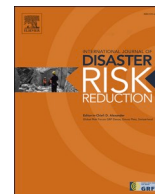




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Review Article

Measuring community disaster resilience at local levels: An adaptable resilience framework

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ABSTRACT

Decision makers, practitioners and community members need to assess the disaster resilience of their communities and to understand better the risks they face from natural hazards. There is a lack of consensus on what resilience means and how it can be measured as each stakeholder potentially brings a different perspective to understanding community disaster resilience. The paper will identify the key features and characteristics of Community Disaster Resilience (CDR) frameworks from the literature to develop a resilience framework that can be adapted and customised according to stakeholder needs. The paper used a 5-step process to develop an adaptable CDR framework. First, a review of 36 resilience frameworks was conducted to identify key features and characteristics of resilience frameworks. In Steps 2 and 3, a matrix of indicators and measures was populated by resilience dimensions covered in the current CDR literature reviewed. Subsequently, the indicators were sorted for similarities and duplicates were removed. Finally, they were clustered by 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 majority 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. An adaptable CDR framework may make resilience assessment more grounded in local stakeholder perspectives and lead to a better understanding of community resilience.

1. Introduction

Since the beginning of the millennium, more than 2.3 billion people have been directly affected by frequent natural disasters, with studies indicating that total damages may have been around \$ 2.5 trillion, with the majority of those affected living in developing countries [1,2]. Due to this rising frequency, and magnitude, of natural disasters occurring worldwide [3], there is an increasing need for local decision-makers, practitioners and community members to assess the disaster resilience of their communities better. Understanding resilience from community stakeholder perspectives can help implement measures to reduce the impact of disasters on the community in general, saving lives and money [4,5]. These stakeholders require clear and precise methods for the understanding of their risk profiles and to conduct assessments of the severity of the impacts of natural disasters [6]. A more inclusive and equitable approach to measuring resilience can help communities effectively utilise the scarce resources available at their disposal in

implementing disaster mitigation measures that make their communities less vulnerable and more resilient [7].

For the last fifteen years the concept of community resilience, the ability of a community to withstand or respond to abrupt changes due to hazards, has been investigated by researchers to explain the impact of disasters on communities [8,9]. As the concept of Community Disaster Resilience (CDR) continues to evolve, research is now increasingly focusing on developing frameworks and tools that can measure and classify community resilience [10–12]. Despite this growing importance, no clear procedure to define and measure CDR has emerged [13–15] with many different disciplinary and methodological approaches now being used in the literature [16].

There are many different perspectives among stakeholders on the understanding of community resilience which translates to varying views on measuring their community's resilience [17]. Until both scientific and practitioner communities agree on the essential focus of CDR, i.e. definitions, baseline attributes or dimensions, capacities and

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processes that emerge and develop in a community, the question of the resilience of who and to what will remain a subject of debate [8,18]. Accordingly, measuring CDR at the local level is often characterised by limited technical knowledge and disagreement about the nature of resilience itself, particularly the goals of interventions required to achieve it [19,20]. If citizen welfare is valued, then the frameworks and tools for measuring community disaster resilience must consider this multiplicity of perspectives [21]. Frameworks that have a built-in method or procedure that allows for building consensus among stakeholders can better address the main issues impacting on resilience at the local level [4]. Recently, more participatory approaches to resilience assessment have been featured in the literature, using more subjective approaches developed in psychological and well-being research to engage stakeholders in the resilience process effectively [22]. Hence, there is a growing need to include shared perspectives, leverage technological innovation for co-creation of resilience assessment tools and to better understand the causal mechanisms for resilience building for evidence based policy making [11]. International development agencies and donor organizations have also realized the benefit of developing resilience assessment tools with greater inclusivity because it can help communities measure the impact of interventions and hold the government and others to account [6].

The purpose of this paper is to present an inclusive and adaptable resilience framework to assist key community stakeholders (residents, local government officers, practitioners, and researchers) in measuring CDR at the local level. The study conducts a review of selected resilience frameworks, models, indexes, and toolkits that have been applied successfully to measure resilience at the local community level to develop a CDR framework. The paper reviews 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 finally, what measures or indicators are used in some of these frameworks. The paper also seeks to develop a generic, customisable CDR framework by synthesising a library of resilience indicators across the most cited CDR dimensions. The adaptable CDR framework uses Systems approaches, like Systems Thinking (ST) and System Dynamics (SD), to engage stakeholders in group model building (GMB) sessions to co-develop community-level resilience assessment tools that are more fit-for-purpose according to their needs and perspectives at the local level.

1.1. Community disaster resilience frameworks: definitions and approaches

Although several definitions for community exist in the literature, they are usually classified as an entity within geographic boundaries and a shared outcome with respect to a hazard, shock or stress event [8]. In this study 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 settings” [9]. 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.

1.2. Defining community disaster resilience

While the word resilience has had its origins in the physical sciences, where it was used to indicate how much a material can bend and then bounce back before it breaks [23], it came into use in its present form in ecological resilience in the work of Holling [24,25]. Subsequently, researchers in disaster management (and other fields like development studies and sustainability) extended and adapted the concepts used in ecological sciences such as non-linear dynamics, thresholds, uncertainty, surprise and multiple adaptation outcomes to community resilience in facing adverse shocks and stresses such as hazards [26,27]. 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 adaptation pathways, while for others many of the same criticisms still apply [28,29].

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 different dimensions, and often excluding relevant processes from the analysis [30]. Virokannas et al. [31] cautions of the danger of using vaguely defined concepts like vulnerability to stigmatize, label, marginalize and objectify communities and hereby deny them their agency. They go on to 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 with respect to issues of their own vulnerabilities and risks [31]. 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.

In a recent review Koliou et al. [16] listed seventeen definitions of community resilience. They identified three key components of community resilience – reducing impacts or consequences, reducing recovery time and reducing future vulnerabilities [16]. Two definitions that stand out and have influenced resilience researchers are shared here, 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,” [32] and, the second one from the United Nations International Strategy for Disaster Reduction (UNISDR), 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” [1].

Although the terms resist, absorb and recover are used in both definitions, it is important to realize that these are distinct processes that can vary from hazard to hazard, place to place and country to country [8,33]. Therefore, one of the main challenges of measuring resilience is the operationalisation of these processes, particularly when capturing the hazard itself, and the cultural and national diversity that exists in the global context [34]. In addition to developing a robust operational definition, it is vital to identify the measures and processes that influence or predict resilience as well as the variation of resilience within different communities [15].

