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Integrating social narratives of flood events into a text network analysis-based decision support framework to reduce vulnerability to climate change in Africa

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ABSTRACT

In many African countries, the response to climate change is obstructed by a lack of accessible and usable information, such as localised flood maps. Compounding this, current disaster risk management systems often fail to account for context-specific drivers of social vulnerability and environmental risks, crucial for enhancing social resilience to flood impacts. This paper captures the community-based narratives of flood risk in Lusaka, Zambia. Using a well-established network from the Future Resilience for African Cities And Lands (FRACTAL) group, a cross-disciplinary approach of natural and social sciences to support decision-making for flood resilience is presented as the Participatory Climate Information Distillation for Urban Flood Resilience in Lusaka (FRACTAL-PLUS) project. Local flood inundation maps were created using global rainfall and GIS datasets and then analysed across two interactive "Learning Labs" with local stakeholders. Historical observations and lived experiences were distilled from the learning labs into three community-based social narratives of flood risk. These narratives were used to calibrate the flood maps with insights from Lusaka's stakeholders using Natural Language Processing (NLP) and Text Network Analysis (TNA). The narrative-informed flood maps provide a dynamic entry point for enhancing stakeholder engagement by discussing social vulnerability to floods and climate change, highlighting future challenges and opportunities for resilience planning. The outputs demonstrate the value of convening stakeholders to discuss these topics in a sustainable setting for addressing the interdisciplinary challenges of climate resilience, offering a benchmark for better use of available resources and enabling a swift evaluation of needs and measures for resilience building.

Practical implications

The Future Resilience for African Cities And Lands (FRACTAL) project's Participatory Climate Information Distillation for Urban Flood Resilience in Lusaka (FRACTAL-PLUS) exemplifies climate services in action. By merging local knowledge with advanced analyses and technology, FRACTAL-PLUS enhances resilience strategies with contextual accuracy. Localising global rainfall data and GIS datasets with regional climate data to create relevant flood hazard maps, discussed and refined by end users, brings narrative fidelity to scalable climate services beyond academic and geographic boundaries.

Key to this was the learning lab format, initiated with evidence

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gathering and dialogue in late 2021. Twenty in-person attendees, including city stakeholders (e.g., Lusaka Water Security Initiative – LuWSI, Lusaka City Council), a community project team, and a UK Met Office representative, participated, with additional team members engaging virtually. The labs used interactive exercises, games, presentations, and discussions to reveal complexities in addressing urban flood risks under a changing climate. This collaborative effort united the lab participants to co-develop strategies for future adaptation and resilience. Two bridging surveys completed in February 2022, with 20 in-depth responses from flood-affected Lusaka residents, guided the strategic representation of flood risk across Lusaka's diverse socio-economic settings. This participatory approach generated valuable data, engaging local stakeholders meaningfully and ensuring relevant findings for future needs. The learning labs were also instrumental in gathering historical observations of flooding and climate change experiences for Lusaka, and in helping to distil community-based narratives of flood risk, resilience, and socio-economic vulnerability. These narratives added a human dimension to the technical data presented in the labs, making it more accessible and actionable. Using Natural Language Processing (NLP) and Text Network Analysis (TNA) through the open-source InfraNodus model visualised the large volume of text data generated by the learning labs, uncovering patterns, gaps, and insights from within the learning lab transcripts, providing a rapid processing format for experiential and sensory data into actionable goals around the themes of climate services.

The implications of this approach for policy and practice are profound. Policymakers can use narrative-informed flood maps to identify high-risk areas and develop targeted interventions that align with local experiences. This approach has potential to enhance social resilience to floods and climate impacts across Africa. For climate services practitioners, this model fosters community engagement in data gathering and decision-making, ensuring scientifically robust and socially relevant outputs. The interactive learning labs fostered trust and collaboration, improving communication of climate risks and resilience strategies. Beyond flood resilience, these methodologies can address other climate challenges like droughts, heatwaves, and sea-level rise in different locations. Integrating local knowledge with advanced data analysis enhances resilience across various impacts with minimal resources. The FRACTAL-PLUS project therefore demonstrates and underscores the importance of interdisciplinary collaboration, uniting natural and social scientists to address the complexities of climate resilience, serving as a benchmark for future climate services research and practice.

In sum, this paper demonstrates the power of combining local knowledge with advanced modelling tools to improve climate services through enhancing flood resilience. Localised flood maps informed by community narratives can act to enhance stakeholder engagement and address social vulnerability to climate change. The project's success highlights the value of interdisciplinary collaboration and offers practical insights for policymakers and practitioners to enhance resilience and support communities facing climate change.

1. Introduction

Tackling the complex water-related crises of the Anthropocene (Crutzen, 2006), including floods (Neal et al., 2012a; Neal et al., 2012b), demands an urgent re-thinking of how environmental and social factors influence human decision-making and can be better integrated into actionable climate change research. The IPCC 6th Assessment Synthesis Report highlights the increasing frequency of compounding and cascading climate risks, with water-related crises, including floods and drought, increasing in frequency and severity also (Scott et al., 2023). These crises adversely impact communities, with low-income and marginalised communities disproportionately affected. Historically, disaster risk management frameworks have failed to fully incorporate factors that can influence human decision-making during flood events, such as context-specific drivers of social vulnerability and environmental risks (Lavell and Maskrey, 2014; Pelling, 2003). Such factors have been recognised as a critical facet of enhancing resilience to the impacts of flood events and planning for an uncertain future, thus improved incorporation of them into the processes and strategy of resilience building for the future should be a priority at all scales (Hubbard, 2020; Lavell and Maskrey, 2014).

At the global scale, there are observed links between urban development, and the increasing occurrence, and severity of floods (Andreadis et al., 2022). Major floods in 2021 and 2022 across Asia, Europe and parts of Africa indicate that societies need to better adapt to the increasing severity and frequency of such events, whilst also ensuring that urban development is not *maladaptive*, which can exacerbate the negative impacts of floods despite the best of intentions (Best et al., 2022). Climate change is also influencing the impacts of these events, driving increases in rainfall (Hendrix and Salehyan, 2012), coupled with the pressures of growing populations living in flood-prone areas, and increased urbanisation, the likelihood of flooding leading to negative impacts has increased markedly (Mabuk et al., 2019; Hosseinzadehtalaei et al., 2021; Tellman et al., 2021).

The dynamics of urban development, increasing flood frequency and climate change are particularly complex in Africa, due to rapidly growing populations, widespread urbanisation in flood-prone areas, and the exacerbating effects of climate change on rainfall patterns; with impacts dramatically varying between communities in different locations (Chabala et al., 2013; Conway and Vincent, 2021). Beyond this broad understanding, the relationship between flood event frequency and the *exposure* of the growing urban populations is unclear and difficult to estimate (Nchito, 2007), persisting as a significant challenge to adaptation efforts across the continent overall (Favretto et al., 2018). Acknowledging these complexities and challenges, some adaptation efforts have begun to be informed by a deeper understanding of the relationship between climate and water (Umar et al., 2023), enabling a better decision-making process and more effective adaptation for the impacts of climate change to be developed (Leal Filho et al., 2022) with community *sensitivity* at the forefront of efforts (Taylor et al., 2021a).

A key effort in advancing methodologies for Africa has been through the *Future Resilience for African Cities And Lands* (FRACTAL) project (Daniels et al., 2020; Jack et al., 2020). Between January and March 2022, a core component of this FRACTAL project extension, titled *Participatory Climate Information Distillation for Urban Flood Resilience in Lusaka* (FRACTAL-PLUS), was completed through two *learning labs* (aims illustrated in Fig. 1.). The definition of the learning lab is, broadly, '*…an interactive and collaborative environment designed to facilitate experiential learning, innovation, and problem-solving around complex challenges for all lab participants*' (Sanchez et al., 2022). Building on initial evidence gathering and a dialogue phase at the end of 2021, the two learning labs were held between 26–27 January and 26–27 March 2022 in Lusaka, Zambia, with 20 in-person attendees, including city stakeholders, a community project team, a Met Office representative and a further project team engaged in the process virtually. Learning labs often involve interactive exercises, games, presentations and discussions on key challenges, to help overcome the initial complexities of these challenges presented to the participants and unite them in a mutually assured, solution-focused, process. By bringing together the participants

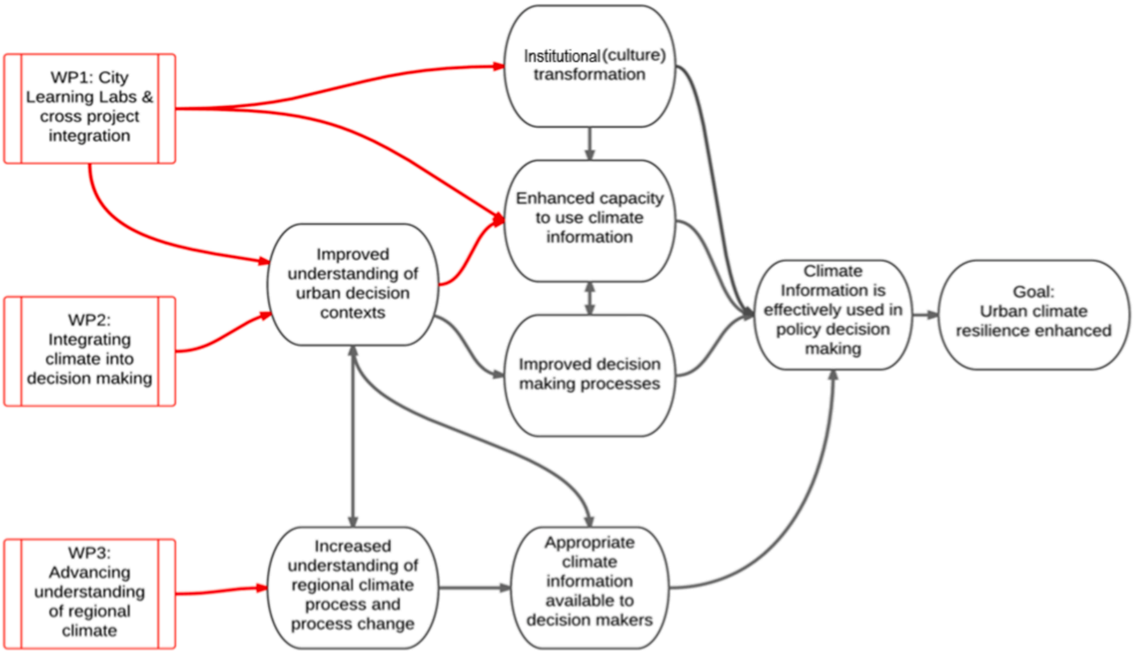

Fig. 1. The FRACTAL Theory of Change (ToC) towards enhanced African urban climate resilience with immediate foci for the Lusaka learning labs denoted at the end of the red arrows. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Source: FRACTAL Theory of Change)

from diverse backgrounds, including community members, city stakeholders, and research experts, to engage in hands-on activities, discussions, and simulations, the labs primarily aimed to foster knowledge exchange, co-create solutions, and drive actionable solutions to real-world scenarios. The research basis for the FRACTAL-PLUS extension involved a cross-disciplinary, mixed-method approach around this format to support decision-making for enhancing flood resilience under a changing climate. This approach emphasised the value of community-based narratives and participants' *perception* of current, and future, flood risk and resilience in Lusaka, Zambia; providing a valuable learning opportunity for further uptake of co-created adaptive strategies and their applications in Africa.

