International Journal of Environmental Impacts
https://www.acadlore.com/journals/IJEI

Climate Change, Flood Disasters, and Household Vulnerability: Evidence from KwaZulu-Natal, South Africa

Vikesh Singh[1], Raisuyah Bhagwan[2*]

[1] Department of Community Health Studies, Faculty of Health Sciences, Durban University of Technology, 4000 Durban, South Africa
[2] Department of Community Health Studies, Child and Youth Care Programme, Faculty of Health Sciences, Durban University of Technology, 4000 Durban, South Africa

* Correspondence: Raisuyah Bhagwan (bhagwanr@dut.ac.za)

Received: 08-17-2025 **Revised:** 11-04-2025 **Accepted:** 11-28-2025

Citation: V. Singh and R. Bhagwan, "Climate change, flood disasters, and household vulnerability: Evidence from KwaZulu-Natal, South Africa," *Int. J. Environ. Impacts.*, vol. 8, no. 6, pp. 1252–1266, 2025. https://doi.org/10.56578/ijei080612.

Abstract: Floods are among the most frequent and destructive environmental hazards in South Africa, with their impacts increasingly intensified by climate change. In April 2022, KwaZulu-Natal experienced one of the most severe flood events in its history, resulting in significant loss of life, widespread displacement, and extensive damage to infrastructure. This study examines the effects of the floods on vulnerable households, with particular attention to the ways in which socio-economic and spatial inequalities exacerbate disaster risk. A qualitative case study design was employed, drawing on data from semi-structured interviews with 34 participants residing in urban, peri-urban, and informal settlements. Data were collected between January and June 2023 and analysed using thematic analysis. The findings reveal three dominant patterns: extensive destruction of housing and loss of essential household assets; disproportionate exposure of socio-economically disadvantaged groups to flood-related risks; and disruption of critical services, including water supply, sanitation, and electricity. The results indicate that households already marginalised by poverty, insecure housing, and limited access to basic services experienced the greatest challenges in coping with and recovering from the disaster. The study highlights the urgent need for enhanced disaster preparedness, inclusive climate adaptation strategies, and strengthened early warning systems to better protect vulnerable populations. These findings contribute to the literature on climate-related disasters in sub-Saharan Africa and offer evidence to inform policy interventions aimed at strengthening resilience in flood-prone communities.

Keywords: Climate change; Flood disaster; Household vulnerability; KwaZulu-Natal; Resilience

1 Introduction

Climate change is widely recognised as one of the defining challenges of the twenty-first century. It is reshaping environmental hazard patterns globally and increasing the frequency and intensity of extreme weather events. Among these hazards, floods are considered the most recurrent and destructive hydro-meteorological disasters, affecting more people worldwide than any other natural hazard [1]. In sub-Saharan Africa, flood events have intensified in both frequency and severity over the past two decades. These changes have had severe consequences for vulnerable communities whose livelihoods, health, and social stability depend on fragile environmental and economic systems [2].

South Africa, although classified as a middle-income country with comparatively advanced infrastructure, remains highly vulnerable to climate-related flooding. This vulnerability results from the interaction between biophysical exposure and persistent socio-economic inequalities. As a result, flood impacts are unevenly distributed, disproportionately affecting households with limited resources and weak adaptive capacity.

1.1 Climate Change and Extreme Rainfall in South Africa

South Africa's geographic location and climatic variability make it particularly susceptible to rainfall extremes. Climate projections for southern Africa consistently indicate an increase in the intensity of short-duration, high-rainfall events linked to global warming [3]. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change

notes that Africa is warming at a rate exceeding the global average. It further highlights that southern Africa faces increasing risks of both droughts and floods.

This dual exposure creates a complex risk environment in which prolonged dry periods are interrupted by intense rainfall episodes. Each of these extremes presents distinct challenges for food security, infrastructure stability, and social well-being [4]. Historically, floods in South Africa have been associated with cyclonic activity in the Indian Ocean, cut-off low-pressure systems, and tropical–temperate cloud bands. These systems generate intense rainfall across both coastal and inland regions.

In recent years, climate change has increased the unpredictability of these weather systems. As a result, rainfall events increasingly overwhelm local drainage infrastructure and disaster management capacities [5]. Traditional climate indicators, such as the El Niño–Southern Oscillation (ENSO), have become less reliable predictors of rainfall extremes. Even neutral ENSO years have produced severe flooding. These trends raise critical concerns regarding the ability of municipalities and households to adapt to rapid-onset flood disasters in the absence of resilient planning frameworks.

