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A framework for assessing climate resilience of informal settlements: the case of Eswatini

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ABSTRACT

Informal settlements are the most climate change vulnerable areas in cities due to poor-quality buildings and infrastructure, and lack of risk-reducing measures. This paper presents a context sensitive resilience assessment framework to assess the climate vulnerability of informal settlements and identify actions to improve their resilience and functionality. While various frameworks exist for assessing urban resilience, few are directly applicable to the context and needs of informal settlements in African contexts. An informal settlement, Msunduza, located within a tropical climate zone in Eswatini, Southern Africa, was selected as a case study for the development of the framework. The study draws on in-depth expert interviews and field observations, to identify key climate change hazards, impacts to which informal settlements need to adapt, and vulnerable components critical for maintaining functionality under climate stress. The findings of the study were synthesized to develop a resilience assessment framework for informal settlements, incorporating components from established urban resilience assessment frameworks, with fine-grained observational tools. The study contributes to resilience thinking by offering a framework that could leverage informal settlement upgrading interventions. While based on the context of Eswatini, the framework is designed to be flexibly adapted to similar informal settlements in Southern Africa.

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1. Introduction

Climate change is considered one of the major and urgent challenges faced by humanity in the twenty-first century (IPCC, 2021). While its effects are already intensifying and affecting the proper functioning of cities, there is still limited planning for and investment in adaptation measures (UNEP, 2023). The World Bank predicts that by 2030 climate change threatens to push millions of Africans into poverty and unravel hard-won development gains (Hallegatte, 2016).

The areas most vulnerable to the impacts of climate change within cities are informal settlements. This vulnerability is particularly extreme in the Southern African context (UN Habitat, 2014) where informal settlements are rapidly expanding and shaped by historical inequalities, colonial legacies, and post-independence urban policy (Charlton & Meth, 2017; Huchzermeyer, 2011). These settlements are commonly underserviced and lack risk-reducing infrastructure and services addressing resilience (IPCC, 2014; UN-Habitat, 2018).

While informal settlements are generally defined according to their legal status (Ploeger & Groetelaers, 2006; Potsiou & Loannidis, 2006; UN-Habitat, 2014; UNECE, 2009), this study adopts a broader definition, similar to scholars such as Roy (2005) and Sarmiento et al. (2020), who hold the view that informality is not a fixed legal category but a dynamic continuum of urban development that blurs the boundaries between formal and informal systems. In Southern Africa, informal settlements are characterized by incremental housing processes, overlapping tenure arrangements, and diverse government structures (Chipungu, 2011; Turok & Borel-Saladin, 2016). Hence, informal settlements should be understood as evolving socio-spatial systems with varying levels of formality and access to resources.

Generally, informal settlements are not well prepared for climate change, making them exposed to floods, heavy storms and heat waves (Revi et al., 2014), which exacerbate already harsh living conditions. In Southern Africa, these areas are exposed to climate-related risks due to their location, limited infrastructure, and socio-economic marginalization (UN-Habitat, 2014). While several interventions (Keivani & Werna, 2001; Nassar & Elsayed, 2017; Satterthwaite et al., 2020; Wekesa et al., 2011) have been implemented to improve living conditions in informal settlements, a few have considered assessing and building climate resilience into these areas to keep them functional. UN-Habitat (2018) warns that if we do not consider building climate resilient informal settlements, adapting cities to climate change will have limited success, especially since these areas contribute least to greenhouse gas emissions but suffer the most from climate impacts (UN-Habitat, 2018). Thus, questions arise regarding the vulnerability of informal settlements to climate change and the specific climate change impacts to which these settlements should adapt.

Resilience thinking is proposed as a lens through which to understand the extent of the vulnerability of informal

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settlements and identify opportunities for interventions that will keep these settlements functional and build their resilience to climate change. Resilience thinking is considered a framework for understanding and dealing with adaptive change (Davoudi et al., 2013; Du Plessis, 2012) and a bridging concept between urban planning and adaptation (Davoudi et al., 2012).

This paper forms part of a larger study that was aimed at developing design strategies for building climate resilience in informal settlements in Southern Africa. The first part of this study, presented in this paper, aimed to develop a resilience assessment framework that could be used to determine the climate vulnerabilities and spatial resilience of informal settlements in Southern Africa. An informal settlement, Msunduza, in Eswatini, which is within the subtropical climate zone, was selected as a case study area to develop a fine-grained assessment framework. Msunduza was chosen because it represents a hybrid space where informal and formal practices intersect, which is typical of many Southern African informal settlements (Huchzermeyer, 2011).

The following section reviews the climate change risks facing informal settlements, the resilience concept and existing resilience assessment frameworks that informed the development of context-appropriate tools for resilience planning in these areas.

2. Literature review

Climatic change is causing risks to the vulnerable living in low- and middle-income countries linked to a decline in food security, migration and poverty (IPCC, 2014). Several authors (Broto et al., 2015; Childers et al., 2015; Muchadenyika, 2015; Ndebele-Murisa et al., 2020) claim that southern African cities are more vulnerable to climate variability and its associated effects, and these are likely to increase in the future. These cities, located in sub-tropical climates, experience very heavy rainfall, river floods, high temperatures and drought (Tiepolo, 2016). There is, therefore, a concern about the adaptive capacity of cities in underdeveloped regions in southern Africa, considering the poor connectivity and fragility of the urban ecosystems (Ndebele-Murisa et al., 2020).