Norris et al. [8] proposed that definitions of resilience can be operationalized 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 stress, adaptation, wellness, and resource dynamics. Subsequently, building on the previous work of Norris et al. [8]; Sherrieb et al. [35] 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 a number of possible outcomes. Hence, CDR can be considered as a complex multi-dimensional phenomenon with diverse perspectives and multiple interdependencies, making it hard to define and conceptualise [28,36,37]. This methodological difficulty is especially apparent when resilience is considered as a single static value and not as a dynamic value, that changes over time to reflect both evolution and degradation as the case may be [12]. This difficulty also extend 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 [20]. Bene et al. [38,39] differentiate between tangible and intangible factors that may impact community resilience where 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 largely 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 both used innovative tools for capturing intangibles such as risk perception, self-efficacy and aspirations of individuals in communities [40]. Capturing stakeholder world views and mental models require an increase level of participation of communities using participatory tools that may enhance engagement and representation of diverse groups in the assessment of resilience, as well encouraging conversations about resilience among these diverse groups [41]. This engagement process may lead to the development, co-creation and use of resilience assessment tools by stakeholders that are fit-for-purpose and measure what they want and need rather than what researchers think is needed [42].

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?) [43–45].

One way to address some of these methodological considerations is applying a systems approach to the community resilience context and to use 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 [46]. 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 using a combination of objective and subjective methods and hence require more attention from researchers in community resilience [6,47].

1.3. 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 [21]. 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 [39,48]. Most resilience frameworks tend to use objective measures to assess tangibles such as income, assets, and other relatively easier to quantify variables [49]. 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 [50].

Objective approaches can also be considered "positivist" in their outlook in that the variables measured with objective measures can easily be applied in other settings to measure the same type of variables [51]. Hence its popularity due to its relative ease of use to develop and deploy in different contexts and settings [48]. 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 [52]. Hence, if designed properly, it may provide a deeper level of understanding as the indicators themselves are not free from interpretation and their selection may generate useful insights for resilience intervention design and implementation [53].

Recently, more subjective approaches to measuring resilience has found acceptance among resilience researchers, where these approaches seek to actively include the perspectives and judgements of the subjects themselves to understand their own circumstances [48]. Clare et al. [54] 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 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 the capacities of their household, community, or social system to underlying risk and rely heavily on perceptions, judgements, and preferences. For example, self-assessment of what is resilience (defining it), what resilience consists of (dimensions), and other factors that impact resilience as well as if people are confident in responding to current or future shocks and stresses [4]. Often these perspectives and judgements are used to look at intangible variables like social cohesion, trust, and other social dimensions [20]. Although intangibles may be difficult 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 providing context and representation to marginal voices [38]. Additionally, bottom-up approaches where community members participate in resilience assessments and provide input to the measurement process may also minimize or remove biases like external framing that may lead to errors in resilience intervention design and implementation [55].

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 its assessment process that are subjective and, vice versa [48]. Jones [6] 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) in question to define resilience. Secondly, how resilience is evaluated? Objective approaches are reliant on external observation; subjective approaches make use of a subject's judgments and self-evaluation of their resilience" [6]. Fig. 1 illustrates the Subjective-Objective continuum and also reveals some of the relative strengths and weaknesses of each quadrant according to Jones [6].

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 the set of critical characteristics, dimensions, features, and approaches used across existing CDR frameworks. The results of the study can then be used to develop an adaptable CDR framework that can be applied to a specific location, hazard, or case context – allowing interpretation and customisation by key stakeholders from across the community spectrum.

1.4. Methodology

A literature review of current community resilience frameworks was conducted to assess their applicability in the community resilience context, especially those frameworks that have been 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 for providing the structure for the community resilience literature review at the first stage of analysis. The PRISMA method is a widely used literature review methodology and has four steps: identification, screening & eligibility, and inclusion [56].

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 the 2005 to 2019 in Title, Abstract, and Keywords. The research team chose these electronic databases because of the comprehensive selection of peer-reviewed journals, papers and grey literature (published by organizations), particularly in those fields related to disaster resilience, and



Fig. 1. Subjective-Objective continuum with strengths and limitations [6].

Google Scholar 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 1. 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 that have been used to measure resilience of a community with results or an outcome indicating that it had been operationalized at the local level.

The initial search strategy from all databases combined yielded 3842

Table 1
Inclusion/exclusion criteria. (n.b. Articles include peer-reviewed and grey literature sources)

Inclusion Criteria	Exclusion criteria
Articles with a clear definition of CDR, framework, model, tool, or index	Articles which did not clearly define CDR Articles which 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 community context)	Articles that specified resilience of a specific material or product Articles that focused on mental or psychological resilience only
Articles published between 2000 and 2020	Articles on organizational or institutional resilience Articles on Wider Regional or national level resilience

documents which required a change in the key words for the criteria, a finer 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 further reduce the documents to 1039 articles. The researchers then began to apply the steps of the PRISMA approach to refine the search further and include only subject disciplines that are related to disaster management (i.e. social sciences, environmental sciences and multi-disciplinary research) and to exclude duplicates as shown in Fig. 2. 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 that were applied at the local level in different settings.

The study conducted a closer review of the 49 articles looking at the full texts separately. From the 49 articles, 36 were selected for inclusion. 13 articles were excluded because either a complete framework, model or index was not included in the text or they were examples of the same framework being implemented in another setting and only counted as a duplicate after individual scrutiny. Each of these thirty-six articles was separately evaluated and analysed. Articles were checked for the approaches used in defining resilience, and for the capacities or dimensions used in that definition. Additionally, the frameworks were also analysed on the method used for evaluation, the methodology used for data collection, as well as types of data required.