1.2 The April 2022 KwaZulu-Natal Floods

A clear illustration of these climate-related risks occurred in April 2022, when KwaZulu-Natal experienced extreme flooding following several days of intense rainfall. The storm system, which primarily affected eThekwini Municipality, triggered widespread landslides, river overflows, and infrastructure failure. Official records report that more than 435 people lost their lives, over 40,000 individuals were displaced, and thousands of homes were either destroyed or severely damaged [6].

Critical infrastructure, including roads, bridges, water pipelines, and electricity networks, was extensively disrupted. These failures significantly constrained economic activity and limited access to essential services. In response, the South African government declared a national state of disaster, recognising the event as one of the most severe natural disasters in the country's democratic history.

Beyond immediate physical damage, the floods exposed entrenched vulnerabilities within KwaZulu-Natal's urban and peri-urban landscapes. Informal settlements located along riverbanks and unstable slopes experienced the most severe impacts. Many households lost not only their dwellings but also essential documents, educational materials, and livelihood assets [7]. Although middle- and high-income areas were also affected, poorer households faced greater hardship. Limited access to insurance, savings, and social protection reduced their capacity to cope with losses. These outcomes reflect enduring spatial inequalities rooted in apartheid-era planning, which continue to shape contemporary patterns of flood vulnerability.

1.3 Household Vulnerability and Disaster Risk

Vulnerability has become a central concept in disaster risk research, explaining why certain groups experience greater losses and slower recovery following hazard events. Vulnerability is determined not only by physical exposure but also by social, economic, and political conditions that influence a household's ability to anticipate, cope with, and adapt to shocks [8].

In flood contexts, household vulnerability is often reflected in poor housing quality, insecure land tenure, low income levels, limited access to information, and weak social support networks. These factors frequently interact, creating cumulative disadvantages that intensify disaster risk. International studies demonstrate that vulnerable households often experience a "triple burden" during flood events. This burden includes higher exposure due to residence in hazard-prone areas, greater susceptibility to loss because of fragile assets, and reduced coping capacity resulting from limited institutional and financial support [9].

Evidence from countries such as Bangladesh, the Philippines, and Kenya illustrates that marginalised populations face prolonged recovery periods and heightened risks of long-term poverty following flood disasters. In contrast, empirical research on household-level flood vulnerability in South Africa remains limited. Existing studies largely prioritise infrastructure damage, economic losses, or institutional disaster management frameworks.

1.4 Gaps in the Existing Literature

Despite increasing attention to climate-related disasters in South Africa, several gaps remain in the literature. First, much existing research focuses on macro-level analyses, including hydrological modelling, infrastructure resilience, and economic impact assessments [10]. While valuable, these approaches often overlook household-level experiences, particularly within informal and marginalised communities.

Second, limited attention has been given to the psychosocial consequences of flooding. Issues such as trauma, loss of social cohesion, and the disruption of community networks are rarely examined, despite their importance for recovery processes. Third, the intersection of climate change, poverty, and historical inequality in shaping household vulnerability has not been systematically documented in the South African context [11]. This omission is significant given the country's legacy of spatial segregation and persistent socio-economic disparities.

Policy approaches to climate adaptation and disaster risk reduction often emphasise technical solutions, such as early warning systems and infrastructure upgrades. Although necessary, these approaches may inadequately address the lived realities of households confronting floods as immediate threats to survival [12]. A household-centred perspective is therefore essential for developing socially equitable and context-sensitive interventions.

1.5 Aim of the Study

Against this background, this study examines the effects of climate-induced flood disasters on vulnerable households in KwaZulu-Natal, with specific reference to the April 2022 floods in eThekwini Municipality. A qualitative case study design was adopted to explore household experiences, losses, and coping strategies following the disaster [13].

The study aims to generate insights into the interaction between climate change, socio-economic inequality, and disaster vulnerability at the household level. In doing so, it addresses a key gap in South African flood research by shifting analytical focus from macro-scale impacts to lived household realities.

