-0.1167	0.2168	0.1691
SRPAKA6	-0.0331	0.3688	0.3929	-0.3679	0.0749	-0.1501	0.0583
SRPAKA7	0.6279	0.0429	0.2085	0.1124	-0.363	-0.3145	0.1466
SRPAKA8	0.2606	0.2868	0.0053	0.1863	0.2517	-0.4305	0.0281
SRPAKA9	0.2426	0.3589	0.1451	0.3493	-0.4654	0.1466	-0.1823
SRPALA10	-0.0752	0.7171	0.3625	-0.0741	0.1788	-0.0492	0.1372
SRSLA1	0.6356	0.2648	-0.306	0.0117	-0.3645	-0.3565	0.294
SRSLA3	-0.2823	0.4458	-0.0049	0.3224	0.2036	0.312	0.0602
SRSLA4	0.5107	-0.3799	0.058	0.4201	-0.0573	0.0771	-0.07
SRPAKC1	0.4659	0.1352	0.3679	0.4042	-0.4658	0.1905	-0.172
SRPAKC2	0.7453	0.0516	0.1646	-0.2314	0.183	-0.2737	-0.2453
SRPAKC3	0.5918	-0.2142	-0.3229	-0.1457	-0.2188	0.2275	0.1621
SRPAKC4	0.5956	0.1905	-0.199	-0.1053	-0.1371	0.1179	0.1403
SRPAKC5	0.8926	0.2171	0.0235	0.0111	0.1774	0.0488	-0.1294
SRPAKC6	0.3059	-0.1833	0.2779	0.6388	0.2647	0.3616	0.0285
SRPAKC7	0.5994	0.0573	0.0083	-0.3181	0.376	0.1487	0.4894
SRPAKC8	-0.2084	0.484	0.1664	-0.4257	0.1275	0.0522	-0.1193
SRPAKC9	0.1229	-0.28	0.7064	0.1118	0.1859	0.1836	-0.1967
SRPAKC10	0.607	0.1824	-0.1969	-0.0525	0.0475	0.168	-0.3317
SRPAKC11	0.2336	-0.4155	0.232	-0.4572	-0.0851	-0.1481	0.5178
SRPAKP1	0.4455	0.2617	-0.1839	0.2522	0.6349	-0.057	0.1753
SRSLP1	0.522	0.5413	-0.1684	-0.2619	-0.1817	0.1801	-0.1606
SRSLP2	0.5257	-0.244	-0.5908	-0.1384	0.1762	-0.0538	0.1049
SRSLP3	0.6873	-0.0395	-0.1787	0.0839	0.2872	-0.47	-0.1079
SRSLP4	0.6032	0.3082	0.2519	-0.0082	0.1233	0.2999	0.2831
SRPAKP5	0.8827	-0.1422	-0.0467	-0.1893	0.2156	-0.0812	-0.3191
SRPAKP6	0.077	0.4649	-0.3514	-0.1953	0.033	0.036	0.2363
SRPKPM1	0.266	0.2063	-0.7576	-0.1095	-0.1144	0.2027	-0.2242
SRPKPM4	0.4529	0.5523	0.2674	0.3045	0.1865	0.217	0.1925
SRPKPM10	-0.1495	0.7003	-0.2111	-0.0845	-0.1153	-0.3925	0.0505
Eigenvalues	8.3568	3.7914	3.3902	2.7842	2.216	1.6376	1.7076
% Explained Variance	25	11	10	8	7	5	5
Cumulative% Expln Var	25	36	46	54	61	66	71

Brown's Factor Loadings Test

Significant Factor Loading for the case study =2.58 × (1 ÷ √number of statements in Q set)

= 2.58 × (1 ÷ √16)

= 2.58 × (1 ÷4)

= 2.58 ×0.25

= 0.645 rounded up to ±0.65

Each factor loading is checked for having at least two factors that are above +0.65 or below -0.65. According to this criteria, Table 0-3 shows that only Factors 1, 2, and 3 satisfy this condition (highlighted in Red in the table).