All the selected frameworks are shown in Table 2. A critical analysis

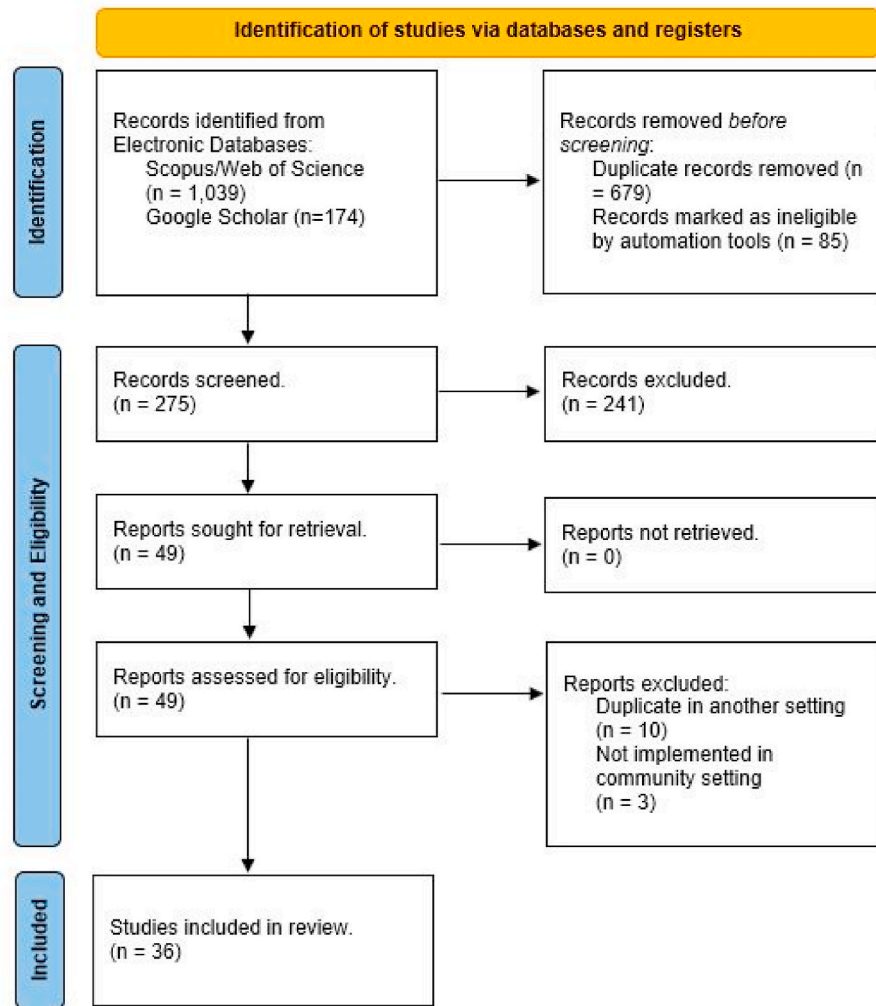


Fig. 2. Stages in PRISMA review as carried out in the study.

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, also, to evaluate it. Keywords describing the dimensions used in determining the most common themes covered in these frameworks are shown in Table 3. The dimensions and capacities used in each framework indicate how those frameworks operationalise resilience. The following five steps were taken to develop the adaptable framework (and the library of indicators) as shown in Fig. 3. In steps 1 to 2, a matrix of all dimensions and categories mentioned in the thirty-six frameworks was created, followed by clustering into the main dimensions identified in those frameworks in step 3. At the fourth step, measures were sorted according to capacities as well as the removal of duplicates. Finally, the measures were sorted due to similarity and combined into the final set of 6 dimensions to form the library of indicators for adaptable CDR framework proposed in this study.

1.5. Results/findings

This section details the analysis of the selected frameworks in terms of hazards covered, approaches used to measure resilience, the main dimensions or categories covered in those resilience frameworks and, finally, the library of measures that forms the basis of the generic adaptive community disaster resilience framework being proposed in this paper.

1.6. Analysis of resilience frameworks

The selected thirty-six frameworks are listed in Table 2 in alphabetical order and review current practices and approaches used in these frameworks as well as listing the hazard type covered by each framework. Most of the frameworks ($n = 26/36$, 72%) had an all-hazards approach whilst 4 frameworks have been developed for climate change hazards another 4 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 in different ways based on the approach, context, and the research focus of each of the frameworks detailed in the articles.

1.7. Resilience measurement approaches

Table 2 also indicates what type of framework it is, classifying them according to being either; a scorecard, an index, a model or a toolkit. Scorecards are used for evaluation of performance or progress towards a goal and are often implemented as checklists. An 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 assessment of resilience using two or more of types listed above, i.e. scorecard, index or model [10]. The table also indicates the sort of data required for its

Table 2
Selected frameworks for review by type (n = 36).

Framework/tool	Full name/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 [57]	Index	Drought	Secondary	Quantitative	Objective	Objective
B16	Béné et al. [39]	Model	All	Both	Both	Objective	Subjective
Baseline Resilience Index for Communities (BRIC)	Cutter et al. [36]; Siebenek et al. [127]	Index	All	Secondary	Quantitative	Objective	Objective
Climate Change Agriculture and Food Security (CCAFS15)	Hills [58]	Toolkit	All	Both	Both	Objective	Objective
Coastal Cities Adaptive Resilience (CCAR)	Peck and Simonovic [59]	Toolkit	All	Both	Both	Objective	Objective
Coastal Community Resilience Framework and Assessment (CCR)	Courtney et al. [60]	index	Coastal	Primary	Both	Objective	Subjective
Conjoint Community Resilience Assessment Measure (CCRAM)	Cohen et al. [61]	Toolkit	All	Both	Both	Objective	Subjective
Climate Disaster Resilience Index (CDRI)	Prashar et al. [62]	Index	Climate	Secondary	Both	Objective	Objective
Community Disaster Resilience Index (CDRI2)	Mayunga [63]	Index	All	Both	Both	Objective	Objective
Community Resilience Index Korea (CDRI-K)	Yoon et al. [130]	Index	All	Secondary	Quantitative	Objective	Objective
Community Disaster Resilience Scorecard and Toolkit (CDRST)	Arbon et al. [120]	Toolkit	All	Primary	Qualitative	Objective	Subjective
Community Based Resilience Analysis (CoBRA)	UNDP [64]	Toolkit	All	Both	Both	Subjective	Subjective
COPEWELL	Links et al. [65]	Model	All	Both	Both	Objective	Subjective
Community Resilience to Disasters Saudi Arabia (CRDSA)	Alsheri et al. [119]	Toolkit	All	Primary	Both	Objective	Subjective
Community Resilience Index (CRI)	Ainuddin and Routray [66]	Index	Earthquake	Primary	Quantitative	Objective	Subjective
Community Resilience Index (CRI2)	Norris et al. [8]; Sharreib et al. [35]	Index	All	Secondary	Quantitative	Objective	Objective
Community Resilience Toolkit (CRT)	Schwind [126]	Toolkit	All	Primary	Qualitative	Objective	Subjective
Climate vulnerability and capacity assessment (CVCA)	CARE [67]	Toolkit	All	Primary	Qualitative	Subjective	Subjective
DRLA/UEH evaluation resilience framework FAO14	Sylvestre et al. [68]	Toolkit	All	Both	Both	Objective	Objective
JS16	Alinovi, L. et al. [118]	Index	Food security	Secondary	Quantitative	Objective	Objective
L15	Jones and Samman [49]	Model	All	Secondary	Quantitative	Objective	Subjective
Localized Disaster Resilience Index (LDRI)	Lockwood et al. [69]	Index	All	Primary	Qualitative	Objective	Subjective
Livelihood change over time (LCOT)	Orencio and Fujii [124]	Index	All	Primary	Both	Objective	Subjective
MM07	Vaitla et al. [70]	Index	All	Primary	Quantitative	Objective	Objective
NJ13	Marshall and Marshall [71]	Model	Climate	Primary	Quantitative	Objective	Subjective
PEOPLES	Nguyen and James [72]	Index	Floods	Primary	Qualitative	Objective	Subjective
PRIME	Cimellaro et al. [73]	Toolkit	All	Both	Both	Objective	Objective
ResilSim	Smith et al. [74]	Index	All	Both	Both	Objective	Objective
ResilUS	Irwin et al. [75]	Model	All	Both	Both	Objective	Subjective
Resilience index measurement and analysis (RIMA)	Miles and Chang [76]	Model	All	Secondary	Quantitative	Objective	Objective
Self-evaluation and holistic assessment of climate resilience of farmers and pastoralists (SHARP)	FAO [77]	Index	All	Primary	Quantitative	Objective	Objective
Tracking adaptation and measuring development (TAMD)	Choptiany et al. [78]	Model	Climate	Primary	Quantitative	Objective	Subjective
WB15	Brooks et al. [79]	Toolkit	Climate	Primary	Both	Subjective	Objective
Weather and climate-resilience indexes (WCRIs)	Alfani et al. [80]	Model	All	Secondary	Quantitative	Objective	Objective
UNISDR12	Kimetrica [81]	Model	Food	Primary	Quantitative	Objective	Objective
	UNISDR [128]	Toolkit	All	Both	Both	Objective	Subjective