While the formal part of cities can respond to the impacts of climate change, informal settlements attached to the cities are often vulnerable and poorly prepared (Hugo, 2023). Informal settlements are most exposed to climate-related disasters due to their location on flood plains increasing their vulnerability to flooding, lack of risk-reducing infrastructure which can address climatic impacts, and poor-quality buildings which are sensitive to the impacts of climate change (Revi et al., 2014). UN-Habitat (2018) further highlights that the socio-economic characteristics of the residents, such as high poverty levels, reduce the capacity of informal settlements to deal with climate change impacts.

Climate-related disasters affecting cities are categorized as meteorological (e.g. storm, extreme temperature, and fog), climatological (e.g. drought, glacial lake outburst, wildlife), or hydrological (e.g. flood, landslide, and wave action) (Centre for Research on the Epidemiology of Disasters [CRED], 2020). UN-Habitat (2018) argues that addressing climate change in cities requires a renewed focus on the most vulnerable communities (informal settlements) to protect them from hazards. Building resilience to such disasters requires an understanding of the risks of climate change to informal settlements in their respective climatic regions, the particular vulnerabilities posed by the nature of informal settlements, and understanding them as complex social-ecological systems that are constantly changing.

2.1. Climate change risks to informal settlements

Climate action in informal settlements first requires an in-depth understanding of the physical conditions, demographics, and vulnerabilities to enable proper planning of feasible interventions (UN-Habitat, 2018). The physical conditions of informal settlements can be generally characterized by the lack of critical services (paved roads, storm drains, sewer lines, public water lines), a lack of durable houses, poor sanitation, and lack of clean water (Ndlangamandla & Combrinck, 2019; New Climate Economy, 2018; Revi et al., 2014).

These settlements, which are home to more than a billion people, are particularly vulnerable to floods, heavy storms and heat waves because of the poor-quality buildings and lack of infrastructure to absorb the hazards from climate change (Cerè et al., 2017; Revi et al., 2014). Climate change in subtropical climates is characterized by extreme storm events and related flooding, as well as heatwaves and dust storms. The latter two hazards are less explored components of climate change due to the lack of sufficient data to evaluate change (Tiepolo, 2016), but they are considered to have intense impacts in cities.

There are several projected impacts from climate change on informal settlements: increased mortality rates because of heat stress; escalating risks of floods, landslides and mudslide damage which may lead to loss of life and damage to property; damage to buildings and urban infrastructure; limited access to water; decreased soil quality; and impacts on agriculture (UN-Habitat, 2018). These impacts are a result of the projected changes such as higher average temperatures, more intense precipitation events, intense windstorms, and drought. The IPCC suggests that not only will human vulnerability be concentrated in informal settlements, but that investing in climate adaptation and reducing climate risks in these areas presents the greatest possibilities for achieving well-being (IPCC, 2018).

Considering the above, there is an urgent need to build resilience to climate change in these settlements without disrupting their livelihoods and social networks (Satterthwaite et al., 2020).

2.2. Understanding resilience and adaptation

Climate change has forced humans and social-ecological systems to constantly change throughout history (Pelling, 2011). The uncertainty regarding the scope, pace and impact of climate change makes studying and addressing climate change effects critical to help sustain livelihoods and wellbeing in urban areas. While climate mitigation is important, adaptation in the most vulnerable parts of the city is becoming more urgent to deal with the effects of climate change already experienced.

Adaptation is well explored in urban planning literature, and it has been defined as the 'inherent physical characteristics of a system (e.g. a building and infrastructure) guided by this system's physical planning and design by which it copes with changes and uncertainty over time' (Dhar & Khirfan, 2017, p. 75). Adaptation is associated with adaptive capacity and vulnerability. Adaptative capacity can be understood as the ability of a system to adapt to the impacts of climate change, and vulnerability refers to the degree of a system's susceptibility to these impacts (Dhar & Khirfan, 2017). The goal is to improve a system's adaptive capacity, which reduces its exposure to the impacts of climate change, and in the process, reduces the vulnerability of the system and increases its resilience. Walker and Salt (2006) state that adaptive capacity is an attribute of resilience, and the two terms cannot be separated.

Resilience is understood as the capacity of a system to adapt through time to change for the purpose of maintaining the system's functionality (Peres et al., 2017). It is therefore vital to understand the behaviour of systems through the lens of resilience theory to enhance their adaptive capacity to change. Over the past decades, several publications have provided different views on the role of resilience. However, most are in agreement that it must play a role in assessing preparedness of certain systems or entities to respond and recover from natural and man-made threats (Davoudi et al., 2013).

Resilience is considered necessary to achieving urban sustainability. Peres et al. (2017) argue that the aim of urban sustainability is not only about meeting human needs and protecting natural systems, but also ensuring that the functional integrity of cities is well maintained. This ties resilience to the qualities of a sustainable city due to the assumption that a social-ecological system (city) which is resilient also supports quality of life (Walker & Salt, 2006). The qualities of a sustainable city include health, safety and security, mobility, and more recently, qualities and relationships giving rise to a thriving and regenerative urban system in which the relationships within and between social and ecological systems are healed and renewed (Hes & Du Plessis, 2015). In the absence of resilience, the system may degenerate and fail to maintain the intended function of the system, leading to unsustainability. A city is considered sustainable because of the existence of resilient qualities in the system. One of the main goals of upgrading informal settlements is to improve living conditions by establishing and maintaining functioning systems. With extreme climate events and gradual climatic changes being regarded as shocks or stressors which affect these urban systems, it is vital that urban resilience to climate change be built into urban systems so that these systems maintain their function and flourish.