Humphrey's Rule

Standard Error in the case study= $1 \div \sqrt{\text{number of statements in Q set}}$

= 1 ÷ √16

= 1 ÷4

= 0.25

Humphrey's Rule states "that a factor is significant if the cross product of its two highest loadings (ignoring the signs) exceeds twice the standard error" (Watts and Stenner, 2012). In this research this means checking the cross products of the highest two loadings (ignoring signs) in each column in Table 0-4 (highlighted in Yellow) and making sure they are greater than 2 x the Standard Error, i.e. 0.25 x 2 = 0.5. For ease of reference the Table below looks at these calculations in more detail.

Table 0-4. Calculation of Humphrey's Rule for Significant Factors.

Factor	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
Cross product	0.787	0.502	-0.535	0.487	-0.295	0.168	0.26
Humphrey's Rule: Cross Product must be > 0.5 (ignoring the signs)							

In this analysis, only Factors 1, 2 and 3 are found to be significant matching the outcome of Brown's Factor Loadings Test indicating that these three factors should be used in the study.

For the CFA, Ken Q Analysis was used to conduct Varimax Rotation of 3 Factors that were found to be significant to generate Factor Scores with Ranks for each statement. *Table 0-3* shows that Factor 1 explains 25 percent of the variance in the q-sorts while Factors 1 and 2 together can account for 36 percent of the cumulative variance and adding Factor 3 raises the cumulative explained variance to 46 percent. In contrast to other statistical methods like Principal Component Analysis (PCA) that look at factor loadings of the variables, Q methods looks at the factor scores of the Q sorts. In this case, the factor scores are the average value of each factor's Q sorts representing how each statement is viewed by the factor. *Table 0-5* Rotated Factor Loadings Table shows the total number of Q sorts (participants) per Factor as well as their values.

The Rotator Factor Loadings Table show that Factor 1 is defined by 19 Q sorts (with 16 flagged), Factor 2 is defined by 5 Q sorts (all flagged) and Factor 3 defined by 9 Q sorts (with 5 flagged). The next section goes into detail about each of the 3 Factors and their interpretation for Indicator selection in our case study.

Table 0-5. Rotated Loadings Table with Defining Sorts Flagged.

Nm	Q sort	Factor Group	Factor 1	Factor 2	Factor 3
17	SRPAKC5	F1-1	0.9167	0.0331	-0.0552
29	SRPAKP5	F1-2	0.8196	-0.266	-0.243
3	SRPAKA4	F1-3	0.7969	0.0472	-0.4268
14	SRPAKC2	F1-4	0.7266	0.0379	-0.2364
1	SRPAKA1	F1-5	0.7224	0.1536	0.025
10	SRSLA1	F1-6	0.6942	-0.1244	0.2651
27	SRSLP3	F1-7	0.6622	-0.2566	-0.0398
28	SRSLP4	F1-8	0.6501	0.3001	-0.0982
25	SRSLP1	F1-9	0.6482	0.1825	0.3748
22	SRPAKC10	F1-10	0.6412	-0.1017	0.1379
16	SRPAKC4	F1-11	0.6323	-0.0957	0.1472
6	SRPAKA7	F1-12	0.609	0.0803	-0.2495
19	SRPAKC7	F1-13	0.5936	-0.045	-0.0909
32	SRPKPM4	F1-14	0.5656	0.5046	0.0847
15	SRPAKC3	F1-15	0.532	-0.465	-0.0337
24	SRPAKP1	F1-16	0.5044	-0.0126	0.2149
13	SRPAKC1	F1-17	0.4688	0.2807	-0.2686
7	SRPAKA8	F1-18	0.3239	0.165	0.1343
8	SRPAKA9	F1-19	0.3187	0.3158	0.0861
9	SRPALA10	F2-1	0.0924	0.7664	0.2352
2	SRPAKA3	F2-2	0.2548	0.713	-0.2456
26	SRSLP2	F2-3	0.4721	-0.6627	0.1516
5	SRPAKA6	F2-4	0.0441	0.5374	-0.0279
20	SRPAKC8	F2-5	-0.0867	0.4866	0.2471
21	SRPAKC9	F3-1	0.0182	0.278	-0.7176
31	SRPKPM1	F3-2	0.3414	-0.4243	0.625
33	SRPKPM10	F3-3	0.0156	0.2958	0.5827
30	SRPAKP6	F3-4	0.2065	0.0688	0.5461
23	SRPAKC11	F3-5	0.1113	-0.1646	-0.4915
4	SRPAKA5	F3-6	0.0834	0.0122	0.4089
12	SRSLA4	F3-7	0.3957	-0.303	-0.4002
18	SRPAKC6	F3-8	0.2378	0.0191	-0.384
11	SRSLA3	F3-9	-0.1605	0.3515	0.3593