implementation and the approach it uses to define and evaluate resilience.

The selected frameworks either rely on existing secondary data sets or primary data collected or on both types combined. Secondary data sets used 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-profits. Primary data has been collected through either household or individual surveys, interviews or focus groups. In the review, many frameworks (12/36, 33%) have used both 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 included in the evaluation, only three articles (n = 3/36, 8%) used the subjective approach to define resilience from the perspective of the community members themselves. The rest used an objective approach where resilience was defined externally by the authors themselves, as shown in Table 2.

Fig. 1 had previously shown the subjective-objective continuum across which CDR frameworks lie as described in Jones [6]. Fig. 4 illustrates where the frameworks reviewed in this study are placed on that subjective-objective continuum. Most of the frameworks (n = 33/36, 92%) lie to the right of the continuum, where they are classified as

Table 3
Keywords used for Dimensions by framework.

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
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

objectively defined. With regards to evaluation, there is a more even spread with many of the frameworks (n = 15/36, 41%) using some sort of participatory methods that allowed for the direct input of key stakeholders like community members. Fig. 4 shows 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 Fig. 1.

Purely objective approaches are the most common type in our selected frameworks (n = 17/36, 47%), where both the definition and measurement of resilience is done using objective tools of assessment. Objective tools and approaches are more standardized and are easier to use for comparisons between different communities [54]. These approaches are relatively well researched and are covered more extensively in the literature with many (47%) covered in this review falling under this bracket. One of the major drawbacks of this type of assessment is the requirement of socio-economic 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 [33,82]. Additionally, in these purely objective frameworks, it is hard to quantify intangible resilience dimensions like social and human factors that are important to include for resilience measurement [20]. Also, another limitation of these frameworks is that it is difficult to contextualize or customise the resilience assessment to the needs of stakeholders. Hence, these frameworks may not be suitable for implementation in communities that are diverse, ever-changing, and have continually evolving needs like those at risk from increasing climate change hazards [82].

In the case of those frameworks that used a combined or mixed approach (n = 17/36, 47%), all but three frameworks used an objective approach to define resilience and are considered as outliers in CDR frameworks reviewed here. These three exceptions, the Climate Vulnerability and Capacity Assessment (CCVA) [67], Tracking Adaptation and Measuring Development (TAMD) [79] and the Community Based Resilience Analysis (CoBRA) [64], used a participatory community-based approach to define community resilience. Clare et al. [54] suggest that these participatory based subjective approaches have the advantage of including people's self-evaluations about risk and vulnerability and consider the community's knowledge base regarding resilience. Also, 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 [20,38]. On the other hand, due to the nature of the qualitative methods used, more care and

attention was needed to avoid cognitive biases, social desirability and priming [6].

Significantly, two of the three outlier cases, the TAMD framework [79] and the CoBRA framework [64], used a subjective approach to defining resilience and an objective approach to evaluating and measuring resilience signifying the relative rarity of tools using this approach. Both these frameworks utilised innovative approaches where CDR was defined by subjective means and then measured using standard objective measures. This approach allowed for the inclusion of localized knowledge of resilience factors and, also, allowed for the use of more validated and standardized objective resilience indicators [79]. Using this combination allows CDR frameworks to be contextualised to the needs and requirements of a community's stakeholders – a key desirable outcome for more inclusive Disaster Risk Reduction (DRR) policy and programming [54]. Jones [6] reports that the utility of the TAMD approach is better suited to capture the uncertainties in complex environments and fast-changing situations that exist 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 categorized [38]. This approach also generates value due to its ability to customise and adapt resilience measurement tools according to the needs of their respective stakeholders, hence resulting in more "fit-for-purpose" resilience assessments [42].

1.8. Resilience dimensions and indicators

The frameworks show a considerable diversity of dimensions 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 brief analysis of the keywords used as dimensions or categories in these frameworks is shown in Table 3. 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 in the assessment of community resilience.