2.3. Building climate resilient settlements

Planning for adaptation requires understanding of 'what adapts', 'to what' and 'how to adapt' (Resilience Alliance, 2010). The hazards associated with each climatic zone influence planning that responds and adapts to the rapidly increasing climate-related disasters. The uncertainty of a new climatic future also requires a shift from planning for adaptation to a specific known hazard towards planning for future unknown changes and disasters (McEvoy et al., 2013). Such adaptation is referred to as anticipatory adaptation, which is built-in preparedness of systems that occurs before the disaster (Dhar & Khirfan, 2017). This is believed to be more affordable than dealing with a system post disaster during an emergency.

There are certain characteristics that make an urban system adaptable and therefore resilient to risks and disasters. These are characteristics that would make the system capable of absorbing, adapting, and transforming in the case of perturbation to maintain the functioning of the system. Design for resilience requires building these characteristics into components which make up the system (Du Plessis, 2022). Ribeiro and Gonçalves (2019) highlight eight characteristics of resilience: robustness, connectivity, independence, efficiency, resources, adaptation, innovation, inclusion, integration, diversity and redundancy. However, the most common characteristics cited in literature are diversity, modularity, redundancy and connectivity (Du Plessis, 2012; Meerow et al., 2016; Peres et al., 2017; Wang et al., 2018). The existence of these characteristics in a neighbourhood can be assessed to understand its general and specific resilience (Stagrum et al., 2020).

Resilience assessment of settlements is critical to identify where interventions and strategies to build or enhance resilience are necessary. The following section reviews several existing urban resilience assessment frameworks that informed the development of a resilience assessment framework for informal settlements.

2.4. Resilience assessment frameworks

The understanding that resilience theory is a lens through which to find the strengths and weaknesses of a system (city) in response to change (Walker & Salt, 2012) provides a starting point in the development of a resilient system. It is proposed that a system should first be evaluated to understand its condition (strengths and weaknesses) before relevant interventions can be devised to prepare the systems for uncertainty.

Resilience theory offers an opportunity to do that and further offers an opportunity to create a better neighbourhood. Several studies explored frameworks of resilience theory in urban planning (Masnavi et al., 2019), and many studies have developed assessment methods, involving physical and biological components of the city (Pickett et al., 2014), to measure urban resilience to climate-related disasters (Tong, 2021).

There are several common international resilience assessment frameworks, developed by governments, international donor organizations and researchers aimed at understanding and evaluating the resilience of cities (Patel & Nosal, 2016). These include the City Resilience Index (Rockefeller Foundation & Arup, 2014), City Resilience Profiling Tool (UN Habitat, 2017), Disaster Resilience Scorecard for Cities (UNDRR, 2017), City Resilience Action Planning Tool (UN-Habitat, 2020), and Resilience Assessment Framework by Resilience Alliance (2010). Table 1 compares the frameworks by presenting their dimensions of assessment and how they manage risks.

These frameworks present different approaches and dimensions of assessment where the tools aim to strengthen the

Table 1. Urban resilience frameworks and their dimensions of assessment.

Framework	Reference	Risk management	Dimensions of assessment
City Resilience Index	Rockefeller Foundation & Arup (2014)	Reduce exposure	Health and Wellbeing Economy and society Infrastructure and environment Leadership and strategy
City Resilience Profiling tool	UN-Habitat (2017)	Identify shocks and stresses	City ID Local governments and stakeholders Shocks, stresses and challenges Urban elements
Disaster Risk Scorecard for Cities	UNDRR (2017)	Identify hazards and exposure	Governance and financial capacity Planning and disaster preparations Disaster response and recovery
City Resilience Action Planning Tool	UN-Habitat (2020)	Urban disaster risk management	Urban governance Urban planning and environment Resilient infrastructure and basic services Urban economy and society Urban disaster risk management
Resilience Assessment Framework	Resilience Alliance (2010)	Addresses change	Dimensions determined through a defined process (system description process)

resilience of cities, and the developers of the frameworks further present their implementation process. The City Resilience Index (CRI) was developed for over three years by Arup, with the support of the Rockefeller Foundation, to assess the resilience of cities, identify vulnerable areas or areas of improvement, and identify possible actions to improve the city's resilience (Rockefeller Foundation & Arup, 2014). The approach is to identify drivers which contribute to resilience of cities and use them to assess the level of resilience. The CRI is based on four dimensions and 12 goals, which each city should aim to meet to achieve resilience, and 52 indicators, which are critical to evaluate the resilience of a city (Arup, 2017). The four dimensions which make up the CRI are health and wellbeing, economy and society, infrastructure and environment, and leadership and strategy.

The City Resilience Profiling Tool (CRPT) provides a framework to assess resilience in urban areas through outlining the context of the city including stakeholders, shocks and stresses, and further identifies gaps and opportunities regarding the city's structure and functionality to inform decision-making tailored for the study area (UN Habitat, 2017). It outlines a comprehensive process of training, data collection and analysis to understand the main challenges and stakeholder processes to develop actions for resilience.