Measuring Economic Resilience

Economic Resilience (ER) was one of the three CDR dimensions selected for inclusion in the resilience assessment of the BNB case study based on the Thematic CLD Models in Chapter 5. 19 respondents participated in the ER Resilience Q sort interviews who ranked 16 statements corresponding to 16 indicators that can be used for measuring ER. *Table 0-6* shows the overall averaged ranking as well as the rankings of each group separately, including highlights of the top (green) and the lowest (red) ranking between them for contrast.

During the interviews, several (n=3/6) of the participants from the Academics group shared the viewpoint that ER is a product of both the social and built environments resilience, and this is reflected in the high ranking given to indicators on Household Wealth, Hazard Awareness (for business and commercial entities) and the Diversity of Livelihoods in the area. On the other hand, indicators measuring the level of Economic System Failure and the existence of Recovery plans as not as important. Most (4/6) of the Academics indicated that there is no system or plans for recovery at the local levels in BNB area despite frequent flooding and these indicators are probably useful for data rich case studies such as in developed countries.

The participants from the Community also emphasise the role of Household Wealth and Hazard Awareness among the business community as the most important indicators followed by Household Income. According to most (4/5) of the Community members interviews, both Wealth and Income of Households play a key role in disaster resilience in the Area with those who can afford it can build their homes with stronger materials, on higher ground (more expensive land), and can also recover quicker if having a larger income to depend on. Alternatively, indicators for Post Damage Assessment, Economic System Failure, Recovery Time, and Training programs were ranked of low importance. Once again, the reason given from some (2/5) of the respondents was that these systems do not exist on the ground for them at the community level and hence did not feel they could be measured for their community. This raises a recurring theme among participants that perhaps the indicator statements taken from the Library of Indicators were based on developed countries with the researcher having to explain that the absence of these systems is also important to discuss and consider for raising awareness that such options exist in more resource rich settings.

Finally, for the Practitioner group the most important indicator was Hazard Awareness among the business enterprises in the area along with equal importance to preparedness and training programs to increase awareness and build local capacities to deal with disasters. The Practitioners also emphasised the need to measure the extent of public private partnerships for disaster preparedness, like Early Warning mechanisms as well the importance of hazard mitigation planning for the community at the local levels. The preference among Practitioners for this set of indicators reveals the influence of their own work processes as several (6/9) respondents in this group belonged to disaster management response agencies whose remit it was to provide guidance and training on Hazard Awareness and Mitigation measures at the local level. Unfortunately, this emphasis on training and planning was not reflected in the interviews of Community members participating in the study who found the role of training and awareness programs to be negligible to non-existent in the case study area. Additionally, like the other two groups, the participants in this group also found the indicators measuring the Severity of the Economic Failure to be of least importance.

Table 0-6. Raw Q Sort Ranking of Economic Resilience Indicators by Group.

No.	Indicator Statement	Acad. Ranking	Community Ranking	Prac. Ranking	Overall
1.	Hazard Risk Awareness (Businesses)	2	2	1	1
	Preparedness Plan	4	4	1	3
3.	Disaster Mitigation Measures/Strategies	6	9	3	7
	Private Public Partnership for DRR	5	6	2	4
5.	Training Programmes for DRR	9	11	8	11
	System Failure	14	9	8	13
7.	Severity of Failure	11	11	12	14
	Diverse livelihoods	3	10	5	6
9.	Maintenance	8	8	7	10
	Income Status	7	3	4	5
11.	Wealth (Assets)	1	1	6	2
	Post-event damage assessment	10	12	9	12
13.	Recovery time	13	11	10	15
	Government Relief	7	7	7	9
15.	Household Support	12	8	11	13
	Risk Transfer (Insurance)	7	5	7	8
Note when number repeats - it is because the total score was the same.					