A textual analysis of the dimensions, indicators and measures used in these frameworks to measure and assess CDR resulted in the selection of five of the thirty-six for closer scrutiny. These frameworks were chosen because they covered a broad range of dimensions shown in Table 2 and

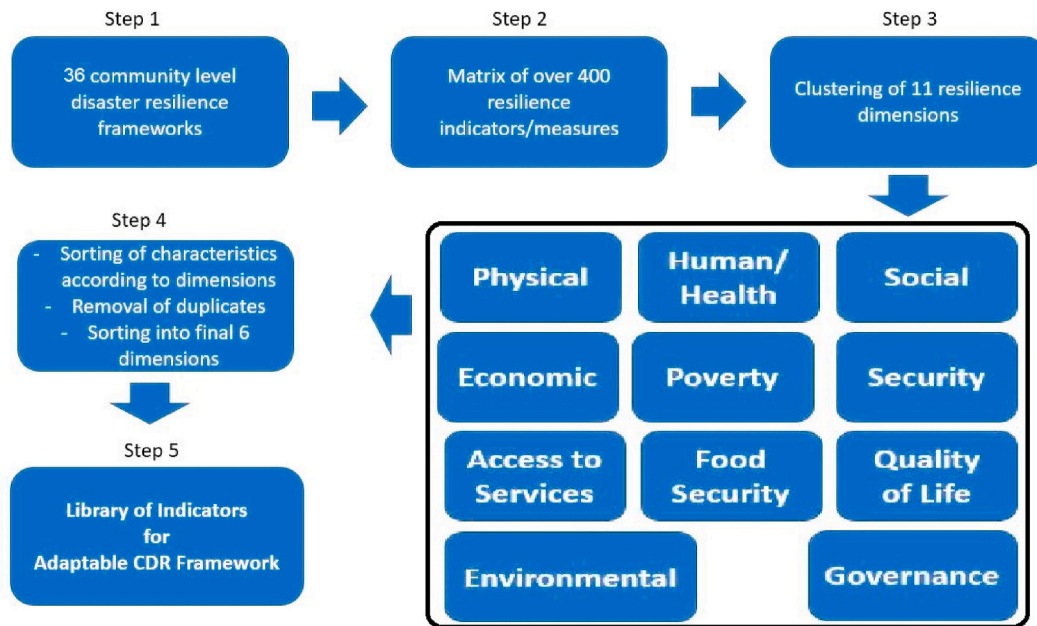


Fig. 3. Steps taken to develop a generic adaptable Community Disaster Resilience framework.

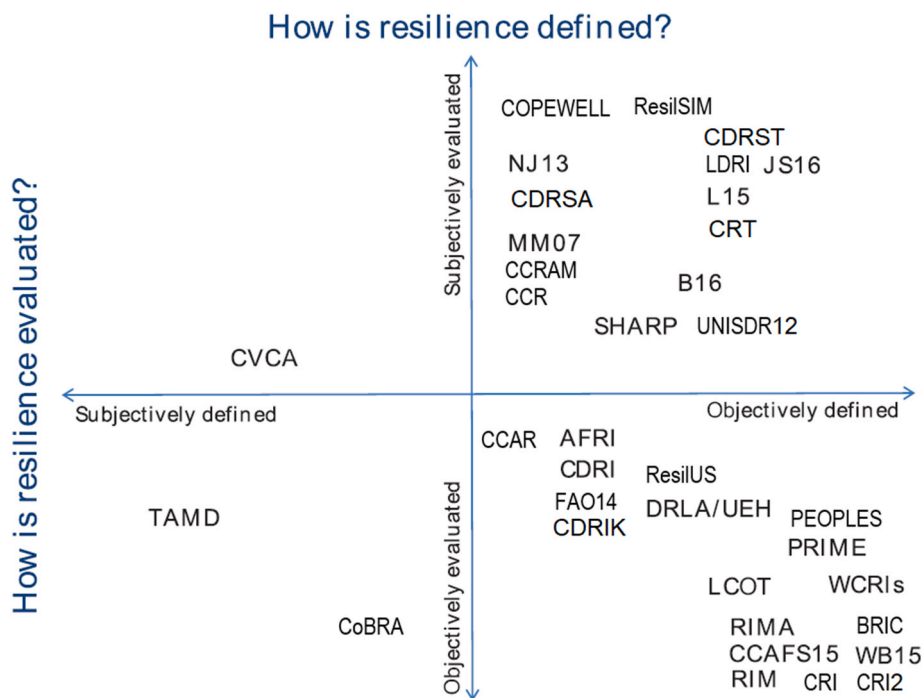


Fig. 4. Selected frameworks in the subjective-objective continuum (adapted from Ref. [6]).

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 4 shows how comprehensively these dimensions were covered by listing the indicators and measures that were used to operationalise the CDR frameworks. The matrix of indicators was then used as the basis for the library of indicators developed in this study.

The dimensions and indicators shown in Table 3 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 4 show some of the diversity, as

well as the similarities between the frameworks.

2. Discussion

This study completed a review of thirty-six CDR frameworks for approaches that can be used for the assessment and measurement of resilience at the local level, noted the different approaches used to define and evaluate resilience and documented some of the main characteristics and features of these CDR frameworks. The selected frameworks used a diverse set of methodologies, as shown in Table 2, ranging from qualitative interviews and focus groups to developing scorecards and forming indices to econometric analysis using secondary data from

questionnaire surveys. The broad diversity of approaches indicates the multi-disciplinary nature of resilience measurement, and this is reflected in the selected frameworks reviewed in this study.

In another review of CDR frameworks published earlier, Serfilippi and Ramnath [15] note that community resilience is inherently a context specific notion and requires a holistic approach to measurement

across multiple dimensions and capacities. They further specify that it is a function of a system of systems with interdependence and inter-linkages and hence is particularly challenging to measure. Vulnerable communities suffering from impact of repeated hazard events may have a high degree of complexity due to diverse stakeholders and the feedback loops between these groups and their environments requiring the

Table 4
Selected frameworks with dimensions and indicators. (green = covered extensively, yellow = partially covered, red = not covered).

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

			Sanitation						
			Integration of services						
		Early Warning Systems	Warning system and evacuation						
			Evacuation routes						
			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							
		Private-Public partnerships	Unity of the leadership after the disaster						
			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						

employment of innovative participatory approaches [83]. Similarly, Beauchamp et al. [55] report that any resilience assessment that ignores local priorities, their contexts, and the aspirations and motivations of local actors, may result in mis-diagnosis of resilience issues which can result in missed opportunities to support communities with their existing goals, programs and strategies.

Other researchers have shared concerns that the resilience concept, like vulnerability before it, has becoming a fashion concept, an idea of the times [122]. Resilience thinking and practice can also be considered as “ideas” travelling from one group where the term originated to another [117], for example, in the field of ecological science into others and can take form in each discipline as to fit the needs and requirements of that field [84]. This can be observed in how terms from ecology relating to populations of animal and plant life can translate into socio-technical understanding of system boundary, equilibria and thresholds, feedback mechanisms, self-organization, and function in infrastructure systems in urban settings [73,84]. The concept of travel and adoption of “ideas” can explain how resilience is translated and understood, or “interpreted”, in each setting differently and may explain how resilience is inherently a subjective concept and the need for approaches that allow the customisation of the term to the needs and requirements of stakeholders [4]. Such concepts, which may be seen as intangibles, have long been studied in operational science research that look at institutional memory, learning and change, or resistance to it, within organizations [85,86].