The Disaster Risk Scorecard for Cities, developed by the United Nations Office for Disaster Risk Reduction (UNDRR), is used to understand the disaster risks, mitigate risks, and respond to disasters to minimize damage to livelihoods, infrastructure, property, environment and economy (UNDRR, 2017). It is structured around UNDRR's 'Ten Essentials for Making Cities Resilient' developed as part of the Hyogo Framework for Action. This covers several issues which cities should address to be resilient to disasters. The first 3 essentials address governance and financial capacity, then essentials 4–8 address several dimensions of planning and disaster preparation, and essentials 9–10 cover the disaster response and post-event recovery.

The City Resilience Action Planning Tool (CityRAP), developed by the United Nations Human Settlements Programme (UN-Habitat) and the Technical Centre for Disaster Risk Management, Sustainability and Urban Resilience (DiMSUR), aims to 'enable local governments of small to intermediate sized cities, or neighbourhoods/districts of bigger cities or metropolitan areas, to plan and undertake practical actions to strengthen the resilience of their cities' (UN-Habitat, 2020, p. 6). This tool targets local governments of cities with a maximum of 250,000 people in the developing world, with limited experience in addressing risks and planning for resilience. It constitutes a guideline for participatory action planning, with high-level data collection regarding mainly institutional risks and challenges.

The last framework reviewed is that which was developed by the Resilience Alliance (2010). This assessment framework can provide insights into how strategies for addressing change can be developed. It is based on the concept of social-ecological systems (SES) in which human and ecological systems are considered one integrated system. The assessment framework has five main stages: the first stage describing the system, the second stage understands the system dynamics, the third stage probes system interactions, the fourth stage evaluates governance, and finally, the fifth stage, and finally acting on the assessment. According to the Resilience Alliance, the process is iterative and reflexive at each phase and requires going back to previous steps and revising where required.

These frameworks show that cities are multi-dimensional entities that require urban resilience interventions to consider multidisciplinary insights. The commonalities of the frameworks include their availability to all cities for adoption; they support the development of cities towards meeting sustainable development goals, and they consider a multi-sectoral approach. As much as they are all implemented differently, they all involve understanding the vulnerability of the city, identifying opportunities for intervention, and acting to improve the resilience of the cities. Further, the frameworks directly or indirectly identify the valued attributes of the city that should be maintained to keep the city functional, such as health and wellbeing, a stable economy, safety, and environmental health. The frameworks discussed employ a combination of different data collection and analysis methods to achieve specific outcomes.

The reviewed resilience assessment frameworks fall short in that they do not fully address spatial and infrastructure considerations, focusing mainly on policy development and planning, and do not differentiate between strategies suitable for formal or informal neighbourhoods. Furthermore, these frameworks prioritize city-level resilience above neighbourhood-level and localized resilience. They also assume processes and institutional structures and competencies that may not be available or relevant in the context of informal settlements in Southern Africa. Most importantly, because they tend to be high-level and policy-oriented, they do not directly allow for the identification of infrastructure design strategies to enhance the resilience of specific informal settlements.

While all of the above frameworks provided useful input, one stood out. The resilience assessment developed by the Resilience Alliance (2010) is a flexible framework that does not limit the user to specific dimensions of assessment but provides a process for a deep understanding of the system of concern to develop relevant solutions to the identified disturbances. Its flexibility makes it useful in any context, especially in the areas that are normally ignored in city development, such as informal settlements (UN-Habitat, 2018). This framework was therefore used as a starting point for developing a context-sensitive, fine-grained resilience assessment framework for informal settlements located in Southern African urban areas.

3. Research method and context

This study used a qualitative research approach to collect the data necessary to develop a resilience assessment framework for informal settlements. The four phases of the framework were developed by identifying climate change hazards and impacts to which informal settlements need to adapt, and by identifying settlement components and systems expected to adapt to climate change disturbances. An informal settlement, Msunduza, located in Eswatini, southern Africa, in the tropical climate zone, was purposely selected to demonstrate how a resilience assessment of informal settlements in such contexts can be developed and to test the proposed assessment framework. This study area, covering 143 hectares and with an estimated 1,700 households, was selected using the following criteria: a settlement in the interior of a country in the global south; located in the subtropical climate zone; currently undergoing upgrading; and accessible to the researcher.

Data was collected through in-depth interviews with experienced experts in the built environment who have dealt with climate-related issues in Mbabane city, where the informal settlement is located. Snowball sampling was used to get respondents for the interview. The participants that were interviewed came from diverse professions, which ensured that a holistic picture about climate change hazards was provided from almost all affected disciplines in the built environment (Table 2).

The informal settlement residents who are affected by the impacts were not engaged due to accessibility issues and the assumption that the residents' responses could be contaminated by their expectations of assistance. For triangulation purposes, climate data was acquired from the Meteorological Services Department in Eswatini and further analysed to understand how climate has changed over the past 40 years (1981–2020).

An interview guide was used with questions that required information on how the participants observed the climate to be changing, the hazards experienced, how it has affected informal settlements, and suggested interventions. Participants were asked to relay their experiences of the observed effects of climate change on informal settlements. The voice-recorded interview data was transcribed and analysed through thematic

Table 2. Sample of participants.