The objectives of the study are threefold. First, it documents the lived experiences of households affected by the 2022 floods, including both material and non-material losses. Second, it identifies socio-economic and infrastructural factors that heightened vulnerability before, during, and after the disaster. Third, it derives policy-relevant insights to inform more inclusive and equitable approaches to disaster risk reduction and climate adaptation in South Africa [14]. Collectively, the study contributes to understanding how climate change and social inequality interact to produce uneven disaster outcomes and offers evidence to support resilience-building interventions.

2 Literature Review

2.1 Floods and Climate Risk in Sub-Saharan Africa

Floods are among the most recurrent natural hazards in sub-Saharan Africa and cause substantial losses to lives, livelihoods, and ecosystems. The International Disaster Database (EM-DAT) indicates that floods account for more than 40% of recorded disasters in the region over the last three decades [15]. Climate change has intensified this risk by increasing the likelihood of high-intensity rainfall events. Projections from the Intergovernmental Panel on Climate Change suggest that extreme rainfall episodes are expected to become more frequent and more severe in sub-Saharan Africa under high-emission scenarios [16]. These trends are associated with ocean warming in the Indian and Atlantic basins, shifts in atmospheric circulation, and increased variability in the ENSO system.

Flood impacts in the region extend beyond immediate inundation. Flood events often involve acute hazards, such as flash floods and river overflows, as well as longer-term consequences, including soil erosion, loss of arable land, and heightened exposure to waterborne diseases [17]. Several areas are repeatedly identified as flood-risk hotspots, including the Nile Basin, Niger Delta, Limpopo Basin, and coastal zones of Mozambique and Tanzania. Rapid urbanisation has also intensified exposure in major cities. Informal settlements have expanded into floodplains and low-lying areas where drainage infrastructure is limited, increasing the severity of flood impacts in cities such as Accra, Lagos, Dar es Salaam, and Johannesburg.

The socio-economic consequences of flooding are extensive. The loss of agricultural land and crops undermines food security in subsistence and smallholder economies. Damage to markets and transport infrastructure further disrupts local and regional trade networks [18]. Floods also increase the risk of public health crises, including outbreaks of cholera, malaria, and diarrhoeal disease, particularly in contexts with fragile health systems [19]. In addition, floods often reinforce gendered vulnerabilities. Women and children may face disproportionate impacts due to caregiving responsibilities, constrained access to resources, and social norms that restrict mobility.

Evidence from West and East Africa illustrates how climatic and infrastructural conditions combine to shape flood risk. In Ghana, repeated flood events in Accra and parts of the Volta region have been linked to intense rainfall and inadequate drainage maintenance [20]. In Kenya, recurrent flooding in the Budalangi area along the River Nzoia has been associated with weak embankment systems and settlement encroachment onto floodplains [21]. These experiences are comparable to South Africa, where rapid urban growth, socio-economic inequality, and changing rainfall regimes converge to heighten flood vulnerability.

2.2 Historical Inequities and Vulnerabilities in South African Settlements

South Africa provides a distinctive context for analysing disaster vulnerability because spatial and social inequalities remain deeply entrenched. Under apartheid (1948–1994), racial segregation was institutionalised through policies that concentrated Black African communities in under-serviced and hazard-exposed areas [22]. These spatial legacies persist. Informal settlements continue to cluster along riverbanks, wetlands, and unstable slopes, where flood exposure is elevated.

The April 2022 KwaZulu-Natal floods made these inequalities visible. Informal settlements on Durban's periphery, including areas on steep hillsides and near drainage channels, experienced severe damage. In contrast, higher-income suburbs with more robust infrastructure generally sustained lower levels of loss [23]. This pattern is consistent with

disaster scholarship that conceptualises vulnerability as socially produced and historically conditioned rather than determined solely by biophysical exposure.

Housing conditions represent a key determinant of flood vulnerability. Many low-income households reside in dwellings constructed from corrugated iron, timber, or plastic sheeting. These structures provide limited protection against heavy rainfall, strong flows, or landslides [24]. Insecure land tenure further reduces incentives and capacity for household-level investment in risk-reducing improvements. Service backlogs compound these risks. Limited stormwater drainage, inadequate waste management, unreliable electricity, and restricted access to piped water reduce coping capacity and increase exposure during and after flood events.

Socio-economic disadvantage intersects with these settlement conditions. High unemployment, food insecurity, and limited access to credit constrain recovery following disasters. Insurance coverage is low among poorer households, increasing reliance on constrained public relief systems [25]. In rural KwaZulu-Natal, poverty and dependence on rain-fed livelihoods expose households to both drought and flood risk. This dual exposure undermines resilience and increases the likelihood of repeated losses.