Overall, with perspectives of all three participant groups combined it was found that Hazard Awareness of local business and commercial entities was the most important set of indicators required for measuring ER. The importance of this indicator is perhaps because such awareness can lead to preparedness and mitigation measures that can help protect business and ensure continuity during and after hazard events. Similarly, Household Wealth and Preparedness & Training were also ranked highly by the overall group indicating the importance of initial assets and preparedness measures prior to a hazard event like flooding. For the least important indicators overall, Economic System Failure, its Severity and Recovery Plans were chosen perhaps reflecting their absence as systems in the area and the perception among participants for lack of ways to measure them.

Like the previous two analysis, a comparison of the Eigenvalues greater than 1 in the Unrotated Factor Matrix was conducted to reveal that only 2 of the Factors were significant. The Kaiser-Gutmann Criterion result was double checked with the Scree Plott diagram which also indicated that the slope changes at the second factor. The CFA was then conducted using only two factors.

Table 0-7. Unrotated Factor Matrix for Economic Resilience.

Unrotated Factor Matrix

Nm	Participant	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1	ERPAKA1	0.8758	-0.1611	0.4148	0.1683	0.0197
2	ERPAKA2	0.3985	0.0938	-0.0411	-0.4923	0.2101
3	ERPAKA3	0.2693	0.4187	0.5486	0.2606	0.1389
4	ERPAKA4	0.6379	0.3281	0.0377	-0.1768	0.0929
5	ERPAKA5	0.6316	-0.0682	0.0636	-0.4966	0.196
6	ERPAKA6	0.5876	-0.2466	-0.2814	0.1747	0.0659
7	ERPAKC1	0.3452	-0.0251	-0.6724	0.3412	0.273
8	ERPAKC2	0.676	0.0285	-0.0187	0.653	0.0693
9	ERPAKC3	0.0383	-0.4435	0.4376	0.1757	0.093
10	ERPAKC4	0.8423	0.0959	-0.2976	0.0034	0.0735
11	ERPAKC5	0.5164	-0.4901	0.1802	0.2645	0.0704
12	ERPAKP1	0.1862	0.4486	0.6204	0.3454	0.1909
13	ERPAKP2	0.8092	0.1215	0.1325	-0.2457	0.0702
14	ERPAKP3	0.6001	0.1513	-0.3425	-0.2489	0.1743
15	ERPAKP4	0.1805	-0.4992	-0.2274	-0.472	0.3598
16	ERPAKP5	0.3275	-0.4912	0.1622	0.0206	0.0836
17	ERPAKP6	0.6221	0.1412	-0.4379	0.2233	0.1222
18	ERPAKP7	0.209	0.0663	-0.0506	0.037	0.0035
19	ERPAKP8	0.4284	0.4864	0.0185	-0.1239	0.1389
	Eigenvalues	5.5068	1.821	0.9169	0.822	0.456
	Explained Variance	29	10	11	10	2