Lusaka's experience of pluvial flood events (Mubanga et al., 2022), driven by intense rainfall over a short duration, has historically been negative (Nchito, 2007). This is partly because of the natural and engineered drainage systems across the different settlements within Lusaka not being able to manage intense rainfall effectively (Nchito, 2007; Rosenzweig et al., 2018). Flooding in early 2009 was the worst to affect Lusaka in 40 years (Kangwa and Mwiya, 2024) and despite the severity of that event, little advance has been made in management or planning for floods as an outcome (Muchanga, 2013; Mubaku et al., 2019). However, there is a clear understanding of the impacts of flood events amongst the communities of Lusaka (Umar et al., 2023), who largely reside in unplanned settlements, regarding both the historic flooding of the city and the events of more recent times (Mabuku et al., 2019). This is likely because these communities are disproportionately affected by the impacts of flooding events (Nchito et al., 2018; Umar et al., 2023).

This dynamic is likely to be more pronounced in areas which are growing quickly, but also in those areas with pre-existing socio-economic disparities that impact community coping capacities to flooding (The Human Cost of Disasters - An overview of the last 20 years: 2000, 2020; Habitat, 2020). Specifically, the urban dynamic in Zambia is influenced by a range of conflicts between, and disconnects in, climate and settlement governance (e.g. spatial planning, enforcement of by-laws) and general *management* at a local level (Adano and Daudi, 2012). Historic, imperial and colonial legacies continue to present significant challenges to establishing adaptive efforts (Harris et al., 2012; Milner-Thornton, 2011; Parnell, 2014). Flooding in Lusaka is, then, ultimately the consequence of a complex interaction between environmental (geology, topography, climate), socio-economic (lack of affordable and suitable land, available building options and access to materials) and political factors (changing priorities linked to electioneering and government makeup), in addition to technical and resource considerations (lack of drainage implementation and solid waste management) (Simatele et al., 2012; Muchanga, 2013; Taylor et al., 2021b). Taken together, these factors emphasise Lusaka as a city that requires transformative change to improve flood resilience.

Advancing the efforts for enhanced flood resilience in Lusaka therefore requires a multifaceted approach constituted by an engagement with both the present (and ever-present) crises (Quagraine et al., 2019; Ziervogel, 2021). Requiring 'mid-range' planning (for the next 20 to 30 years) and a longer-term vision of sustainability, such as that historically offered in the structure of the United Nations Sustainable Development Goals (SDGs) (Uleanya and Yassim, 2024). To this end, the Lusaka learning labs were informed by a series of local scale, flood inundation, and model forecasts, coupled with observed rainfall data and modelled projections of future climate change scenarios (Taylor et al., 2021a). To further enrich the understanding of these narrative themes, a Text Network Analysis (TNA) based on Natural Language Processing (NLP) was applied to the learning lab scripts, through InfraNodus (Hegazi, 2022; Paranyushkin, 2019), generated from the lab participant discourse representing the interests of civil society, local and national government (particularly urban planning and disaster risk management units), development agencies, water utilities, NGOs, and academia. The outputs from this approach informed the FRACTAL report 'Supporting climate-resilient urban planning: 10 lessons from cities in southern Africa' (Bharwani et al., 2023) and have further informed considerations for capacity building and climate-informed engagement in Africa (Bates et al., 2024; Kiptum et al., 2023).

Thus, the objectives of this paper are:

- The introduction of a methodology that improves understanding of urban decision-making, flooding and climate change.
- To articulate how this methodology has integrated climate and physical modelling with community narratives to begin: i) shifting decision-making culture, ii) enhancing capacity for using climate information in decision-making, and iii) assessing perceptions of the decision-making related to flooding and climate change.
- To illustrate an innovative approach that can be used to advance the understanding of socio-environmental dynamics, through the FRACTAL learning lab format, to inform resilience building strategies for flooding and climate change.

Section 2 covers the **methods** for generating the community flood narratives for Lusaka, including the Text-Network Analysis (TNA) (**section 2.1**), merging these narratives with perceptions and realities of climate change (**section 2.2**), and generating the flood maps (**section 2.3**). Following this, **section 3** provides **a discussion** of the outputs generated from the application of these methods, closing with **conclusions** in **section 4**.

2. Methods

2.1. Generating Lusaka's community flood narratives

Aligned with the Work Packages (WPs 1–3) for the initial FRACTAL project (Fig. 1), the primary aim of the two learning labs in FRACTAL-PLUS was to determine key narrative themes on the drivers of vulnerability at the individual, household and community scales through initiating discussions between the 20 lab participants, who were maintained across both labs. These themes were then harnessed to improve understanding of how flood events happen at these different scales, what informs perceptions of future flooding events, and the dynamics of interaction at different scales of operation (e.g., between individuals, communities, local governance of disaster management and climate change adaptation measures). This approach further aimed to reconcile a methodology to integrate quantitative flood maps with qualitative information of household and community perceptions of flood events in Lusaka's recent history. Integrating these different sources of evidence would inform understanding of long-term vulnerabilities and help develop community-based strategies to reduce these vulnerabilities under the pressures of climate change. The format of the labs was like a typical workshop, varying between one large group, and sub-groups that focused on, and interactively interrogated, the research presented across the two labs. Questions were both deployed and generated around the key themes of community flood resilience and vulnerability, institutional accountability, as well as water security and governance (Bharwani et al., 2023). The discursive outcomes of both learning labs, generated through the participatory techniques with the voluntary cohort of lab participants, formed a broad set of socio-environmental perceptions. Initially, the discursive outcomes were distilled into a set of key narratives and sub-narratives by the lab participants to help identify the key themes emerging from the perceptions of socio-historic, socio-economic, and future flood risk in Lusaka. Of these perceptions, the following three narratives, with the author's expanded summary, have been selected from the Lusaka Labs to form the primary narrative at the base of analysis and discussion for this paper:

1 **It always has, and always will, flood** – Lusaka has always experienced flooding, and it always will, because of where it is built and the heavy rainfall it experiences during the wet seasons.
2 **Flooding is a climate change problem** – Climate change is worsening the problems of flooding, but we lack information about its precise impacts and the resources to tackle them successfully.
3 **If we had better early warnings, we could plan and prepare for flood events (more effectively)** – We do not have good warnings of heavy rains or floods, and so we cannot prepare for flooding.

Broadly, this analysis followed a similar format to that devised for informing the 'resilience ranges' adaptation methodology for reducing negative climate impacts on coastal heritage sites in North Africa (Hegazi, 2022). Expanding on that approach by differentiating the use of the InfraNodus model, from arranging data for site specific solutions, to using it for specifically highlighting social narrative themes and concerns in an urban setting through the Text-Network Analysis (TNA) (Figs. 2 - 4). Analysing the transcripts from the two learning labs using the InfraNodus TNA platform (see Paranyushkin, 2019), which uses Natural Language Processing (NLP) (e.g. Fu et al., 2023) to help "identify the most influential words in a discourse based on the terms' co-occurrence" (Paranyushkin, 2019, p.3584,) from the full-length of the Lusaka learning lab transcripts. This aligns the learning lab format with a *semantically enhanced analysis* (Bromhead, 2021) of the influential contexts and domains within which the participants might experience and perceive flooding and climate change in Lusaka. Applied across other fields of research, including education (e.g., Tadeo and Yoo, 2022) and management (e.g., Flyvbjerg et al., 2022), the TNA provides a form of visualisation for the Natural Semantic Metalanguage (NSM) theory, which uses a set of simple, universal concepts to express complex ideas across different languages and facilitate clear and precise communication without cultural misunderstandings. The theory is built around a set of universal words, or *semantic primes*, that are understood across all languages, including *I*, *You*, *Body*, *Mind*, *See*, *Hear*, *Feel*, *Touch*, *Life* and *Death,* amongst others (Goddard, 2021). By integrating the learning lab transcript, flood model, and climate data into semantic 'primes,' we gain strategic insights into Lusaka's specific and shared concerns. This approach dissects the transcript and research terminologies, producing a shared analysis reflecting participatory themes and perceptions of flooding in Lusaka's changing climate.

To do this, the TNA tool uses an artificial intelligence language-modelling framework to parse through the learning lab transcripts and establish emergent keyword *clusters* and themes from the text data held within the extensive lab notes and based around the different activities and interactions. This enhanced the analyses detailed in this paper and focused on the evaluation of the quantitative flood maps developed with the Global Flood Model (GFM) (Wing et al., 2024) for the learning labs (Figs. 5–10). The narratives can be attached to, and categorised alongside, these flood inundation maps; this is the approach taken to inform mapping exercises further required for discussion in the second Lusaka learning lab. Owing to the depth of the transcript developed from the first learning lab, the themes that emerged through the TNA from this lab were used to inform the scenario mapping exercises for the second lab, providing insights into the overall themes of the discourse taking place in the labs. Following a process of text normalisation (Paranyushkin, 2019) to remove bridging words and semantic elements in sentences (e.g., 'and' 'an' 'it' etc.) as well as extremely high-frequency terms of the lab transcripts (including 'climate' 'local' 'flood' 'plan' and 'day'), the main *topical clusters* identified from the learning lab transcript were: 1) Flood Resilience, 2) Financial Governance, 3) Climate Sensitisation, 4) Waste Management, 5) Adaptive Learning, 6) Weather Thresholds, 7) National Policy (Fig. 2).