Vulnerability is further shaped by social differentiation. Women-headed households, particularly those led by widows or single mothers, may face elevated risk due to limited access to land rights, lower incomes, and substantial caregiving responsibilities [26]. Children, older persons, and people with disabilities may also face higher risk due to mobility constraints and dependence on household support. These intersecting dynamics reinforce the argument that flood disasters are mediated by structural inequality and governance conditions rather than by hazard processes alone.

Urbanisation intensifies these challenges. South Africa is highly urbanised, with more than two-thirds of the population residing in urban areas [27]. Rural–urban migration has contributed to the continued expansion of informal settlements, including in flood-prone locations. In many municipalities, capacity constraints and governance challenges limit the provision of adequate housing and the enforcement of land-use regulation. Consequently, apartheid-era spatial patterns, combined with contemporary urban pressures, continue to reproduce uneven geographies of flood risk in cities such as Durban, Cape Town, and Johannesburg.

2.3 Disaster Risk Reduction Frameworks

In response to escalating climate hazards, South Africa has aligned its disaster governance with global frameworks, including the Sendai Framework for Disaster Risk Reduction (2015–2030), which emphasises prevention, preparedness, and resilience [28]. At the national level, the Disaster Management Act (No. 57 of 2002) provides a legislative basis for integrated disaster risk management. The National Climate Change Adaptation Strategy further outlines policy directions for strengthening resilience across sectors. At provincial and municipal levels, Integrated Development Plans and Disaster Management Centres are expected to translate these priorities into operational plans.

Despite these policy instruments, implementation has been uneven. Studies of disaster risk governance in South Africa identify persistent constraints, including limited funding, insufficient technical capacity, and weak inter-institutional coordination [29]. Early warning systems exist but do not consistently reach vulnerable households. Barriers include limited access to technology, language constraints, and low trust in official information channels. In addition, disaster management responses often remain reactive and relief-oriented, with limited emphasis on proactive risk reduction. This institutional pattern contributes to repeated cycles of loss and recovery.

Community-based disaster risk reduction (CBDRR) has been advanced as an approach for strengthening the link between policy and local realities. Evidence from other contexts suggests that community participation in hazard mapping, preparedness activities, and resilience planning can improve both effectiveness and sustainability [30]. For example, community flood committees in Mozambique have been associated with reduced mortality during cyclone-related floods. In South Africa, however, community participation remains limited in many settings, and disaster governance frequently relies on top-down approaches that marginalise affected communities.

There is also growing recognition that disaster planning should integrate social vulnerability assessment. Tools such as Household Vulnerability Indices and participatory vulnerability mapping have been applied in several African settings to identify at-risk populations and to target interventions more effectively [31]. Greater use of such approaches in KwaZulu-Natal could strengthen prioritisation and align resilience initiatives with household-level realities.

Disaster risk reduction is increasingly understood as inseparable from long-term climate adaptation. Flood risk cannot be addressed effectively without broader interventions that tackle environmental and social drivers of vulnerability. These interventions include investment in resilient infrastructure, climate-resilient housing, ecosystem restoration (including wetland rehabilitation for flood buffering), and expanded social protection measures [32]. In South Africa, linking disaster risk reduction with poverty reduction and spatial justice is particularly important because inequality strongly shapes flood impacts.

2.4 Synthesis

The literature on floods and climate risk in sub-Saharan Africa highlights an increasing threat from extreme rainfall under climate change. In South Africa, these risks are amplified by historical inequities, persistent socio-economic

disparities, and rapid urbanisation. Although disaster risk reduction frameworks exist at global and national levels, implementation often fails to engage directly with the lived experiences of vulnerable households [33]. Addressing this limitation requires empirical research that foregrounds household-level impacts and policy responses that integrate vulnerability reduction with climate adaptation and social justice objectives.

This study contributes to this agenda by using the April 2022 KwaZulu-Natal floods as a case study of how climate change and inequality interact to shape disaster outcomes [34]. By centring the experiences of affected households, it responds to gaps in the South African literature and provides context-sensitive evidence to inform more inclusive approaches to disaster risk governance. Existing scholarship has advanced understanding of climate-related flooding in sub-Saharan Africa, but household-level realities remain under-examined in South Africa. In particular, limited research has analysed how spatial inequality, insecure tenure, and poverty interact to produce differentiated vulnerability and uneven recovery. The present study addresses this gap by examining how socio-economic and spatial inequalities shaped household exposure, loss, and coping during and after the April 2022 floods.