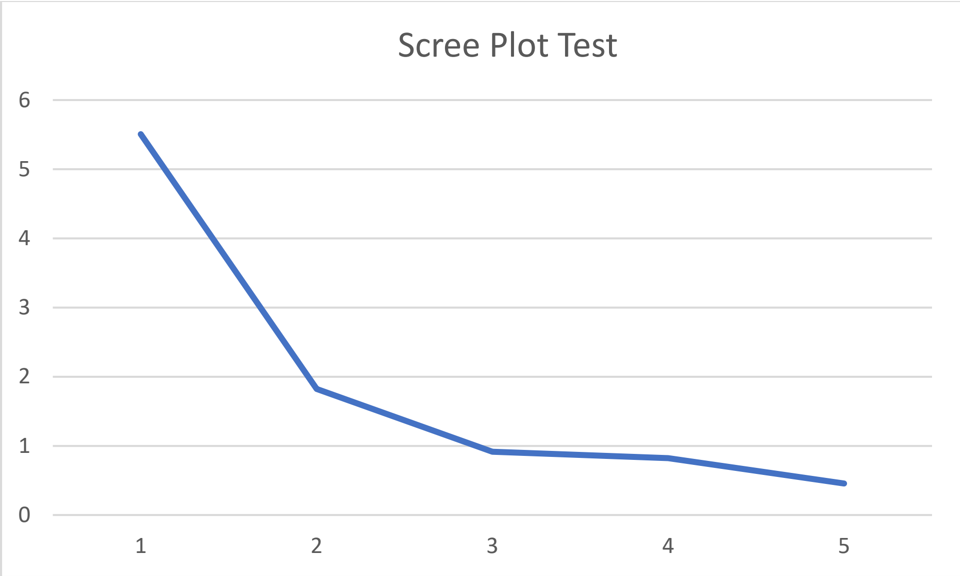

Figure 0-2. Scree Plot of Factors for Economic Resilience

Weights from the Sort Values

Finally, the parameter for Economic Resilience are calculated using the same equations as in the previous sections and are shown in Table 5-15. The highest parameter weight of 11.8 is given to Hazard Awareness among Business entities, followed by 10.4 for Household Wealth, 9.75 for Preparedness & Training, and 8.22 for Household Income.

Table 0-8. Economic Resilience Q-sort Factor Scores and Weights by Indicator.

No.	Statement	Factor 1	Factor 2	Weights per Statement			
		score	score	Statement	Add 3	Normalise	x 100
1	Hazard Risk Awareness (Businesses)	3	2	2.684	5.684	0.118	11.842
2	Preparedness Plan	2	1	1.684	4.684	0.098	9.759
3	Disaster Mitigation Measures/Strategies	1	-1	0.368	3.368	0.070	7.018
4	Private Public Partnership for DRR	1	-1	0.368	3.368	0.070	7.018
5	Training Programmes for DRR	-1	1	-0.368	2.632	0.055	5.482
6	System Failure	0	-3	-0.947	2.053	0.043	4.276
7	Severity of Failure	-1	-2	-1.316	1.684	0.035	3.509
8	Diverse livelihoods	1	0	0.684	3.684	0.077	7.675
9	Maintenance	0	-1	-0.316	2.684	0.056	5.592
10	Income Status	0	3	0.947	3.947	0.082	8.224
11	Wealth (Assets)	2	2	2.000	5.000	0.104	10.417
12	Post-event damage assessment	-3	0	-2.053	0.947	0.020	1.974
13	Recovery time	-2	-2	-2.000	1.000	0.021	2.083
14	Government Relief	0	1	0.316	3.316	0.069	6.908
15	Household Support	-2	0	-1.368	1.632	0.034	3.399
16	Risk Transfer (Insurance)	-1	0	-0.684	2.316	0.048	4.825
	per cent explained variance	26	12		Total=48		Total=100
	Cumulative explained variance	26	38				
	Eigenvalues	5.5068	1.831				

Measuring Physical Infrastructure Resilience

The third and final resilience dimension identified in Chapter 5 was Physical Infrastructure Resilience, one of the most important dimensions that can form a baseline for resilience assessment linked to others. A previous study on PI resilience using the Q methods was completed by the author and published using Q methods Workshops to understand the perspectives of stakeholders from the Academic and Practitioner communities. That study used 128 indicators from the Library of Indicators and reduced it to 38 indicators and ranked those 38 in order of importance to the participants groups. This study used a similar approach and applied it to the resilience issues being faced locally in the BNB area in Peshawar.

Sixteen respondents participated in the PI Resilience Q sort interviews, with 5 Academics, 5 Community Members and 6 Practitioners in this phase of the study. Table X.X below shows the ranking of statements by group. In the Q sort exercise, the Academics group ranked Construction according to Building Codes as the most important indicator for PI Resilience, followed by Mitigation Planning and Hazard Awareness among critical infrastructure service providers. For the Community members, indicators that look at the presence or absence of a important.ly Warning System was the most important measure of resilience. They also attached importance to new Construction according to Mitigation Standards, and hazard Awareness among utility providers. Practitioners prioritised Hazard Awareness as the most important indicator while also giving importance to Mitigation Planning, and the number of Buildings constructed according to Mitigation Standards. For the least important, Academics chose indicators that measure the Probability of Failure in the Utility Services, Community members chose Post Event Damage Assessment, and Practitioners chose Restoration Time for full operation.

When considered overall, Hazard Awareness received the highest ranking, while Built According to Mitigation Standards was second, and Mitigation Planning was third in order of importance for measuring PI resilience in the BNB area. On the other hand, for the least important indicators, Restoration Time for full operations, Time for Recovery, and Probability of Failure were considered as not a priority for understanding local PI resilience.