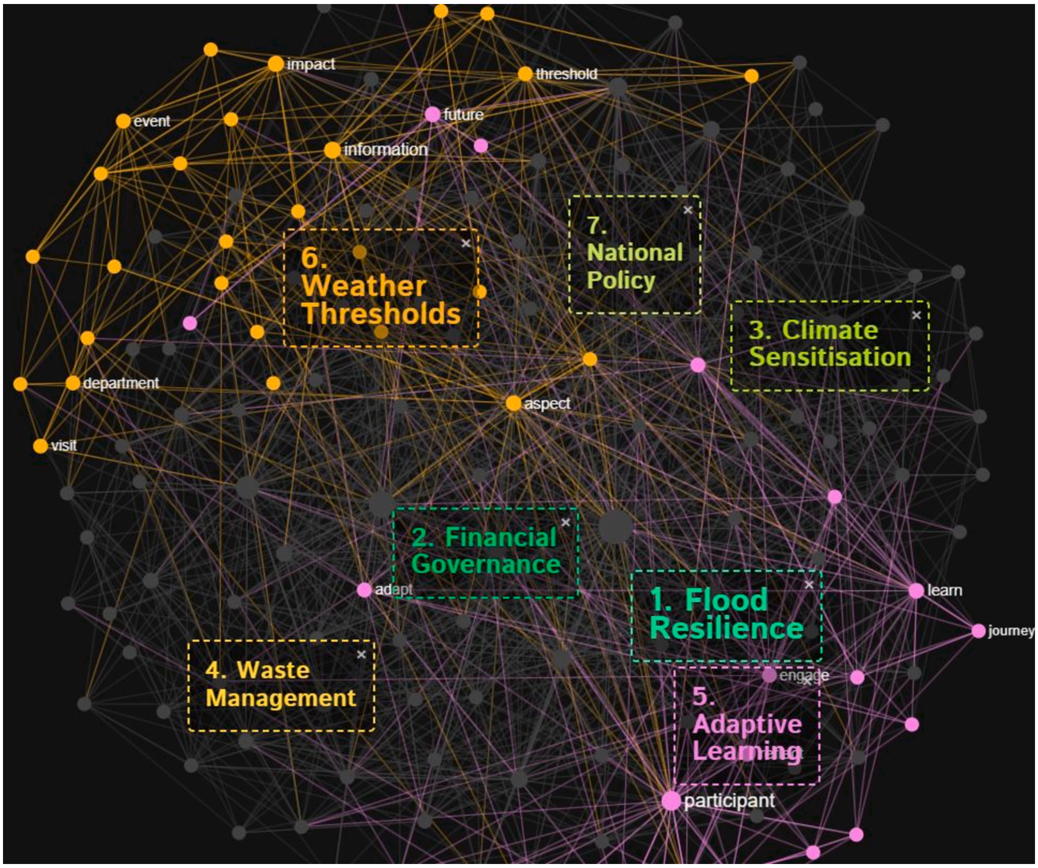

Fig. 2. The first-order TNA generated from analysis of the learning lab transcripts. The colourway is a standardised differentiation within the programme, and the order of topical clusters was defined by their overall relevance to the learning lab transcript.

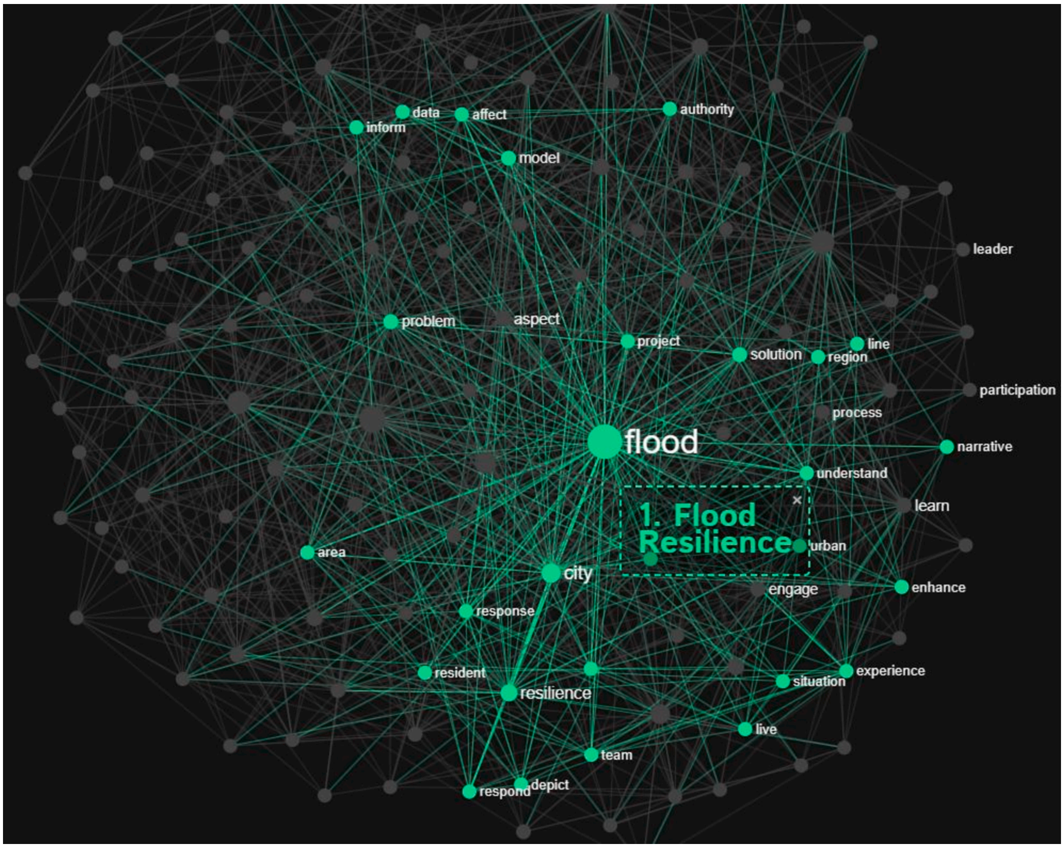

Fig. 3. The 'flood' topic dominated the learning lab discourse across both Lusaka learning labs, with the related terms extending into all the 7 topical cluster areas illustrated in Fig. 2.

Fig. 3 illustrates the key topics and topic clustering for **flood resilience** in Lusaka. The TNA structures the full learning lab discourse into interconnected 'syntactic webs' of related and dominant terms. In doing this, the TNA reveals the underlying areas of interest and illustrates the ways that the term 'flood resilience' connects to the primary topical clusters (Fig. 2) generated from the analysis of participant discourse via closely related terms between these primary clusters. In addition to being the foremost discussed topic across the Lusaka learning labs, the TNA also illustrates the extent to which building a discourse around flood resilience extended into the other topics discussed, as well as how analysis and discussion of flood dynamics can, by extension, bridge discourse gaps between other key areas of concern including *climate*, *drainage* and the flood affected *communities* (Fig. 4).

Within the TNA topical clusters, keywords were grouped and affiliated with scaling, from small to large, introduced to indicate the volume of occurrence within the learning lab transcripts as well as their relevance to the related topical cluster by occurrence. For example, alongside the topic of floods, 'drainage' was amongst the most occurrent topic throughout the learning lab discourse (Fig. 4) being most closely affiliated with the 'Waste Management' topical cluster (Fig. 2). Other key sub-topics emerged to guide the narratives and support the development of relevant quantitative analyses demonstrated in the flood maps for Lusaka, including 'community' 'participant' 'ownership' 'plan' 'improve' and 'create'. Together, these keywords and topical clusters speak to the lab participant's understanding of the key areas of intervention and action, necessary to move towards better future resilience (Kaack et al., 2022; Leal Filho et al., 2022; Boehm and Schumer, 2023).

2.2. Lusaka's community narrative on flooding & climate change

The TNA approach outlined in the previous section was used as a summative application to support the bridging between the learning lab transcript and the quantitative flood mapping exercises described in the following section. Given in this section is a broader outline of the narrative and sub-narrative themes that emerged across the two Lusaka learning labs. Alongside the primary social narratives outlined in the method section of this paper, three sub-narratives emerged from the learning labs. The first of these sub-narratives was that '*flooding is not a climate change problem; it has always been a problem*', followed by the second sub-narrative, '*flooding is just something residents need to accept*', and finally, the third sub-narrative, '*there is very little that can be done about the flooding*'. These sub-narratives are components in the overall challenge of realising enhanced climate resilience, particularly the third sub-narrative. Thus, the authors have sought to expand on these sub-narratives, by attributing them to the social narratives described in **section 2.1**, to highlight where practical steps may be taken to unpack the associated challenges of the sub-narrative context and, where possible, better identify routes through them towards enhanced, cross-scale, urban climate resilience in Lusaka.

Social Narrative 1: *'It always has and always will flood.'*.

Narrative 1 highlights that *Lusaka has always experienced flooding and that it always will flood because of where parts of the city are built and the heavy rainfall it experiences during the wet season.* Some of the lab participants did not perceive flooding as a climate change problem but rather a problem of social and other physical causes. In line with the existing literature (Nchito et al., 2018; Taylor et al., 2021b), the lab participants emphasised that flooding in unplanned settlements was

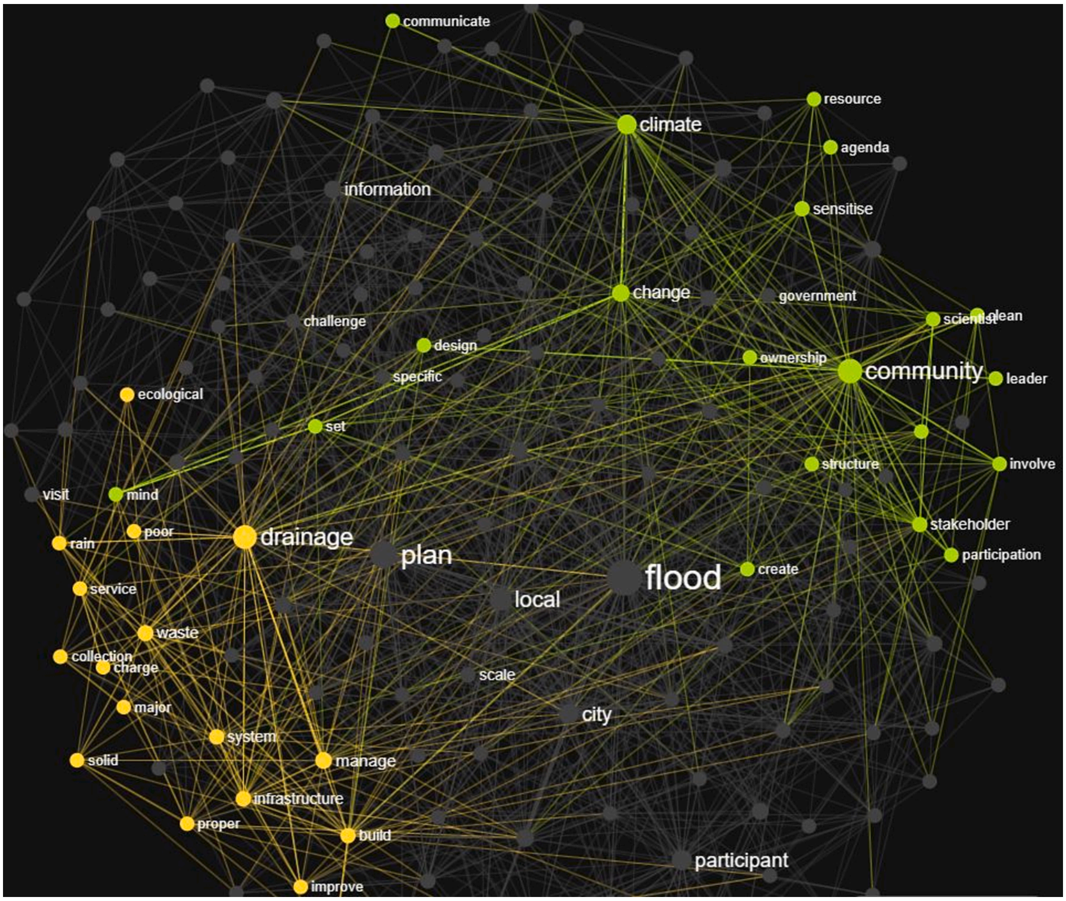

Fig. 4. The TNA can also provide insight into topical blind spots. Here, the topics of drainage and community are identified as showing a disconnect, with key connective topics highlighted in grey illustrating potential pathways for better connection between the topics.

attributable to different social and physical causes, which are unrelated to climate change. These include outdated and insufficient water and sanitation supply infrastructure, poorly designed and maintained drainage systems, a lack of solid waste management, and unplanned urban development failing to account for the risks of flooding. However, the learning lab discussion emphasised that the participants perceived many of these causes to be systemic and difficult to tackle. This is in part because past interventions have been unsuccessful in changing this, and actions are constrained by a lack of available financial resources; as also found by Wragg and Lim, 2015.