Participants	Profession	Field	Experience/role
A	Environmental health specialist	Housing sector	Environmental assessment at a government parastatal. Involved in climate change mitigation and adaptation strategies at the national level
B	Meteorologist	Weather and climate	Climate monitoring for a government ministry. Monitoring and reporting on extreme climate, making climate summaries, annual climate summaries and similar work
C	Health Inspector	Housing sector	Public and environmental health. Participate in stakeholder engagements for climate change at the national level
D	City Planner	Town Planning	Town planning. Use of town planning scheme as a regulatory document
E	Maintenance Engineer	Civil Engineering	In charge of infrastructure maintenance in the whole town. Construction of new roads, new infrastructure, maintenance of roads, and scrutiny of architectural documentation.
F	Environmental and Public Health Specialist	Environmental and Public Health	Ensure health and safety of residents. Ensure preservation or avoiding pollution to any natural resources.
G	Disaster Risk Coordinator	Disaster Management	Creating awareness about disasters, risks and mitigation in communities. Coordinating stakeholders in all that relates to addressing disasters. Engaging in climate change forums to inform policy
H	Climate Change consultant	Climate Change Unit/ academia	Consultant for government, NGOs, UNDP, and SADC on climate change-related issues. Prepared Technology Needs Assessment for Eswatini. Author of the Climate Change Yearbook for SADC. Prepares Climate Change proposals for funding. A researcher and academic.
I	Environmental and Public	Environmental and Public	Scrutiny of Architectural Documentation.

(Continued)

Table 2. Continued.

Participants	Profession	Field	Experience/role
	Health Specialist	Health [Town Board]	Looks at the public health and safety issues, like ventilation, and drainage systems within residential plots. Addresses drainage issues for commercial buildings. Sits in the technical working group of NDMA, and prepares disaster risk management plans
J	Disaster Risk Manager	Disaster Management	Preventing risks, preparing the region for any impending disaster, coordinating any kind of response to any disaster that has occurred, and coordinating recovery ultimately. Works with the Red Cross on cash transfers and also works with World Vision.

analysis using an abductive approach, starting the analysis with theoretically derived themes (expected climate change hazards and impacts), which were then modified as the data set was explored. Data were categorized through coding to identify the climate hazards and impacts of climate change on informal settlements.

This data was used to identify the neighbourhood components and systems expected to absorb and adapt to climate change disturbances at the settlement and building levels to sustain the valued attributes of the settlement. The components were initially determined from preliminary literature review and then narrowed down through the in-depth interviews. A checklist was further developed by identifying subcomponents that have a potential to improve resilience, and this was tested through field work consisting of an observational study conducted by walking within the site and taking photographs of the settlement components and systems for assessments The data and location of these components (subsystems) were captured using Epicollect5, an open-source online documentation tool developed by the Imperial College of London which uses a survey approach to document, geolocate, and store data using individual cell phones. This data was then mapped in ArcGIS. This part of the study aimed to ensure that the checklist covered all components that had the potential to address adaptation to climate disturbances.

4. Findings and discussion

The study contributed to the development of a climate resilience assessment framework aimed at increasing spatial resilience of informal settlements based on the identification of climate hazards, climate impacts, vulnerable components, and potential interventions. The framework is presented in Figure 1, with four phases of implementation. The paragraphs which follow discuss how the results of the study contributed to the development of each phase of the framework, and contrast the findings with existing resilience frameworks.

4.1. Phase 1: Identification of climate hazards

Climate change hazards vary in different geographical regions and climate zones, and result in a wide range of impacts across different regions and different economic sectors (World Bank, 2022). The analysis of the interviews revealed that in the context of Eswatini, the hazards experienced are extreme heat, extreme and erratic rainfall and strong winds. These are the hazards to which informal settlements should adapt.

Drawing on their professional experience and observations, participants shared that average temperatures are generally increasing, becoming extreme with an increase in the number of hot days. They further indicated that rainfall is now erratic with extreme rainfall episodes, noting unpredictability in magnitude, period, and intensity and an overall decline in rainfall.

The Department of Meteorological Services, in their analysis of temperature and rainfall over a 40-year period, noted that there is an increase in maximum temperatures and a general decline in the amount of average total annual rainfall in Eswatini, with the greatest decline being observed in the last 10 years (2011–2020). This period was noted to have included the 2015 El-Niño episode, which was claimed to be one of the driest years on record.

The main climate hazards identified, therefore, were high temperatures, drought, uncertain precipitation and storms with high winds and flooding. This phase of the framework aims to identify climate change hazards for the region where the settlement under assessment is located. The threat of climate hazards may be different in different areas depending on the location of the informal settlement. It is critical to compare the opinion and experiences of local city officials and design experts with data attained from official records normally received from meteorological departments.

When compared with other frameworks such as the City Resilience Index (CRI), which broadly categorizes shocks and stresses, this phase emphasizes context-specific hazard identification, which is a necessity that is often lacking in general frameworks. This phase therefore contributes a micro-scale, hazard-specific lens that aligns with the Resilience Alliance (2010) emphasis on system description and contextual hazard recognition in the initial stages of resilience assessment.

4.2. Phase 2: Climate change impacts

Upon identification of climate change hazards and disasters experienced in the area of concern, it is critical to identify the climate change impacts (caused by the hazards) to which informal settlements need to adapt. Thematic analysis of interviews unpacked four categories of climate change impacts on the physical dimension of a settlement at different scales, which can also be referred to as the issues of concern to which the settlements should adapt: social impacts, environmental impacts, infrastructure impacts and building impacts (Table 3).

Infrastructure impacts affect clean water supply, energy supply, communication, movement, and health of residents.