The participants of the previous study on PI Resilience also prioritized Hazard Awareness but apart from that the results were markedly different, for example that group of stakeholders prioritised Recovery Planning, which is ranked as eighth overall in this study versus second in the previous. Similarly, Cost of Damaged Assets ranked very highly in that study but is ranked near the bottom in this study. This difference could be attributed to the inclusion of the community in this study as it was omitted from the other, or the difference in research design and data collection in workshops versus interviews.

Table 0-9. Raw Q Sort Ranking of Physical Infrastructure Resilience Indicators by Group.

No.	Indicator Statement	Acad. Ranking	Community Ranking	Prac. Ranking	Overall
1.	Hazard Awareness (Utilities, Critical Service Providers)	3	2	1	1
	Procedures/plans for hazard mitigation exist	2	4	2	3
3.	Community-level Early Warning System (EWS)	4	1	6	5
	Quality/extent of mitigating features	10	7	9	10
5.	Training programme/system for DRR exist	3	5	5	6
	Cost of damaged assets	8	9	12	12
7.	Loss of Essential Services (After Last Event)	11	11	10	12
	Age of structure	6	11	9	9
9.	Safety design factors	5	10	7	7
	Building Characteristics (Kactha, Pacca)	1	6	4	4
11.	Mitigation standards (building codes)	2	3	3	2
	Post-event damage system or mechanism	6	13	8	11
13.	Length of time to conduct damage assessment	9	12	12	14
	Recovery Plan	7	8	8	8
15.	Time needed for recovery	10	12	11	13
	Restoration time for full operation	10	8	13	14
Note when number repeats - it is because the total score was the same.					

Table 5-17 shows the Kaiser-Guttman Criterion for proceeding to CFA and the PI Resilience Factor Scores after the CFA. The Two factors identified as patterns of perspective on measuring PI Resilience are Factor 1 Hazard Awareness and Mitigation Planning and Factor 2 Early Warning Systems for Local Area.

Table 0-10. Physical Infrastructure Resilience Q-sort Factor Scores and Weights by Indicator.

No.	**Statement**	**Factor 1**	**Factor 2**	**Weights per Statement**			
		Score	score	Statement	Add 3	Normalise	x 100
1	Hazard Awareness (Utilities, Critical Service Providers)	3	2	2.815	5.815	0.121	12.114
2	Procedures/plans for hazard mitigation exist	2	1	1.815	4.815	0.100	10.031
3	Community-level Early Warning System (EWS)	0	3	0.556	3.556	0.074	7.407
4	Quality/extent of mitigating features	-3	1	-2.259	0.741	0.015	1.543
5	Training programme/system for DRR exist	1	0	0.815	3.815	0.079	7.948
6	Cost of damaged assets	-2	-1	-1.815	1.185	0.025	2.469
7	Loss of Essential Services (After Last Event)	-1	-2	-1.185	1.815	0.038	3.781
8	Age of structure	0	-3	-0.556	2.444	0.051	5.093
9	Safety design factors	1	0	0.815	3.815	0.079	7.948
10	Building Characteristics (Kactha, Pacca)	1	1	1.000	4.000	0.083	8.333
11	Mitigation standards (building codes)	2	2	2.000	5.000	0.104	10.417
12	Post-event damage system or mechanism	0	0	0.000	3.000	0.063	6.250
13	Length of time to conduct damage assessment	-1	-2	-1.185	1.815	0.038	3.781
14	Recovery Plan	0	0	0.000	3.000	0.063	6.250
15	Time needed for recovery	-1	-1	-1.000	2.000	0.042	4.167
16	Restoration time for full operation	-2	-1	-1.815	1.185	0.025	2.469
					48		100
	Kaiser-Guttman Criterion						

Eigenvalues	Factor 1 6.9763	Factor 2 1.5794	Factor 3 0.9304	Factor 4 0.8352
Explained Variance	44	10	7	5

Weights for PI Resilience from the Q Sort Values

The study uses the same approach used in the previous two section for deriving the weights for the study with Hazard Awareness receiving a 12.11 percent, Structures Built According to Mitigation Standards at 10.41 percent and Mitigation Planning with 10 percent.