Examining Lusaka's topographical, geographical, and historic profile helps to understand why flooding has always been a problem in the past. The city of Lusaka is situated on a flat plateau and has a naturally high groundwater table (Grönwall et al., 2010). The city sits on a highly permeable limestone rock layer, which lies on impermeable dolomite bedrock (Nchito et al., 2018). When it rains heavily, the rapid saturation of the upper limestone layer due to the already-high groundwater level, combined with the impermeability of the dolomite bedrock, can quickly lead to flooding because excess water cannot be taken up by the system (Grönwall et al., 2010; Nchito et al., 2018). The historic spatial planning practices established under British colonial rule prioritised the higher-lying city centre for British settlers, causing many to settle near the outskirts of the expanding city (Wragg and Lim, 2015). Many of these outskirts were low-lying floodplains and wetlands, and it is in these flood-prone areas where multiple unplanned settlements have been developed (Grönwall et al., 2021; Nchito et al., 2018), key examples emerging from the learning labs for Lusaka are Kanyama and George (Grobusch, 2022). While many areas within the city receive heavy rain during the rainy season lasting from November until April, Figs. 4-7 show that not all areas are equally prone to floods, consistent with understanding from other studies (e.g., Pilli-Sihvola and Väätäinen-Chimpuku, 2016). The residents of most unplanned settlements, including Kenyama and George, have been disproportionately exposed to flood hazards. Follow-up interviews conducted with the learning lab participants by Grobusch (2022) revealed that a transition towards more adaptive governance is perceived as favourable, for it could increase community involvement in the decision-making processes that affect their ability to be more resilient. The follow-up research also revealed that alongside measures that the local government can initiate, other measures would also be key to enhancing community flood resilience in Lusaka. Examples include a) improving water and sanitary infrastructure because flood waters commonly interact with the contents of sanitary infrastructure, leading to the outbreak of waterborne diseases such as cholera (Mwamba et al., 2018), b) improving drainage systems, and c) raising existing structures to a higher elevation, such as houses and market stalls.

Social Narrative 2: *'It's a climate change problem.'*.

Zambia is vulnerable to the impacts of climate change (Notre Dame Global Adaptation Initiative, 2022), and there is an interest as well as some sense of urgency in examining the impacts of climate change on localities in the country, including Lusaka. Figs. 5-8 demonstrate that the flood hazard in Lusaka is already substantial, and existing research predicts that climate change may impact the variability, frequency and intensity of flooding events happening in the Lusaka region (Climate, 2016; Nchito et al., 2018; Taylor et al., 2021b). Emerging through the learning lab discourse and highlighted by the TNA via the weather event topical grouping is that *climate change will make the flooding problem worse, but local stakeholders lack both a) information about its precise impacts and b) the resources to tackle them successfully.* This narrative opens questions about climate change and extremes brought about by such change, as well as their impacts on the livelihoods of vulnerable populations. The flood inundation analysis presented in this paper is one of the first localised mapping efforts for Lusaka under future climate scenarios, underlining that, to date, there is still a lack of information about the precise future impacts of climate change on flooding in Lusaka. Specifically, stakeholders from the Zambia Meteorological Department stressed that they *lack information about flooding, flood risks, and future flooding.* This lack of information is largely attributed to resource constraints and creates uncertainty about the future. First and foremost, however, the lack of information hinders the planning of interventions, which are required with relative urgency if community flood resilience is to be enmeshed within unplanned settlements like Kenyama and George.

As resources for managing and mitigating climate change are scarce, it is important to discuss the most efficient strategies for navigating future flood scenarios. The learning labs highlighted that *local governance would play an important role in preparing such strategies*. This is, for example, because the (local) government is responsible for longer-term planning and has the potential to work across institutional silo's by bringing together different ministries and bodies working on relevant topics. This is crucial, given that the question of how the resilience of the communities vulnerable to urban flooding can be improved lies at the nexus of many different disciplines, including governance, urban planning, disaster risk management, health, sustainable development, and meteorology. Current weaknesses will be exacerbated by climate change, heightening vulnerability, and increasing the susceptibility and exposure of citizens and their assets to flooding events. The flood maps demonstrated in the following section support the case for transformation moving forward, but they are ultimately only one facet of the whole picture, albeit a crucial one for demonstrating how long-term environmental change may take shape.

Social Narrative 3: *'If we had better early warnings, we could plan and prepare for flood events (more effectively).'*.

The third narrative which emerged from the learning labs was that *there are currently no good warnings of heavy rainfall or flooding available, which means that people cannot prepare for flooding.* The learning lab discourse, supported by the TNA, indicates that there is some scepticism towards forecasting such events because of the lab participant perception that *forecasts may not be accurate or not early enough.* More specifically, existing forecasts only predict rainfall, but there are no forecasts in place which predict levels of flooding or the associated hazards due to unplanned or poorly developed drainage systems within the unplanned settlements around Lusaka. Participants also emphasised that if better early warning systems were in place in Lusaka, people would be able to better plan and prepare for flood events. As such, the future strengthening of early warning systems will play a crucial role in strengthening community flood resilience as this would create avenues of information on the events which can be communicated to at-risk communities. Considering the potential risk posed by the increasing pluvial flood hazard across Lusaka, combined with the unpredictability of potential variations in the location of intense rainfall patterns driven by climate change (Grenfell et al., 2014; Papa et al., 2023; Trigg et al., 2016), a more proactive approach to intervention that is taking place currently may be necessary. Key to enhancing preparedness for flooding is anticipating climate-driven variability in flood hazard (Mugume et al., 2015; Wung and Tongwa Aka, 2019; Wasko et al., 2021), as the hazard dynamics (scale, magnitude, temporality etc.) may vary quite markedly as a result. By discussing this with the Lusaka learning lab participants, a consensus was that this could affect perceptions of predictability and capacity to cope without more stringent monitoring and communication, with particularly severe consequences for the urban infrastructure network in Lusaka. Bringing together key ideas of *learning*, *planning* and *forecasting*, as reflected by the TNA, the discourse for this narrative focused on solutions between inputs and impacts, with a working consensus being that if flood waters appear in new areas and to greater degrees, there will need to be informed strategies for how this could, and should, be managed. Thus, informing and planning for possible scenarios in advance would be a very positive approach towards enhancing climate resilience in Lusaka.

2.3. Flood mapping of Lusaka

Parallel to the learning lab discourse and narrative analysis, quantitative flood maps were generated in two stages as a supporting component for the labs. In the first instance, general flood hazard maps were produced for Lusaka to illustrate possible flood hazard dynamics across the city (Fig. 7-10). Following the discussions that took place around the presentation of these maps in the first learning lab, a second series of maps were generated to demonstrate the possible changes in the flood hazard presented in the original maps based on modified historical rainfall patterns over Lusaka (Figs. 11 & 12). These Flood hazard maps "…are designed to indicate the probability of flooding over space and serve as a critical decision-making tool for a range of end users including building/infrastructure developers and disaster response planners" (Sampson et al., 2015). Generally, such maps are not available for many countries in the Global South owing to "the extremely high data and computational requirements of the engineering hydraulic models that have traditionally been used in their production" (Sampson et al., 2015; Ward et al., 2015). This has meant that existing research has historically been "directed toward simplified global-scale models of surface water flows", which has typically been limited to hydrological routing schemes that are driven by regional or global climate models (Sampson et al., 2015.).

More recently, the gap between simplified large-scale approaches and detailed reach-scale hydraulic models has been reduced due to significant research advances and increasing computational and data resources (Figs. 5 & 6) (Neal et al., 2021; Ward et al., 2015). This is reflected in the application of detailed hydraulic models, at resolutions of 250–1000 m, for large river reaches in data-sparse regions, including the Amazon (Da Paz et al., 2011; De Paiva et al., 2013), the Ob (Biancamaria et al., 2009), the Niger (Neal et al., 2012), the Congo (Jung et al., 2010), and the Zambezi (Schumann et al., 2013) (Fig. 6). The capture of system complexity in these models varies markedly, generating a wide range of potential interpretations of their results, owing to the various applications of different iterations of hydrodynamic processes within them (Fig. 5).

However, the emergence of highly efficient algorithms to describe the flow of water over the land surface in two dimensions has been pivotal in the development of larger-scale hydraulic models, where the most recent iterations have enabled the application of methodologies that capture complex flow dynamics in a global flood model for flood hazard assessment at ~30 m spatial resolution where local detailed data and observations are not available (Sampson et al., 2015). Despite these significant advancements in the representation of physical dynamics (Hawker et al., 2022), the interactions between flood events and community-level operations are still not represented with the fidelity necessary to engage with, or represent, community dynamics accurately into the future. Relatively recent efforts that have engaged with this need (Kienberger, 2014; Re et al., 2019) have emphasised a *co-creative* and participatory approach, like that used for the FRACTAL + project. The analytical flood maps for Lusaka used the Global Flood Model (e.g., Fig. 6) inundation layers derived from that developed by Sampson et al. (2015), which were built on a sub-grid variant of the LISFLOOD-FP (Bates et al., 2010; Neal et al., 2012) (Fig. 5). This model has then been further extended with a routing scheme for reconciling flow between floodplain cells in cases where the slope is too steep to allow the shallow water equations to be applied in an effective way (Sampson et al., 2013). This then provides the basis for the applied flood hazard maps shown through Figs. 7 to 12, which are specifically the pluvial (rainfall-driven) hazard layers based on the 1-in-5 to 1-in-1000-year event ranges.