Operational research methods, like system thinking and system dynamics, are well suited to capturing the “travel of ideas” across organizations and communities like a “fashion” [31] and how they are adapted and then adopted for their own needs and preferences – either by convenience or design [87]. Hence, these methods may be considered as appropriate for application in participatory resilience assessments at the community level where both subjective and objective methods can be used in combination to provide insight for a more grounded assessment [41].

It is also important to realize that many researchers, and even some stakeholders, view community resilience as a normative concept, i.e. one that 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 [84]. The consideration of resilience as a normative function may ignore the problems arising from conflict within the community, the role of agency, knowledge, and power within it and 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 prior to any event [88]. 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 or not [89]. Such nuance and insight is hard to capture in objective approaches and is often missing from resilience conversations among stakeholders [38].

In their seminal work on the subject, Kahneman and Krueger [90] established the ground for the use of subjective measures in well-being and happiness research which has progressed over the years to the development of a large body of literature on subjective tools in economics, psychology and behavioural sciences in general [91,92] from which resilience research can largely benefit. In well-being literature, researchers have successfully applied subjective well-being assessments in development, economics, and other fields to avoid using top-down, donor-defined indicators of well-being [93,94]. Subjective resilience-based assessments can use tools to capture perception and attitudes of stakeholders towards community resilience and their expectations from it, building on these tools used and validated in the, relatively, longer established research fields of psychological resilience and wellbeing [55].

Jones and Tanner [4] have noted a recent increase in interest among resilience researchers in developing and using more subjective indicators in the literature indicating that observable variables (such as those captured by objective measures) are perhaps not as effective at measuring less tangible variables determining resilience as previously thought. They also highlight a growing realization among some resilience researchers that individuals and households are perhaps in a better position to assess their own capacities to absorb, withstand and recover from hazard events [4]. Resilience scholars like Maxwell et al. [48] and Beauchamp et al. [55] have shown how household perceptions of resilience, taken through subjective self-assessments, can relate to data from observable variables and have found that they are robust for use in resilience assessments if used together to complement each other. They both highlight further the importance of using both subjective and objective measures, as resilience is both subjective and objective, and propose that future frameworks be flexible enough for allowing customisation in resilience assessment tools [55].

As per the review conducted in this study, very few of the frameworks have used subjective assessment approaches to develop an adaptable, customisable CDR framework that uses the knowledge, expertise, and perspectives of community stakeholders at the local level. Only three (TAMD, CoBRA and CCVA) try to be adaptable to the context of the community by utilising more subjective tools that can adapt and contextualize the resilience assessment process to suit the needs of the stakeholders. There needs to be more effort by researchers to develop tools that allow for customisation to specific communities and that do a meaningful measurement of their resilience. A CDR framework that addresses inclusivity and customisation can then potentially help decision-makers in choosing the right interventions for the community [6]. As the review shows, the type of frameworks that have tools for greater stakeholder inclusivity and customisation both are not common among the frameworks reviewed as most can be classified as top-down in design and implementation. The lack of hybrid bottom-up approaches requires a closer assessment.

In their assessment of using subjective approaches with communities in Fiji, Ghana, Sri Lanka, and Vietnam, Béné et al. [21] explored community resilience as a “socially constructed” concept and tested several underlying assumptions of resilience research using perceptions, experience and mental models of local stakeholders in diverse settings. They found that although some assumptions are carried through (such as wealth being an important factor in the recovery proves) other assumptions, like that of social capital and its role in response and recovery, was not so clear and that resilience was, at least partially, a “socially constructed” concept, endogenous to individual and groups and contingent on knowledge, attitudes to risk and culture of the local community [21]. The study could only achieve its stated objectives by developing and employing subjective tools of analysis and conducting a more bottom-up approach to understanding the resilience of participating communities. Studies like Béné et al. [21]; Jones and Samman [49]; Beauchamp et al. [55] and Béné et al. [38] have conducted a comparative analysis of subjective and objective measures of resilience in a varying range of communities to test the validity and rigor of

subjective measures and have found them to be “reasonably robust”. The field-testing and applicability of subjective tools in very diverse settings and environments across the developing world seem to indicate that these frameworks can be applied to other groups, situations and locations and are not limited to applicability in the single case studies but still require more work from the resilience research community [21,38].

This critical approach to assessing the use of the more “interpretive” or “constructivist” subjective measures requires some ontological reconciliation on the part of resilience researchers with the more popular and frequently used “positivist” approach to understand resilience using objective measures [52,95,96]. Social scientists like Archer [97] make the point that when considering complex social phenomenon, like community resilience, researchers sometimes ignore ontological clarity and attribute too much confidence at the ability of objective or positivist approaches alone to understand reality. In a recent review of ontological positions in resilience research, Hamborg et al. [53] have indicated that resilience literature has “... blurred distinctions between positivist and constructivist perspectives and hence between resilience as an analytical concept and resilience as an element of power-knowledge regimes in science, politics and practice.” Perhaps resilience researchers need to adopt an ontological position in the middle of positivist and interpretivist ideals and adopt an approach that considers an objective reality (as the positivists) but consider that some accounts of it may differ, and even be better than others, (as according to interpretivists) such as that adopted by critical systems thinking approaches [98,99].

Accordingly, CDR as a phenomenon takes place in the real-world involving members of the community like local government representatives, practitioners, and citizens – and crucially depends on how they perceive and understand the world. One of the ways to improve the resilience assessment and measurement process is to use subjective measures of resilience, in conjunction with objective measures and not separately, to encourage local community stakeholders themselves to participate in the assessment process and to deliver additional insights not otherwise possible [48]. This highlights a current trend in the literature signifying the need for more bottom-up approaches to be developed in resilience measurement and intervention design [39]. Additionally, donor agencies from relief and developmental sources have increasingly required a more inclusive CDR assessment approach that entails a greater involvement of the community, especially marginal groups, at multiple stages of the community resilience assessment [4]. Although more research is still needed, by capturing the views, experience and knowledge of relevant stakeholders and allowing for more customisation by using participatory methods, researchers have shown that intervention design can be improved upon and this may contribute to overall community resilience than what is otherwise possible using objective measures alone [6,54].