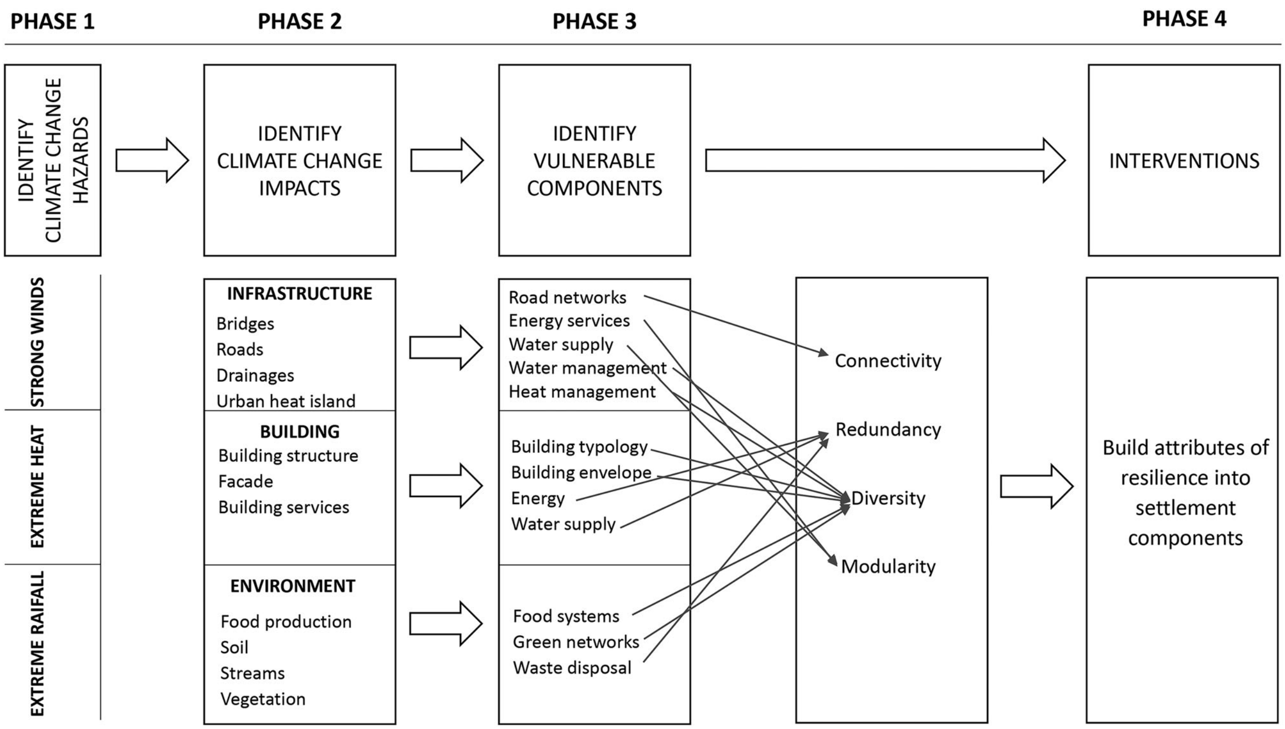

Figure 1. Resilience assessment framework for informal settlements.

Building impacts include effects that test the structural integrity of the building because of high velocity water flow washing away buildings, and strong winds blowing away roof coverings. Impacts such as those caused by extreme heat also affect the performance of buildings. These effects disturb the wellbeing, comfort and safety of residents using the structures, affordability, clean water supply, and uninterrupted energy supply. Impacts to the environment arise from soil failure, erosion, drought, and invasive species, amongst other effects. Such disturbances affect ecosystem services, food security and waste disposal. Infrastructure disturbances entail effects resulting mostly from high-pressure winds and flooding, which erode bridges and affect roads and power lines. Impacts to social life refer to the kind of disturbances that affect the well-being of residents because of changes in climate. These include health and comfort related disturbances resulting from overheating, pollution, and mould because of flooding. It is also important to consider systemic interdependencies such as the degradation of one system (e.g. stormwater drains) cascading into other systems (e.g. sanitation or mobility), thereby worsening the effects.

This phase, therefore, identifies the impacts to which informal settlements should adapt under the physical dimension of the settlement. The impacts are identified so that relevant actions and strategies for each area can be devised in phase 4 to improve the settlement's resilience to those impacts. This phase aligns with the dimensions considered by comprehensive tools like the CRPT and CRI but with a focus on physical systems within informal settlements. For instance, while CRPT maps urban elements and their interactions with hazards, it is primarily at a larger scale (city-level) and requires substantial municipal data input. The findings of this phase, however, show that impacts such as washed-out footpaths and bridges, heat-induced illness, and erosion of informal waste systems demand a component-level diagnostic rather than a macro-level summary.

Table 3. Climate change impacts.

Climate change risks at different scales	Description
Infrastructure Impacts	Destruction of bridges Bleeding of road surfaces Slippery/washed away roads, potholes Disruption of services Overflowing of drainages Urban heat island
Building Impacts	Mould accumulation/ moisture saturation Increased water consumption Weakening of building structures, cracking and collapsing walls, and blown-away roof coverings Sinking houses Increased energy consumption
Environmental impacts	Food production/agriculture Soil failure/erosion/landslides Water/land/air pollution Wildfire Falling trees Ecosystem changes Sedimentation
Social impacts	Spread of diseases Heat stroke and sick building syndrome Effects on socializing patterns Crime Productivity decline

4.3. Phase 3: Identify vulnerable components

Following the identification of the impacts of climate change on informal settlements, the valued attributes were identified by the participants and matched with the impacts. The attributes identified are: free movement, clean water, energy supply, communication, well-being, safety, affordable shelter, affordable energy supply, food security, ecosystem services, biodiversity, social life and work productivity. These attributes may also be the targets for informal settlement upgrading and form the goal of development. However, participants indicated that for informal settlements the most important attributes are the basic services critical for residents to survive.