Figs. 7 to 12 are examples of the flood maps generated for the learning labs in Lusaka using historical rainfall data (Sichingabula, 1998.) to provide illustrative support for the possible extents of flood hazard in the city. The maps were used to help prompt consideration of historical experiences of floods in the city in the first learning lab, with discussions taking place around current understandings of vulnerability as well as perceptions of future exposure in the most at-risk areas of the city, such as Kanyama and George. Further to this, Fig. 7 to 10 were presented and discussed between lab participants, with the narratives around these figures being articulated towards the overall lab theme of enhancing urban resilience. Following the discussions with participants in the first lab, Figs. 11 & 12 were produced as an extension of the earlier flood maps, with emphasis on a more simplified representation of the *probabilistic* floods shown in Fig. 7 to 10. These additional figures also sought to address the sub-narratives forming as sources of division

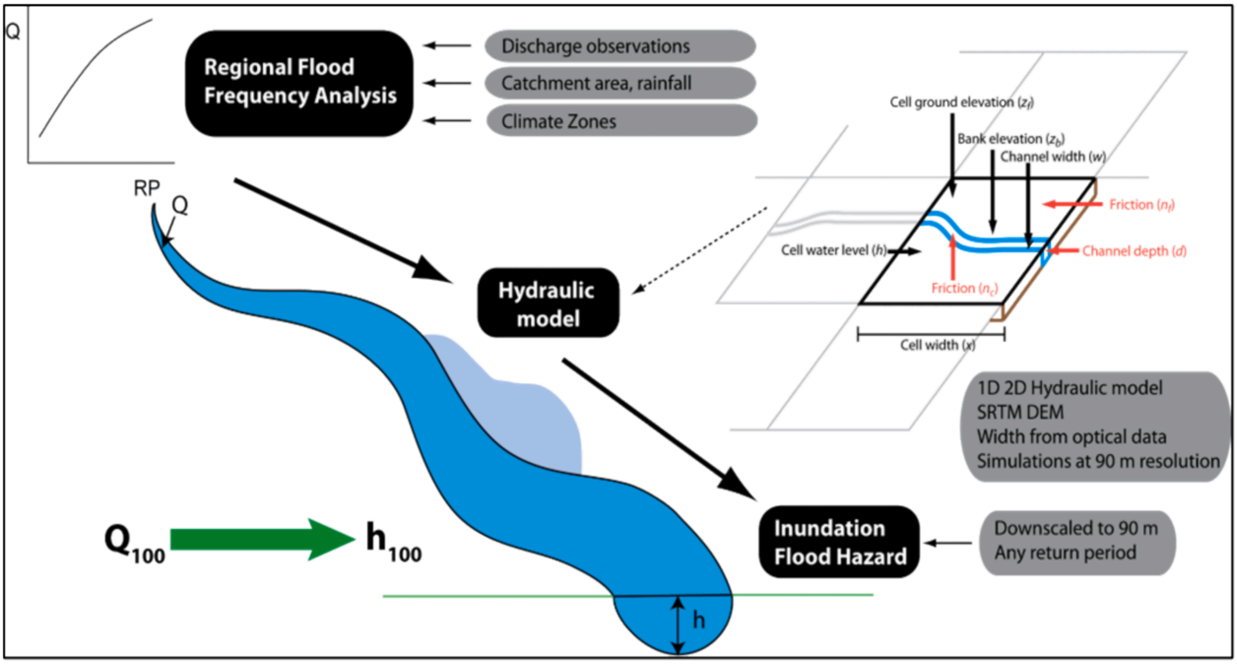

Fig. 5. Schematic for the large-scale hydraulic model, used to generate the flood inundations for Lusaka. Incorporating key metrics, including historical rainfall and climate data, across different spatial scales to generate the semi-realistic flood extents for areas with limited data availability (diagram credit: J. Neal.).

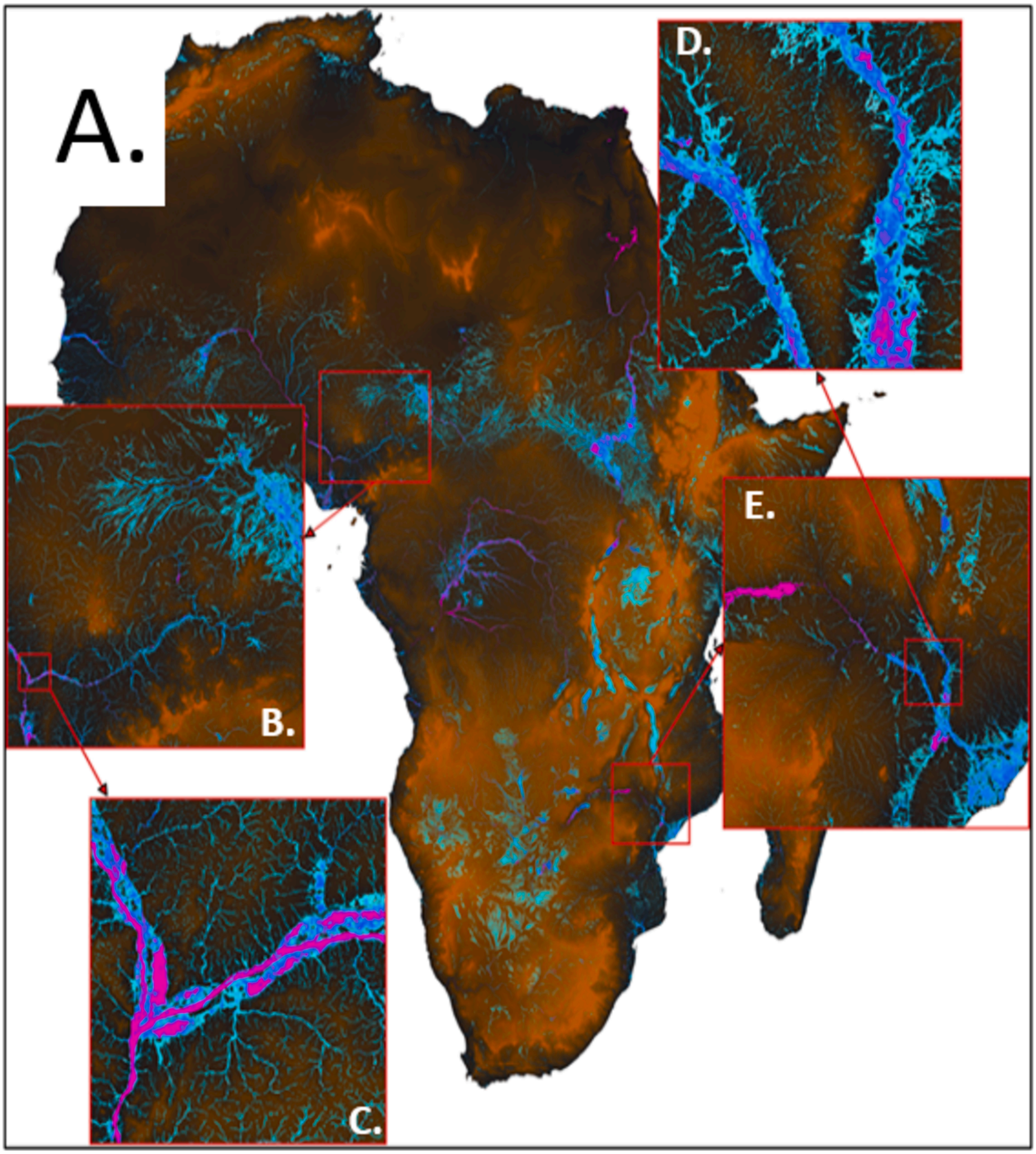

Fig. 6. An example output from the Global Flood model, an expansion on the model illustrated in Fig. 5, it shows a 1 in 100-year maximum flood depth for (A.) all of Africa, Inland Niger Delta (B. & C.), and (D. & E.) Zambezi River floodplain with colour ramp indicating flood depth from deepest (purple) to shallowest (light blue) in 2015–2016 (Sampson et al., 2015). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

within the discussions around the flood maps.

Following the narrative distillation of learning lab 1, in learning lab 2, pluvial (surface flooding) maps were generated for Lusaka and were presented to, and discussed between, the lab participants. The second series of maps were generated using the data derived from a small set of future climate projections to illustrate the implications of the expected increased frequency of heavy rainfall on increasing the likelihood of large-scale flooding. These included projections from the global climate model HadGEM2-ES, downscaled to higher resolution (50 km) over Africa, with a regional climate model (RCA) from the widely used CORDEX-Africa ensemble (e.g. Shongwe et al., 2014; Cabos et al., 2019). Also included were projections from a very high resolution (4.5 km) convection permitting model for Africa, CP4A and its 25 km driving model (R25) (Kendon et al., 2019) (detailed in Tables 1 & 2, Appendices I). This climate and precipitation data was then adapted (Tables 1 & 2, appendices I) to generate 'present day' illustrations for a 20-year return period flood across Lusaka (Figs. 11 & 12) to show the learning lab participants what a relatively likely, rainfall-driven, flood would look like across Lusaka under climate forcing. An included change factor (Graham et al., 2007; Karlsson et al., 2016; Sunyer et al., 2012), derived from the temporal mapping of the climate data, was applied across the observed rainfall data set, as well as the duration for which all models generated data (1970–2005), and interpolated between 2005 and 2021 to allow for data extrapolation between 2021 and 2059. This approach was based on a similar concept to that applied by Chalchissa and Feyisa (2022) for Ethiopia, where mapped visualisations were developed

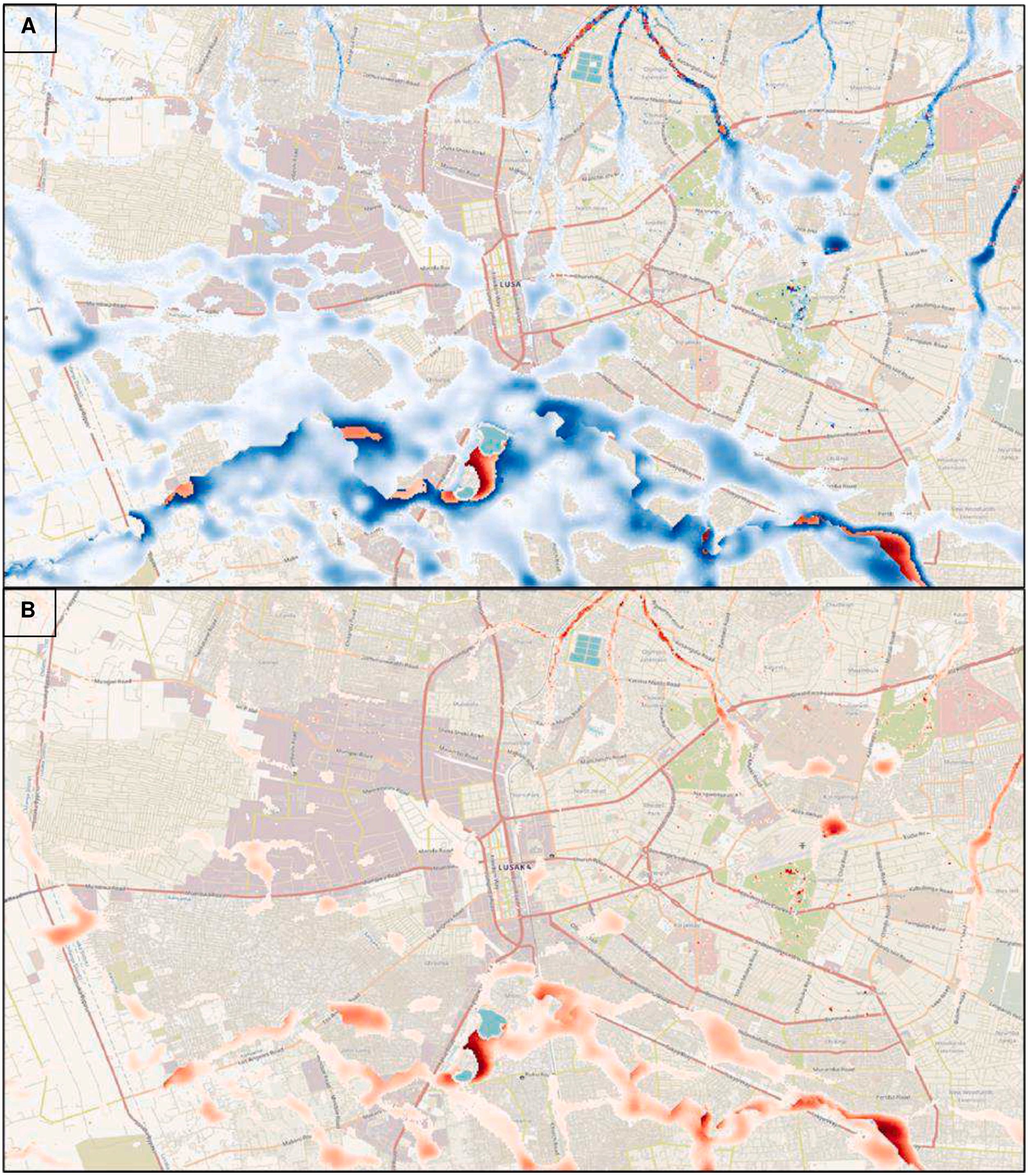

Fig. 7 & 8. A present day modelled composite of 1-in-1000 year (1-in-5 up to and including 1-in-1000-year inundation models) (**A**) and the isolated 1-in-100 year (separated out from the other inundation intervals) (**B**) pluvial flood events generated by rainfall for Lusaka based on the global flood model simulations undertaken for the FRACTAL-PLUS learning lab 1. Depth of colour indicates severity of hazard based on rainfall intensity, deepest red indicating the most likely area of prolonged flood hazard. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

alongside vulnerability narratives (Jack et al., 2020) and used to examine co-evolving circumstances further based on spatio-temporal distributions of the observed, historical, and projected flood *hazard*.