2.5 Conceptual Framework

The conceptual framework for this study integrates insights from climate change research, vulnerability theory, and disaster risk reduction approaches [35]. It proposes that household vulnerability and flood-related outcomes in KwaZulu-Natal are shaped by the interaction between climate-driven hazards and historically entrenched social inequities.

Within the framework, climate change functions as a key driver by intensifying extreme rainfall and increasing the probability of flooding. Flood hazards intersect with exposure, including settlement location in floodplains or on unstable hillsides, and with sensitivity, including poor housing quality, inadequate infrastructure, and fragile livelihoods [36]. Together, these conditions increase household vulnerability, particularly among low-income and historically marginalised communities.

The framework further emphasises the role of coping and adaptive capacity in mediating disaster impacts. Adaptive capacity is influenced by access to financial resources, social networks, and institutional support. Where disaster risk reduction measures are limited or exclusionary, households are more likely to experience repeated losses and prolonged recovery [37]. In contrast, inclusive policies, effective early warning systems, and community-based resilience initiatives can reduce vulnerability and strengthen adaptive capacity. Overall, the framework conceptualises flood disasters as outcomes of coupled social and environmental processes rather than purely natural events, highlighting the convergence of climatic stressors and structural inequality in shaping disaster risk.

The framework thus emphasizes the need to understand flood disasters not merely as natural phenomena but as outcomes of social-environmental interactions, where both climate stressors and structural inequalities converge to shape disaster risk (see Figure 1).

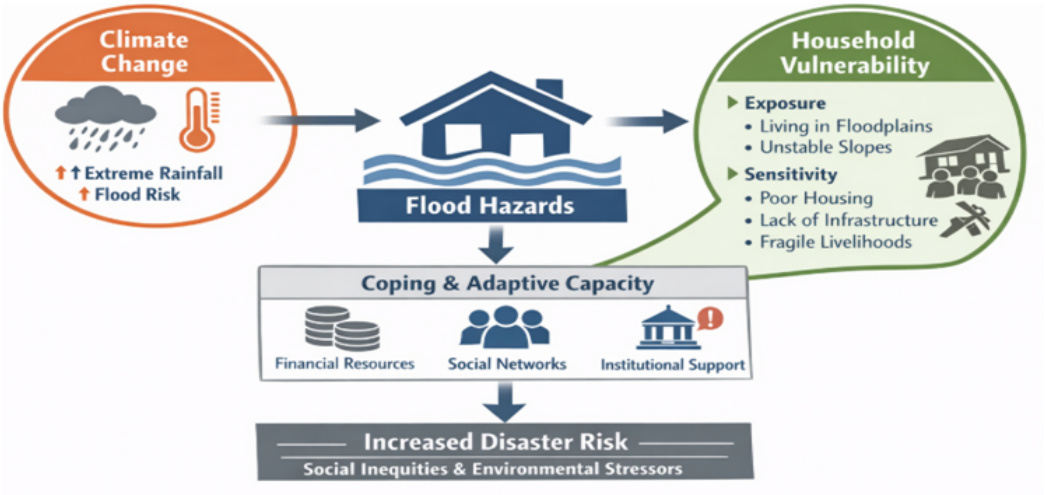

Figure 1. Conceptual framework linking climate change, flood hazards, and household vulnerability in KwaZulu-Natal (adapted from Cutter)

3 Method

3.1 Study Design

The study was conducted in KwaZulu-Natal, a province on South Africa's eastern seaboard that was severely affected by the April 2022 floods. KwaZulu-Natal has a subtropical climate characterised by warm, humid summers

and rainfall influenced by Indian Ocean weather systems. Its topography includes coastal plains, rolling hills, and river valleys, many of which are susceptible to flooding during short-duration, high-intensity rainfall events. Climate change has increased the variability and unpredictability of these rainfall systems, contributing to flash floods and landslides that overwhelm infrastructure and threaten vulnerable communities.