Further analysis identified the components linked to the valued attributes that are considered most vulnerable to the impacts of climate change and therefore the places in the system where an increase in the adaptive capacity can have the biggest impact on improving the resilience of the informal settlement. Table 4 presents the identified valued attributes and matching vulnerable components of informal settlements, which need to adapt to the impacts of climate change.

The third phase of the assessment, therefore, aims to identify valued attributes and vulnerable areas or components within the settlement to inform actions that should be taken to enhance their resilience. These are the components which are responsible for increasing the adaptive capacity (reducing the vulnerability) of informal settlements to meet certain sustainability goals.

Synthesis of the results informed the development of a resilience assessment tool (checklist) for informal settlements broken into the categories of infrastructure, buildings, and resources. The variables (indicators) that contribute to resilience by building diversity, redundancy, connectivity or modularity can be identified through transect walks and literature review and included in the schedule for assessing resilience.

The resilience assessment schedule for infrastructure has five components and 16 subcomponents, which can contribute to developing the resilience of infrastructure. The schedule aims to identify the existence of the subcomponents in informal settlements. A practitioner using the tool will conduct the assessment by ticking the available subcomponents in the settlement. Where all the subcomponents exist (to create diversity or redundancy of function), the component under which they exist can be considered highly adaptable. Where none of the subcomponents exist, the assessed component can be considered vulnerable. The tool is flexible to allow a record of other place-relevant variables that contribute to the resilience of settlement components. Table 5 presents the schedule used for assessing the resilience of infrastructure.

The resilience assessment schedule for buildings consists of six components namely building type, building materials, building envelope (heat adaptation), building envelope (flexibility), building services (energy) and building systems (water). Existence of diverse subcomponents improves the resilience of the main component under assessment and the building as a whole. The development of this tool for a different context may result in a different set of components that build resilience. This schedule, unlike the others, was used to assess a sample of houses and the data can be quantitatively analysed to determine the general resilience or vulnerability of houses to climate change impacts. Table 6 presents the resilience assessment schedule for buildings.

Lastly, the resilience schedule for resources consists of three components: green networks, food systems, and waste disposal, with 15 subcomponents. The tool can be used through observational studies of the settlement under assessment with the help of a topographical map and a mapping software such as QGIS to analyse the distribution of the subcomponents. The resilience assessment checklist of resources is presented in Table 7.

The assessment of the Msunduza informal settlement, where the above tools were used, revealed that all the effects experienced as a result of changes in climate in subtropical climates seem to emanate mainly from flooding due to extreme rainfall events, overheating due to increasing average temperatures, and intense winds that normally accompany the frequent rainfall and hailstorm events. These concerns arise from the fact that these impacts are continuously degrading the valued attributes of the informal settlement and, therefore, affecting their function. The results of the assessment of the Msunduza informal settlement using the developed framework and assessment tool are presented in a different paper.

Other frameworks such as CityRAP, generally stop at participatory mapping and planning, and do not link valued attributes directly to adaptive components. The approach used in this phase is underpinned by resilience theory as components were assessed based on whether they contributed to diversity,

Table 4. Valued attributes and vulnerable components of informal settlements.

Valued attributes	Vulnerable Component
Free movement	Bridges
	Roads and footpaths
Clean water	Water management systems
Uninterrupted energy	Energy management systems
Uninterrupted communication	Communication systems
Well-being (health)	Water management systems
	Heat management systems
	Waste management
Safety, affordable shelter	Wind management systems
	Material
Affordable energy supply	Heat management systems
Food security	Food systems
Well-being	Waste management
Ecosystem services and biodiversity	Green networks
Social life	
Work productivity	Heat management systems

Table 5. Resilience assessment schedule for infrastructure.

Subsystems/components	Variable/sub-components	Availability
1.1. Water Management Systems	Storm drains	☐
	Green cover	☐
	Community tanks	☐
	Sewer line	☐
1.2. Water supply system	Community tanks	☐
	Water taps	☐
	Boreholes	☐
	Natural stream	☐
	Other	☐
1.3. Energy source	Electricity (grid)	☐
	Solar panels	☐
	Generator	☐
	Firewood	☐
	Other	☐
1.4. Road networks	*Use map*	☐
1.5. Heat management system	Vegetation	☐
	Natural water stream	☐
	Wetlands	☐
	Other	☐

Table 6. Resilience assessment schedule for buildings.