This approach aimed to establish, support, enhance and, in the case of narrative theme 2, challenge the Lusaka lab participant's perceptions of the present and future climate-driven hazards and risks. Fig. 11 illustrates the spatial severity of flood hazard from *greatest* to *least* hazardous. Nominally, this is the 5 to 1000-year return period flood extent (0.2 to 0.001 annual exceedance probability). However, when uncertainties due to infiltration rates, drainage system, and the rainfall intensities themselves are considered, it is appropriate to remove the probabilities and simply identify locations that are relatively *more* or *less* hazardous, particularly when the narratives from learning lab 1 are considered. The darker areas of flooding do somewhat correspond to the lived experience in Lusaka, as outlined in the historical accounts of the learning lab participants, news articles, and the available data from Lusaka (with modelled spatial imprecision being broadly expected). The method used in generating these maps does introduce rain *everywhere*

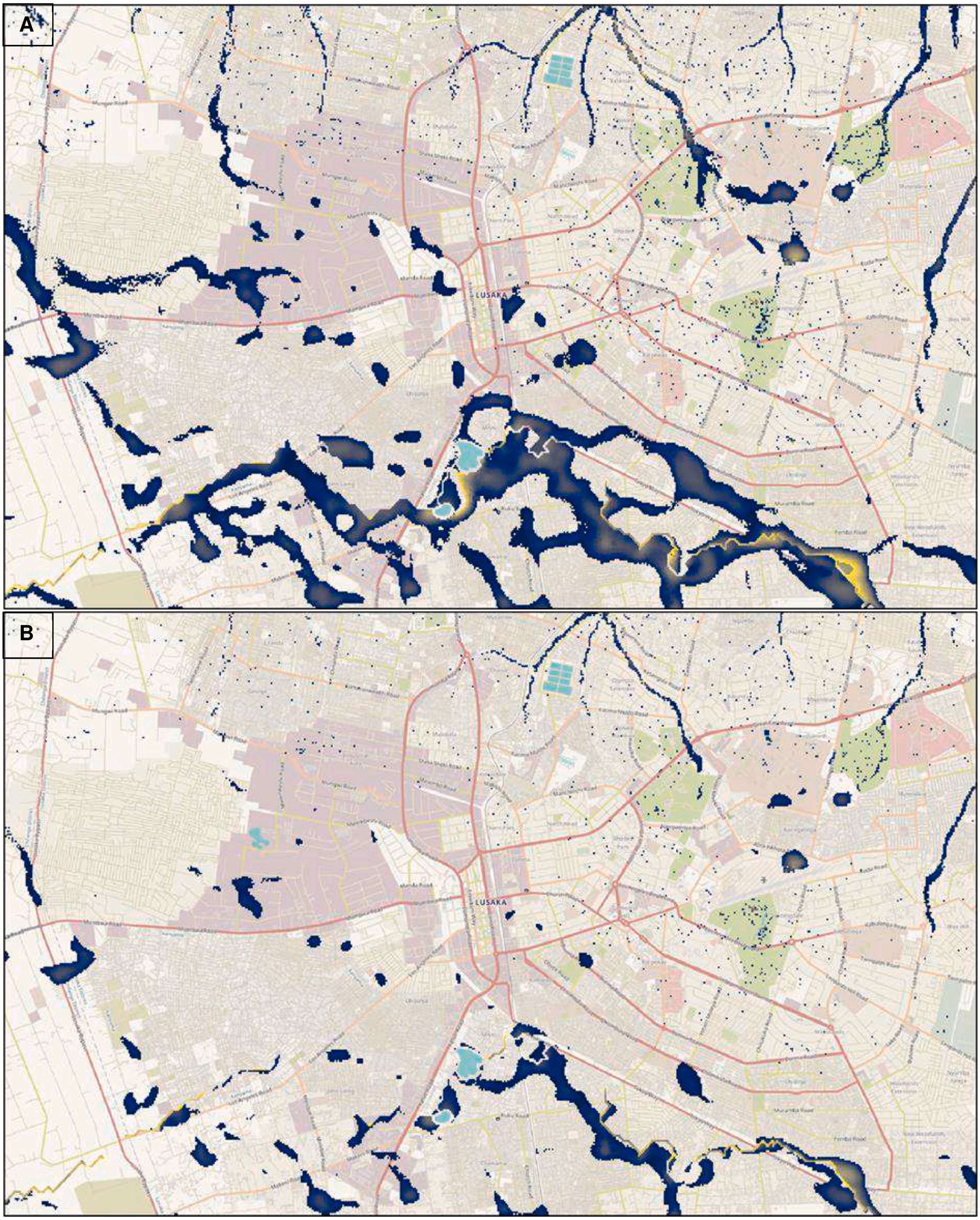

Fig. 9 & 10. Isolated (separate from the other inundation intervals) 1-in-200-year (A) and 1-in-50 year (B) pluvial flood hazard for present day 28 Lusaka based on the global flood model simulations undertaken for the FRACTAL-PLUS Learning Lab 1.

through return periods, to enable all flow routing to be highlighted and appropriate areas of possible hazard to be identified before possibly happening. In *real* or *lived* events, the return period may manifest as a more localised event, with the severity of flood hazard physically experienced in different degrees of severity by communities across Lusaka.

3. Discussion

The aim of this paper has been to demonstrate the capture of community-based narratives and perceptions of flood risk under a changing climate in a developing urban context in Africa, specifically for Lusaka, Zambia. This aim was informed by a series of regional scale

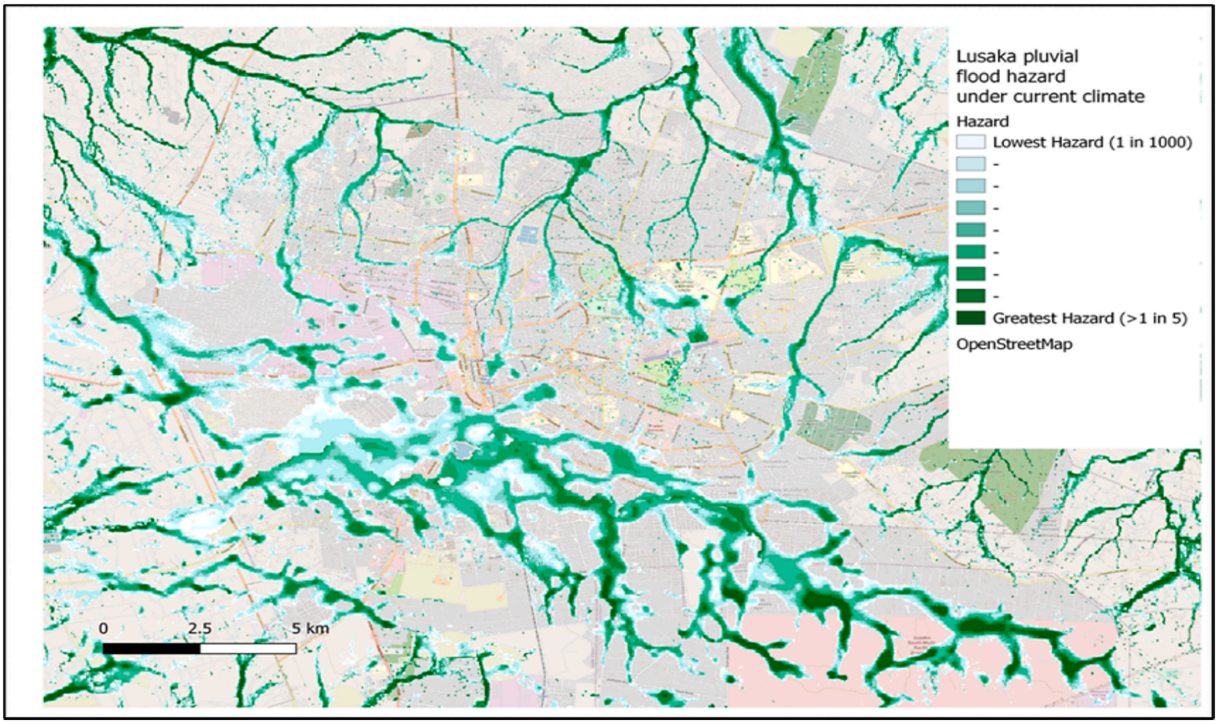

Fig. 11. A flood hazard map generated from the composite probability maps shown in Figs. 7 to 10 under the current day precipitation conditions in Lusaka showing the lowest hazard (1-in-1000 years, or lowest probability) to the greatest hazard (>1-in-5, or most likely) across the city.