Therefore, stakeholder inputs to the CDR measurement process can help make CDR frameworks more relevant to the community’s resilience and developmental goals [79]. The literature suggests that stakeholder engagement in the CDR process can be improved by making the resilience definition part of a co-creation process [4]. To effectively involve key stakeholders, researchers need to adapt and develop research tools that can help capture stakeholder preferences and thought processes. Resilience researchers can learn from the tools already available in participatory action research, like for example, the systems thinking method [100] or the community-based system dynamics toolkit [46] used effectively in international development, education and public health [101].

In disaster management literature, there has been an increasing call for the application of systems thinking (ST) and system dynamics (SD) modelling approaches to disaster management [75,102,103]. This set of methods has application in many areas of disaster management, including participatory research at the community level, Monitoring and Evaluation (M&E) of interventions, and public health [103]. For example in the frameworks reviewed, Irwin et al. [75] has shown in the ResilSim framework how community resilience can be represented as a

complex and dynamic system in system dynamics simulation models. Additionally, Links et al. [65] have demonstrated in the COPEWELL framework how the SD approach allows the explicit separation of baseline community performance or functioning from factors that influence resilience, and the evaluation and understanding of the complex dynamic behaviour that affects both its system performance and its overall resilience.

Participatory modelling approaches such as ST and SD modelling have long focused on the use of group model building to develop shared views of a system with complex feedbacks and interplay between multiple dimensions – an approach well suited to map out the different world views on resilience and how hazards impact a community [104]. Using participatory approaches among the diverse stakeholders has the potential to engage these groups into the conversation about their community's resilience which in some cases may be just as important a process as the resilience assessment itself [55]. International development agencies and donor organizations have also realized the benefit of developing resilience assessment tools with greater inclusivity because it can help communities measure the impact of interventions and hold the government (and/or others involved) to account [6].

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 [65]. For example, Herrera and Kopainsky [104] use GMB sessions to develop Causal Loop Diagrams (CLDs) that can be used as boundary objects to engage stakeholders in the process of food security and resilience. Similarly [105], 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 System Dynamics approaches actively participate in the resilience process by engaging stakeholders in the conversation of resilience and by using GMB for knowledge creation and gaining an understanding of what if scenarios for preparedness and mitigation [41,106].

The adaptable CDR framework outlined in this paper similarly seeks to create a conceptual or simulation model of CDR by using a bottom-up, participatory process for greater stakeholder engagement in the resilience measurement process. Table 5 shows how a four-stage process might benefit researchers in the development of an adaptable CDR framework that uses a systems approach to combine both subjective and objective approaches at different stages to develop a stakeholder-led CDR assessment tool. This approach allows researchers to use interviews, focus groups, and GMBs to involve stakeholders in defining what resilience means to them, and then, asks them to select measures from a library of indicators to determine how resilience is measured thus allowing customisation of the resilience assessment tools according to their needs.

In Stage 1, interviews and focus group discussions with community stakeholders help define the concept of resilience and the critical resilience issues facing the community. The initial phase requires a comprehensive stakeholder analysis (SA) to understand the dynamics of stakeholder groups in the local area selected for the resilience assessment. Conducting a SA can ensure more equitable representation in the CDR assessment process and also helps in problem identification and conceptualization of the critical issues of resilience in the community [107]. Additionally, using established tools like causal loop diagramming (CLDs) and drawing rich pictures, based on interviews and focus group discussions (FGDs), also help in defining resilience from the perspective of stakeholders [108]. For example, the CoBRA framework [64] uses similar tools to develop an understanding of resilience from the community's perspective, hence making sure that the relevant resilience issues are identified to be included in any resilience assessment or intervention design [64,109].

Stage 2 continues the participatory process by conducting workshops for the selection of the vital resilience dimensions (identified in Stage 1)

Table 5

Stages of using the adaptable CDR framework (development and implementation).

Stages	Framework Tasks (Systems Thinking steps in brackets)	Approach	Method used
1	Defining Community Disaster Resilience (problem identification and conceptualization)	Subjective	Stakeholder analysis, Interviews, focus group discussions, causal loop diagrams, rich pictures
2	Selecting Dimensions and indicators for the generic adaptable CDR framework (model development/formulation)	Subjective	Group model building workshops, library of Indicators
3	Community Capacity Assessment Tool (C-CAT) (model use/refinement)	Objective	Secondary data and primary data collected from the community
4	Systems Thinking (qualitative) or System Dynamics Model (quantitative) (model use/validation)	Both	Validation Workshops

and the indicators used in evaluating resilience resulting in the design of a more “fit-for-purpose” resilience assessment tool, customised for their use according to their needs. As mentioned earlier, the review of the different CDR frameworks led to the classification of keywords used to define the various dimensions of resilience, as shown in Table 2. Furthermore, this research then re-classifies and combines them into six broader dimensions or systems that capture the complex nature of community resilience including physical, human, economic, environmental, social and, a crosscutting one, governance resilience dimensions [42] as shown in Table 6. For the library of indicators, it was essential to select the most frequently covered dimensions of CDR in the literature and create a dimension wise library as shown in Table 6 where the number of indicators in the library for each dimension is shown. As an example, the Supplementary Information Sheet document shows in tables SIS1 to SIS6 the type of indicators used in each of those resilience dimensions.

The purpose of the library is to create a repository of indicators used in the reviewed CDR frameworks that can then be sorted and ranked to create a stakeholder needs specific resilience assessment tool for application in the community resilience context being explored. This sorting and ranking process adds another layer of customisation and stakeholder engagement that is important for developing more targeted tools of resilience assessment. By selecting the relevant community dimensions and indicators, the stakeholders help in co-creation of the CDR model and participate in the model development and formulation process that ensures representation of their views, experience, and perspectives in the process. The tool thus developed by the key decision makers or stakeholders themselves can then be implemented to measure resilience in the community as a Community Capacity Assessment Tool (C-CAT), an index formed of selected indicators.

In addition to tools like CLDs and GMBs, Stages 1 and 2 use a sorting and ranking approach called Q-methods to understand the preferences of different stakeholder groups regarding resilience and the issues they face. The Q-method approach is used to help define CDR and also to determine the indicators used to create the index for the community capacity assessment tool [129]. By using Q-methods to design and refine the C-CAT, the resilience assessment process gets a participatory approach built into its implementation whereby key stakeholders are an inherent part of the resilience assessment process [123]. Although the method works well with small, selected samples of individuals, it is not intended to be generalised to a larger population, hence, its appropriateness for ranking among different stakeholder groups [125,131]. The sorting process allows stakeholders to include essential measures in the C-CAT and to drop others, ranking them in order of preference from the most important (+5) to the least important (–5). Q-sort uses a forced choice, quasi-normal sorting distribution designed for use with a 48 item

Table 6
Adaptable CDR Frameworks library of Indicators by Dimensions of Resilience [42].