Subsystems/components	Variable/sub-components	Availability
2.1. Building type	Row houses	☐
	Kiosk	☐
	Marketplace	☐
	Dwelling	☐
	Shop	☐
	Workshop	☐
2.2. Building materials (walls and roofing)	Adobe mud walls and metal sheet roof	☐
	Compressed earth block walls and metal sheet roof	☐
	Metal sheet walls and metal sheet roof	☐
	Concrete block walls and metal sheet roofs	☐
	Concrete block walls and roof tiles	☐
	Wooden walls and metal sheet roofs	☐
	Other	☐
2.4. Building envelope (heat adaptation)	Roof overhangs (provide shading)	☐
	Cross ventilation (opposite windows)	☐
	High thermal mass material (walls)	☐
	Reflective paint	☐
2.5. Building envelope (flexibility)	Expandable (allow for more space)	☐
	Removable/replaceable elements	☐
	Moveable structure	☐
	Accessible (alternative access doors/windows)	☐
	Reusable (materials)	☐
2.5. Building Services (energy)	Solar panels	☐
	Generator	☐
	Electricity from the grid	☐
	Wind turbines on site	☐
	Firewood	☐
	Other	☐
2.6. Building services (water)	Water tanks	☐
	Public water supply connection	☐
	River wells	☐
	Boreholes	☐
	Other	☐

redundancy, connectivity, or modularity (Du Plessis, 2012; Meerow et al., 2016). For instance, having multiple water sources (e.g. boreholes, public taps, streams) contributes to redundancy, while shaded areas and reflective building materials contribute to heat resilience via functional diversity. In this way, the framework does not only identify what is vulnerable in the settlement but also offers a clear method for evaluation, especially in informal contexts.

Table 7. Resilience assessment schedule for resources.

Subsystems/components	Variable/sub-components	Availability
3.1. Green networks	Vegetation	☐
	Park	☐
	Wetlands	☐
	Natural streams	☐
	Swales	☐
	Garden	☐
3.2. Food systems	Shop	☐
	Marketplace	☐
	Vegetable gardens	☐
	Crop farming	☐
	Fruit trees	☐
3.3. Waste disposal	Recycle centre	☐
	Municipality dumpster	☐
	Waste bins	☐
	Landfill	☐

4.4. Phase 4: Interventions

The last stage proposes actions that will be relevant for the context and informal settlement under assessment to build resilience to climate change. This can be leveraged for informal settlement upgrading to prevent the reversal of development gains and is place-dependent.

The assessment framework developed in the study tackles the physical characteristics of infrastructure, buildings, and the natural environment to take advantage of their design or retrofitting potential during the upgrading of the settlements to incrementally transform to increase their adaptive capacity to climate change impacts. This knowledge then provides guidance on the steps that could be followed to understand the nature of the informal settlement under assessment and develop solutions based on the findings.

Most reviewed frameworks propose action planning (e.g. CRI's resilience goals or CityRAP's RFA phase), and they seldom link actions to observed micro-scale vulnerabilities. This study advances the field by presenting a bottom-up, component-level resilience planning tool. In so doing, it provides an example of anticipatory adaptation as discussed by Dhar and Khirfan (2017), reinforcing resilience not post-disaster but during planned upgrading, when intervention opportunities are most viable.

5. Conclusion

The increasing intensity of climate-related disasters, which affect the most vulnerable parts of cities, such as informal settlements, intensifies the need to assess the resilience of these areas. This study proposes a flexible resilience assessment framework aimed at establishing the adaptive capacity of informal settlements during their upgrading, a stage where opportunities for innovation exist. An informal settlement, Msunduza, located in the subtropical climate in Eswatini, southern Africa, was selected to assist in the development and testing of the framework. The selection of an informal settlement further ensured that the assessment framework is developed considering the vulnerabilities of such areas rather than generalizing an assessment for a whole city.

To develop the resilience assessment framework, the study assessed the nature of the selected informal settlement to determine what needs to adapt, to what, and how to adapt in order to devise relevant solutions. Through in-depth interviews with experts, the study identified hazards and impacts of climate change to which informal settlements in subtropical climates need to adapt. These include hazards such as extreme heat, extreme rainfall and strong winds that are causing impacts to informal settlements. Four categories of climate change impacts were identified, namely social impacts, infrastructural impacts, building impacts and natural environmental impacts. Further, the components which need to adapt to the impacts of climate change in informal settlements were identified, and an observation schedule was developed abductively to assess the resilience of these components based on principles of redundancy, modularity, diversity, and connectivity.

The findings were synthesized to develop a resilience assessment framework consisting of four phases of implementation, and a set of observational tools. The first phase determines the boundaries of the study area including the spatial boundaries and climatic zone boundaries. Phase 2 aims to identify the climate change impacts to which the informal settlement of concern needs to adapt in order to meet set sustainable goals. Phase 3 identifies the components of informal settlements that are vulnerable to the identified impacts in Phase 2. Phase 4 outlines a programme of intervention aimed at building the adaptive capacity of these components.

However, the study is not without limitations. First, the framework was developed and tested using expert input and secondary data only. The perspectives from residents of informal settlements who are directly affected by climate change impacts were not included mainly due to accessibility constraints. Secondly, the framework was developed using a single case study in Eswatini, and while it provides valuable insight into subtropical contexts in Southern Africa, broader validation across different cultural settings is needed to generalize its application.

Future research could therefore test and refine the framework in diverse informal settlement contexts across Southern Africa and even the Global South. Inclusion of participatory data from community members would make the study more comprehensive and help validate the identified components and attributes. Additionally, longitudinal studies that track the application of this framework during upgrading interventions would be valuable to measure its long-term effectiveness and adaptability.

Ultimately, this research opens the way for a more grounded, inclusive, and place-based approach to building climate resilience in informal settlements.

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Declaration

I declare that the applicable research ethics approval has been obtained for the research described in this work and that I have observed the ethical standards required in terms of the University of Pretoria's Code of Ethics for Researchers for Responsible Research (Rt 429/99).

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