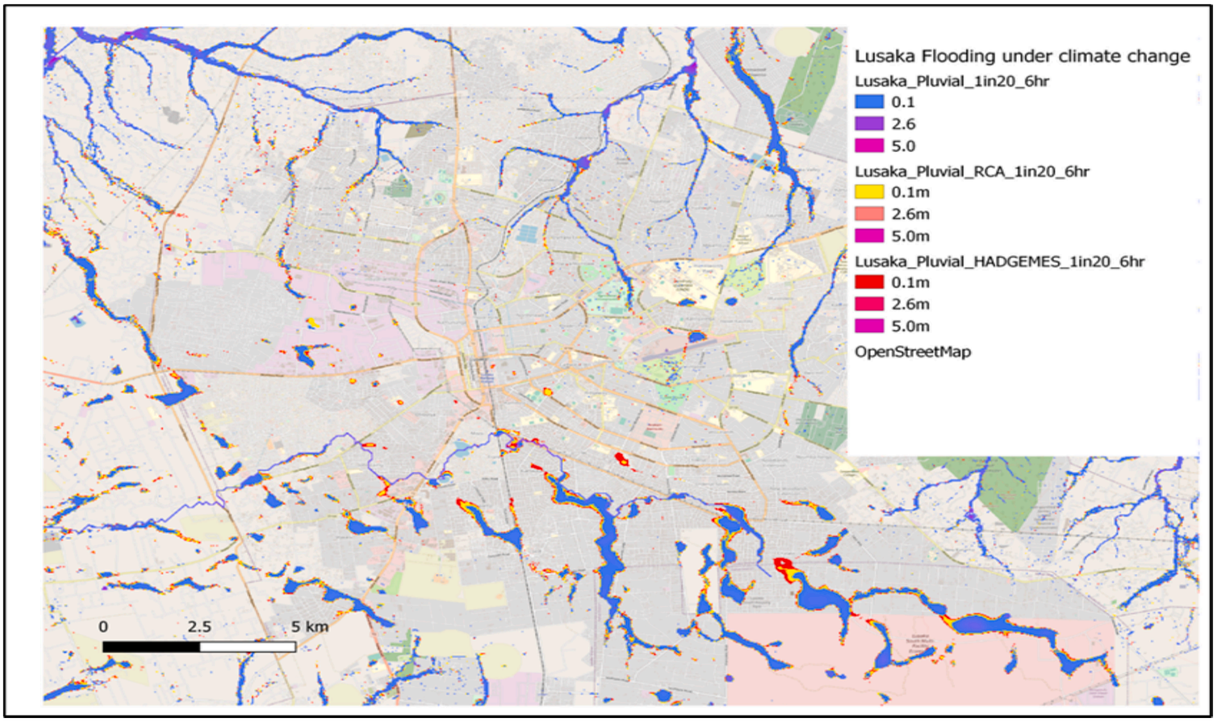

Fig. 12. Present-day flooding from the 20-year return period, calculated from daily observed rainfall totals (blue) and the equivalent with uplifts applied from two different climate models (RCA & HADGEMES – yellow and red, respectively). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

model forecasts (Fig. 7-10) of flood inundation for Lusaka coupled with observed and modelled future climate scenarios (Figs. 11 & 12) (Taylor et al., 2021a). This was undertaken to support the overall enhancement of climate resilience in the city by improving the use of climate information in urban decision making via the cascade of aims set out in the FRACTAL ToC (Fig. 1). The flood maps have synergised with the narratives from the learning labs to illuminate thought and discussion of future scenarios around flooding in Lusaka. However, it is crucial to reflect on the degree of uncertainty in the flood maps, which cannot capture all factors and nuances that were captured by the social narratives of flood experience. Likewise, the flood maps do visually demonstrate a depth of physical phenomena that are not represented in the narratives obtained from participants in the learning lab format. Complementarily, the narratives, supported by the TNA, do offer a panoptic of the social discourses, perceptions, and priorities around flooding in Lusaka. Such perceptions and discourses ultimately do shape the political agenda through policy decision making being guided by the highlighting of community concerns and needs, helping to drive government action towards more adaptive and inclusive flood management strategies (Granderson, 2014), which ultimately influences the implementation of policy options that affect the social vulnerability of individuals, households, and whole communities to flood events.

Central to many of the discussions that took place during the Lusaka learning labs was a theme of *inequality*, with these discussions on this theme moving between the explicitly socio-economic, to governmental, spatial, in the sense of spatial development and expansion of Lusaka in planned and unplanned ways, or a combination of all these dynamics, over time (Kanbur et al., 2005; Kennedy, 2017; Neiman, 1976). The nuance of these discussions can only be fully appreciated from review of the whole learning lab transcript or by having been present to the in-person discussions. Similarly, several possible solutions to the narrative themes were discussed within the learning labs, but only elements of these have been picked up by the TNA tool (Figs. 2-4). These speak to the broader involvement of all actors and stakeholders to develop and strengthen the links between the sectors of society and the governance that determines their dynamics, as well as the socio-environmental links at large. Contextually, what is being discussed here is the formation and strengthening of a sustainable, *human-water system*, described as 'an ambitious blueprint for reducing inequalities' (Di Baldassarre et al., 2019), but which also provides an appropriate contextual starting point for giving dimension to the current and future interventions of all actors involved. The complete formation of such a system requires a comprehensive capture of the dynamics that shape these systems (Scanlon et al., 2023.) It also requires further consideration of what connects the narratives of Lusaka, formed around the participant-led delineation of historical and current perceptions of flood dynamics in the city, to the reality of the environmental dynamics that necessitate changes in the processes of adaptation and risk reduction (Konar et al., 2019). It is only once these links are mapped and tested that avenues of efficient planning, management and communication concerning the structure of future capacity can be clarified, and the allotment of appropriate resources to facilitate this future capacity can be made (Reed et al., 2022; Turner et al., 2003).

The recent practice of managing water has "been dominated by technocratic, scenario-based approaches" (Di Baldassarre et al., 2019). These may "work well in the short term but can result in unintended consequences in the long term" due to a limited address and effective incorporation of dynamic feedback between the natural, technical, and social dimensions of human-water systems (Di Baldassarre et al., 2019). Inequality is a primary limiting factor in this context, with the lack of available, high-quality data and flood records in Lusaka acting to further reduce the capacity for effective risk management. Thus, whilst there is still room for improvement concerning participation in overall water management, Lusaka, and indeed Africa generally, is a particularly pronounced case in terms of limited data availability to inform enhanced resilience strategies (Kitpum et al., 2023). The participatory approach of the FRACTAL-PLUS project aimed to articulate the nature of, and limit the potential for, unintended future consequences by better capturing the social dimensions of such a system, embedding them within a narrative structural process incorporating past, present, and future demonstrations of flood scenarios, thus further aligning with the future orientated, '*resilience building*' emphasis of the FRACTAL ToC and the UN SDGs more broadly (Satterthwaite et al., 2020; Wilkinson and King-Okumu, 2019).

Discussions with participants on the present-day and future flood maps sought to establish a consensus on the agreements and disagreements based on the flood maps initially presented to them in the first learning lab and those constructed from climate models, presented to the participants in the second learning lab. There was a broad agreement between the constructed flows (Fig. 7-10) and the summary flood hazard map (Fig. 11), with the two climate models used indicating adjacent areas at risk in the changing climate. However, the inability of the GFM to model flooding outside of the larger rivers in Lusaka was identified as a key limitation to demonstrating the localised flooding dynamics. This limitation is problematic as the participants in the learning labs, and the subsequent narratives, relayed that a large influence on localised flooding events in the city was from smaller streams and blocked drainage channels. Thus, whilst it is notable across all flood maps that the natural drainage network, as well as topography, is very influential, the roles that smaller streams may play in more localised instances needs closer analysis and further consideration.

Based on the inclusion of the climate model data (Tables 1 & 2, appendices I), there is a subtle but observable spatial variance in the flood hazard (Figs. 11 & 12) from the different data sources which are relevant to narratives 1 to 3, as well as the related sub-narratives. For example, in the north of the city, there are some well-defined rivers and small floodplains, upon which the climate uplifts have little impact on flood extent at the modelled intensity or duration (Figs. 11 & 12). However, in the south and southwest of the city, primarily in the locations of large unplanned settlements and where the topography indicates poor drainage, a greater sensitivity to climate change-influenced flood events can be seen in terms of variation between the coloured extents (Fig. 12). It is expected that this would likely be maintained across most intensities and durations if the same methodology was used. A key assumption for the modelling approach is that the local drainage networks can remove the 1 in 2-year rainfall with relative ease. Thus, in areas with particularly poor infrastructure, such as unplanned settlements, these maps will likely underestimate the hazard relative to locations with better infrastructure (Martínez et al., 2018; Kourtis and Tsihrintzis, 2021).

Therefore, it is understandable that there is not just one single narrative around flooding in Lusaka – *but several different ones*. A homogeneous perception of the flooding problem and, more importantly, how to solve it, ultimately does not exist (Lowe et al., 2006). Rather, a multitude of causes and amplifiers of the problem exist, which will likely be exacerbated by climate change (Fløttum and Gjerstad, 2017), speaking to the overall complexity of the challenges ahead. Because of this causal complexity, it has become clear that a range of solutions to tackle the complex flooding problem are necessary and while the quantitative flood maps have added tremendous value in illustrating the potential future flood hazard, the social narratives from the Lusaka learning labs have illuminated the deeper social dimensions of these hazards. Unpacking these narratives and analysing them further, using tools like the TNA, alongside the visual representations of the hazard can successfully guide responses to the hazard, enhancing scope for potential resilience building pathways to the most vulnerable communities living in the unplanned settlements of Lusaka. To this end, the natural drainage systems, and to some degree the engineered drainage systems simulated for the flood maps, are an important strategic asset for future planning of flood events in Lusaka. Also, the narratives further highlighted the challenge of solid waste management across Lusaka, which must be addressed to ensure that the drainage channels are capable of functioning in this strategic capacity and not congested with waste (Nchito et al., 2018), further ensuring the continued validity and relevance of the mapped visuals generated for FRACTAL-PLUS.

Local governance was also an enduring theme throughout the labs and was variously highlighted by the TNA (Fig. 2) across all 4 topical clusters, particularly across the *climate sensitisation* sub-cluster (marked in yellow) and by the recurrence of the *community* term. It was highlighted in the learning labs that to build community resilience to urban flooding, governance approaches need to be adjusted to build more effectively on the capture of such connections, engaging actively with *complexity* and planning for *uncertainty* (Termeer et al., 2017). These are important considerations for both climate modellers and local policymakers who wish to simulate future flood risk as accurately as possible while engaging with governance and guiding policy measures despite "persistent uncertainties about the nature and scale of risks and proposed solutions" (Termeer et al., 2018, p.1). As such, a departure from *reactive* to *proactive* flood risk management should be an imperative (McClymont et al., 2019) for Lusaka. Synonymously, shifting from *resisting* floods to actively *adapting* and *transforming* the city, and its communities, to become less vulnerable to floods will be key to realising the ambitions of longer-term resilience building (Hegger et al., 2016; McClymont et al., 2019). During the learning labs, the participants defined 'flood resilience' in many ways. Some definitions are more oriented to *resisting* flood events, while some stressed the need for *recovery* from, and *adaptation* to, them; and others emphasised *transformation* to be able to deal with flood events better in the future (Grobusch, 2022). Generally, there was a strong consensus that *adaptation* and *transformation*, as illustrated by the topical clusters of the TNA, are key for enhancing community flood resilience. The definitions of these terms have implications for the types of measures which should be prioritised to enhance community flood resilience in the future, given that financial resources are limited. Hence, how adaptation and transformation, in the form of resilience, physically take shape in practice will require considerable further research.