Dimension/System	Defined as (boundary conditions)	No. Of Indicators/ Measures in library
Physical [16,43,44,110]	Those facilities or structures that form a network of structures that perform a vital function that is 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
Human/Health [65,103,111]	The human category focuses on the skills, knowledge, labor and health outcomes of the community	20/68
Economic [75,112]	The economic resilience category includes both the static assessment of a community's current economy (economic activity) and the dynamic assessment of a community's ability to continuously sustain economic growth (economic development).	11/35
Environmental [34,113,114]	Environmental or ecosystem resilience focuses on the amount of disturbance an ecosystem can absorb without drastically altering its functions, processes and structures.	10/30
Social [20,115]	Social resilience focuses on the capacity of people to connect with each other as individuals, groups and organizations.	16/56
Governance [33,116]	Governance is an overarching dimension that looks at application of laws, regulation and the capacity of organizations to respond to, and assist, in the case of disasters.	10/47
Total		86/360

Q-set. This contains 11 ranking variables ranging from +5 to -5 which sets the number of items at each value (two at +5, three at +4, and so on) [121]. The more times Q-sort exercises are undertaken with stakeholders the larger the library of available C-CAT preferences can become, hence offering additional insights into how different stakeholders think about community disaster resilience, the capacities, and their link to the resilience problem being considered [42].

The C-CAT can generate scores as input for a systems diagram or a system dynamics model of CDR in subsequent stages. C-CATs can be developed for one or more of the dimensions identified in Table 5, according to stakeholder choice and feedback on the critical resilience issues facing the community. For example, a community suffering from persistent blackouts during storm events could potentially select Physical Infrastructure Dimension to be investigated only, if required. Suppose the problem is more comprehensive and hazard impacts cascade onto economic activities (or other dimensions as the case may be). In that case, Economic Resilience (or the other relevant dimensions) could also be selected for inclusion in the C-CAT. The C-CAT co-developed in this manner can be regarded as a community-specific resilience evaluation tool and be used to generate awareness, discussions and debate on resilience issues facing the community.

Stage 3 of the framework entails applying the C-CATs developed to measure CDR of critical dimensions in the community context to generate a score or value representing the overall CDR at a point in time. Most of the indicators selected in the library are objective and are based on validated measures used in other frameworks; hence this approach can be considered a mixed approach using both subjective and objective tools. As shown in Fig. 4, most frameworks reviewed in this study used objective evaluations, more often relying on proxy indicators of socio-economic data. The review carried out in this study provided many such validated indicators that have already been utilised – a source of indicators for a hybrid subjective-objective approach CDR framework as proposed in this study. In a hybrid approach such, as TAMD [79] and CoBRA [64], where a set of objective indicators were used to measure resilience, the benefit of both approaches for CDR assessment can be seen [6]. Finally, the fourth stage brings together these inputs from Stage 3 and, depending on the complexity of the resilience problem or issue, either develops a system's thinking conceptual model or a system dynamics simulation model for discussion and validation with the community stakeholders involved throughout the process.

In a recent application of this adaptable CDR framework in one dimension, Tariq et al. [42] developed a CCAT for Physical Infrastructure where GMB sessions were held with stakeholder groups ranging from infrastructure experts, local government, disaster management professionals and academics to co-create a tool for the assessment of physical resilience at the local level. The PI-CAT developed in the process could be used by the local government and the disaster management

authority to measure the physical infrastructure resilience of key local assets to hazards. The tool allowed those stakeholders to be confident that the metrics being used are ones that are relevant, important and will meet their requirements [42].

This paper highlights the core features of CDR frameworks and collects a library of field-tested and validated resilience indicators that can be used to develop an adaptable CDR framework. The tools developed using this adaptable CDR framework can help communities deploy better resilience assessment tools that are more “fit-for-purpose” for decision-makers and key stakeholders. Tools co-developed in this way allow for a more equitable understanding of resilience that better reflect ground realities and capture the actual resilience issues faced by a community. Researchers can potentially use the adaptable CDR framework for a better understanding of resilience issues at the local level and, hence, contribute to better risk reduction intervention design.

2.1. Policy and practice implications

This review provides a basis for developing an adaptable CDR framework which could result in blending the benefits of both subjective and objective approaches and adopt a more mixed approach as both approaches have a role to play in the resilience assessment process [48]. For example, Tariq et al. [42] used the adaptable CDR framework to first use subjective tools to develop a CCAT for Physical Infrastructure with experts, disaster management professionals and academics using the library of indicators developed in the study that then formed an index composed of objective indicators. 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 a library of indicators for a more participatory and subjective approach for resilience assessment that may help Disaster Risk Reduction planning and intervention design.

Finding wider use for such combined subjective-objective approaches may lead to improvements in problem identification with regards to critical local vulnerabilities as well as leveraging local knowledge and experience to address Disaster Risk Reduction (DRR) issues [6]. Additionally, such combined approaches have been used effectively to map resilience at the local level in frameworks like CoBRA [64] and TAMD [79] and have also proven useful as a means of assessing impact of interventions and holding those intervening in the community, whether government or non-government organizations, accountable for their actions [6].

Hence, the tool developed here is designed to address some of the needs of the practitioner community by tapping into their knowledge, opinions and beliefs and use 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 and 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 where tracking progress of local, national, and international commitments may improve the overall resilience of the community.

3. Conclusion

This research focused on conducting a review of 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 what gaps were found in the CDR literature across the subjective-objective continuum. The study also suggested using more participatory modelling approaches like Systems Thinking (ST) and its more formal application System Dynamics (SD) can prove to be useful tools in resilience measurement. ST and SD can be used together with perspective capturing methods, like Causal Loop Diagrams (CLDs) and Group Model Building sessions (GMBs), to form resilience assessment tools that can be contextualised and adapted to users or stakeholder needs. The paper also discussed the essential dimensions of CDR as extracted from the reviewed articles to form a library of indicators that can be used as an adaptable CDR framework by stakeholders. Finally, it concluded with future work being conducted using these tools and approaches and some policy implications of the tools being developed.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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