Shifting toward enhanced flood and climate change resilience in Lusaka therefore requires 'multiple elements', according to the lab participants. First, *collaboration and bridge-building across institutional silos and between different stakeholders* should be a priority. In Lusaka and elsewhere, flood resilience cuts across the mandate of different stakeholders in meteorology, governance, urban planning, disaster risk management and reduction, long-term planning, health, and sustainable development. Second, this requires *a combination of governance and other measures*. In the governance domain for Lusaka, a shift towards more adaptive governance was perceived as favourable by the learning lab participants, as it could increase community involvement in decision-making processes at the city level, ultimately giving the community a stronger voice in the matters that affect them (Djalante et al., 2011). One example of a measure proposed to directly enhance flood resilience was to improve early warning systems in a way that would be understandable for households. Households are the building blocks of communities; hence, to build community resilience, it is important that individual households can prepare for flood events. Even when models and predictions are not 100 % accurate, it is favourable for communities to consider these outputs in their preparations for flooding if what is shown, does occur (Rollason et al., 2018).

The accessibility of the current early warning system to the flood-prone public in Lusaka's unplanned settlements is apparently very limited and could be improved by translating information into the different local dialects, not just English (Chitengi Sakapaji, 2021). Thus, transposing technical terminology into easy-to-understand, actionable language can provide practical and actionable instructions with tangible benefits A unanimously agreed upon example given in the labs being the advice to store valuables and important belongings in higher up locations in homes and accommodation to avoid loss. This measure could be prioritised even under financial resource constraints, as the information is already present but only requires some adaptation to elicit tangible, and meaningful, large-scale benefit across the social diaspora of Lusaka. It is unclear how future governance arrangements might take place around the implementation of adaptation and transformation measures like these, however. While such dynamics are difficult to capture in the flood map analyses, the flood maps were judged by the lab participants as important and valuable evidence that gave weight to the need for cross scale change needing to happen to ensure a more resilient future for Lusaka's communities.

4. Conclusions

In Lusaka, up to 70 % of residents have been living in unplanned settlements (Lupale and Hampwaye, 2019), presenting a significant challenge to any planning for, management of, and communication around flood events. It is in such settlements, where residents have been, and still are, regularly exposed to flooding, acutely exacerbating existing development challenges on a national scale. Subject to these challenges, the communities in these settlements are further enmeshed in adverse social and economic cycles that further their risk to the unseen, but ever-growing pressures, of climate change. In response to these issues, an extension of the FRACTAL project (Daniels et al., 2020; Jack et al., 2020), 'Participatory Climate Information Distillation for Urban Flood Resilience in Lusaka' (FRACTAL-PLUS) has developed a methodology for utilising flood maps produced by a high-resolution Global Flood Modelling (GFM) system, to engage with historically flood-affected communities in informal urban settlements and inform a socially conscious approach for steering future decision-making, and action; under a changing climate.

This paper has illustrated the many benefits of this co-creative, narrative-based methodology, by incorporating different experiences of flooding in Zambia, and of using these experiences to inform the direction of the event mapping, to enhancing their usefulness in formulating effective strategic interventions at the interface of community and governance. Climate change will increase the frequency, magnitude, and variability of the flooding events that have been demonstrated through the mapping exercises here demonstrated. Consequently, the lab participants welcomed the FRACTAL-PLUS project's focus on demonstrating and discussing the scope for enhanced flood resilience across Lusaka, and particularly for its unplanned settlements. The learning labs, in their capacity of bringing together representatives from different areas of Lusaka's community, further acted as an important sounding board for prioritisation of issues and their solutions, with the most prominent of these being the pressing need for local government to become more *adaptive* and *inclusive,* with a better representation of community voices in the decision-making processes.

To this end, the data generated by the FRACTAL-PLUS project can be implemented through an easily replicable, multi-step, process primarily aimed at delivering climate services through enhancing flood resilience in Lusaka's unplanned settlements. The Lusaka labs were conducted over four days, spread across 2–3 months, utilising a blend of engagement strategies that included games, drawing, writing, interactive challenges, presentations, open discussions, and Q&A sessions. These varied approaches, involving both group and individual activities, ensured that lab participants remained engaged with the complex issues without feeling overwhelmed. Importantly, prior training for participants was not required, as the aim was to foster participation and knowledge exchange between experts and non-experts on shared themes and challenges. Professionals with expertise in data emulation and modelling guided the delivery of modelled outputs, helping to develop a critical understanding and deeper meaning of the session content. These sessions therefore also served as a valuable training opportunity for the participants, expert and non-expert alike. In terms of step approach, the high-resolution flood maps (or comparable media) and their associated data should be integrated into community engagement sessions, like the learning labs, to ensure that residents and local stakeholders are able to engage with the potential risks and impacts of flooding under various climate scenarios. The sessions can also be used to facilitate the co-creation of tailored mitigation strategies that reflect the lived experiences and insights of the affected communities, like the flood narratives generated by the engagement process of the learning labs. Following this, the insights gained from these engagements can be used to inform and guide local government policies and planning efforts. For example, following the second Lusaka learning lab much discussion focused on municipal strategies for solid waste management in and around unplanned settlements, guided by the highlighting of the relationship this has with increased likelihood of pluvial flooding in vulnerable communities through the combination of flood maps, climate data and the TNA.

Establishing a sense of reproducibility in resilience building strategy is crucial for maintaining consistency in climate services, ensuring that policy makers, stakeholders and communities alike have access to dependable information upon which they can inform future planning and share a sense of responsibility in the outcomes. In taking this approach for incorporating community feedback into this process and prioritising adaptive and inclusive governance, local authorities can develop more effective and equitable flood management practices, formed at the nexus of community need and government strategy. Discussions in the Lusaka learning labs indicated that these practices might include infrastructure improvements, such as enhanced drainage systems, and the adoption of broader-scale, Nature-based Solutions (NbS) to mitigate flood risks sustainably. Finally, much discussion focused on improved monitoring and evaluation to assess the effectiveness of implemented strategies and the ability to adjust them as needed. This iterative process reflects a considered, post-project approach that was adopted to ensure that the flood resilience measures remain responsive to changing climate conditions and community needs, ultimately fostering a more resilient urban environment in Lusaka, as well as acting as a blueprint for scaling up similar approaches for addressing these needs on a larger scale, or for different settings.

From deploying the flood maps into the learning lab format, the sense of temporal and probabilistic nature of floods and their severity differs markedly between that which was modelled and that which is experienced in Lusaka, reflecting a primary limitation in the use of this form of data as well as the main challenge that prompted the use of the TNA. The way both, modelled dynamics and experience, are communicated and used to develop an understanding of the other relies distinctly on how each is represented and prioritised within the decision-making process. There have been several key pieces of work which have emphasised the need for equity and balance in this approach, both concerning risk assessment (directly for flooding and coastal storms, see Alexander et al., 2011; Viavattene et al., 2018; Ballesteros et al., 2018) and specifically for pluvial flood risk in urban areas (Schmitt and Scheid, 2020). The broad emphasis of these works has orientated communication of such events towards *severity indexes* (or, comparably, 'resilience ranges' (Hegazi, 2022)), *that* incorporate the rigour and nuance of statistical approaches, but also provide scope to engage with the perceptions and insights of affected communities and non-hydrology experts.

Pluvial floods are, and have for a long time been, common in Lusaka (Nchito, 2007; Umar et al., 2023). They are also a challenging phenomenon to demonstrate with persistent accuracy and clarity (Bulti and Abebe, 2020) in models. Under the pressures of climate change, the intensity, frequency, and spatial extent of such events are predicted to increase, with the impacts likely to be most profoundly felt on localised scales (Tonn and Czajkowski, 2022). Such events are also liable to great variance in that which is modelled against that which is experienced across different scales, with the participants across both learning labs particularly highlighting the high likelihood of negative impacts from domestic solid waste and a lack of drainage networking on the flooding dynamics in the unplanned settlements of George and Kanyama – two of the most consistently flood affected areas in Lusaka. A possible future strategy for managing this in a cost-effective and sustainable way could be the Nature-based Solutions (NbS), involving systems of green roofs, infiltration trenches and swales (Piazza and Ursino, 2023). However, the flood inundation mapping of Lusaka indicates that Lusaka is an urban settlement built on proximal headwaters, with a clear lack of sufficient natural topography to support effective drainage away from the city. Thus, any ambitions for NbS's in Lusaka would need to fully consider water management from within the city or devise a novel solution for managing current and projected imbalances that might go beyond the localised scales of the example NbS's (Seddon et al., 2020).

Furthermore, while the floods cannot be stopped from happening, their negative social and economic impacts can ultimately be mitigated by enhancing community flood resilience, possibly in the most cost-effective way amongst the unplanned settlements where the negative impacts would be most acutely felt (Nchito, 2007; Di Baldassarre et al., 2010; Bizimana and Schilling, 2010; Ali et al., 2017; Umar 2023). Since flood resilience has been found through the FRACTAL-PLUS project to intersect across the mandates of many different agendas in Lusaka, building community flood resilience in the city's unplanned settlements *needs* to be a multistakeholder endeavour, with the many barriers and enablers necessarily embraced, and then built upon incrementally as exemplified by the learning lab approach here described (Ganeshu et al., 2023). The social narratives formed around the flood maps presented in the Lusaka learning labs, and brought together in this paper, do speak to a broader sense of social vulnerability to flooding and climate change in Africa. The methodology presented in this paper also offers a means by which a diverse range of community stakeholders can be engaged in a dialogue of agreement and understanding of risk immediate to natural events, and future impact based on the enhancing potential of climate change. This is a complex endeavour that, in sum, represents a positive advance in benchmarking a strategy for enhanced urban climate resilience in Lusaka, in Zambia, and in Africa also.

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CRediT authorship contribution statement

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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.

Appendices I

Table 1. A sample of the climate model data for precipitation over Africa alongside the Change Factor (CF) calculations for the annual increase and annual average.

Present Day	HadGEM2-ES (1970–2005)	RCA (1970–2005)	Future Period	HadGEM2-ES (2030–2059)	RCA (2030–2059)	CF HadGEM2-ES	CF RCA	CF pa		CF ave/pa	CF ave (2030–2059)	CF pa (2030—–2059)
5-Yr RP	71.2	76.4	5-Yr RP	101.6	104.4	42.70 %	36.65 %	0.75 %	0.64 %	0.70 %	39.67 %	1.37 %
20-Yr RP	89.9	104.8	20-Yr RP	116.2	122.6	29.25 %	16.98 %	0.51 %	0.30 %	0.41 %	23.12 %	0.80 %
50-Yr RP	96.4	127.8	50-Yr RP	121.5	133.5	26.04 %	4.46 %	0.46 %	0.08 %	0.27 %	15.25 %	0.53 %

Table 2. Examples of the Change Factor (CF) approach applied to the Observed rainfall records from Zambia with extrapolations for unobserved periods based on the climate model annual change factors shown in Table 1 above.

					RCA	HadGEM2-ES
Present Day	Observations (1982—–2012)	(1970—–1982)	(2013–2022)	(2030—–2059)	(2030—–2059)	(2030—–2059)
5-Yr RP	97.8	97.3599	98.2401	99.13986	133.6429319	139.5573034
20-Yr RP	120.6	120.28644	120.91356	121.5648	141.0835878	155.8812013
50-Yr RP	136	135.7688	136.2312	136.7208	142.0657277	171.4107884

Data availability

Data will be made available on request.

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