The eThekwini Metropolitan Municipality (Durban and surrounding areas) was the epicentre of the disaster. Heavy rainfall between 11 and 13 April 2022 triggered flooding and landslides, resulting in more than 435 deaths, displacement of over 40,000 people, and extensive damage to roads, bridges, electricity networks, and water infrastructure. Informal settlements were disproportionately affected because many are located along riverbanks, drainage channels, and unstable hillsides. Their vulnerability is further shaped by poor housing quality and limited access to municipal services.

To capture variation in vulnerability across settlement contexts, three community categories were purposively selected:

• Urban settlements: formal residential areas that experienced infrastructure damage but generally had stronger institutional support.

• Peri-urban settlements: mixed areas containing formal dwellings and informal structures, reflecting intermediate service delivery and vulnerability.

• Informal settlements: highly precarious communities on marginal land, often lacking secure tenure and adequate drainage, and therefore disproportionately exposed to flood hazards.

A schematic map of the study area is presented in Figure 2, which shows the flood-affected areas within eThekwini and the surrounding KwaZulu-Natal province.

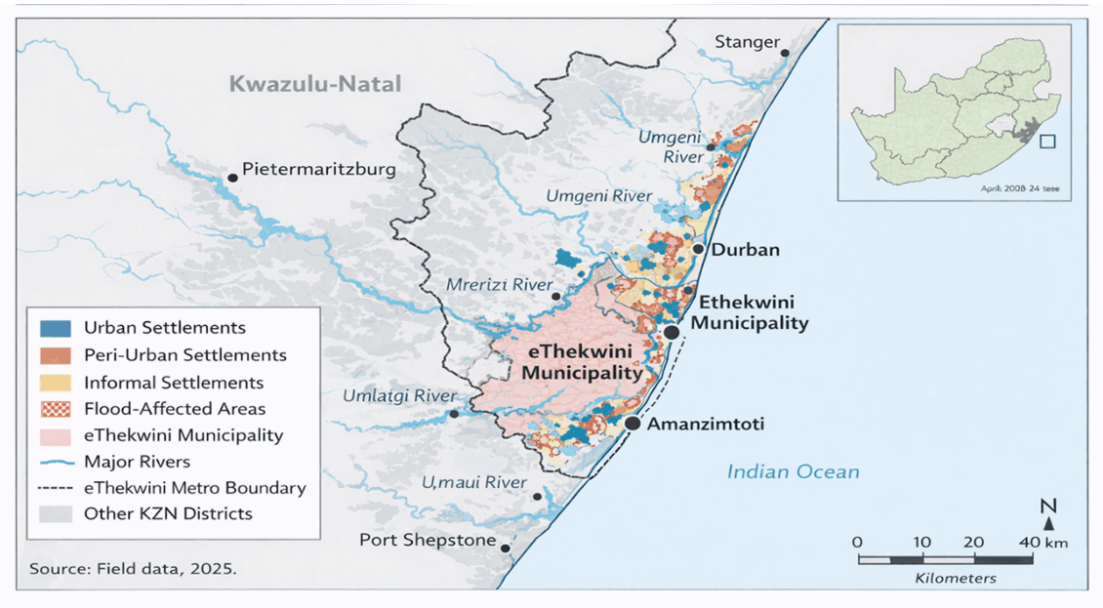

Figure 2. Study area map of flood-affected regions in KwaZulu-Natal

3.2 Participants

Households directly affected by the floods constituted the unit of analysis. In total, 34 participants were included across the three settlement categories. Participants were recruited using purposive sampling to ensure that the sample comprised individuals who experienced substantial losses or disruption during the April 2022 floods. Local non-governmental organisations (NGOs), ward councillors, and community leaders assisted in identifying eligible households, particularly those who had lost homes, essential belongings, or documents, or who had been displaced to temporary shelters.

Recruitment continued until thematic saturation was reached, defined as the point at which additional interviews did not generate new themes. Eligibility was determined using three criteria: (1) direct experience of housing loss, displacement, or livelihood disruption during the April 2022 floods; (2) residence in an urban, peri-urban, or informal settlement; and (3) willingness to participate and share first-hand experiences. Approximately similar numbers of participants were recruited from each settlement category. Efforts were also made to include variation in gender, age, and household structure.

Participant characteristics are summarised in Table 1. Of the 34 participants, 20 were women and 14 were men. Ages ranged from 22 to 70 years, with a mean age of 41 years. Household structures included single-parent

households, child-headed households, elderly-headed households, and nuclear families. Most participants were low-income earners engaged in informal employment or reliant on social grants, reflecting the socio-economic conditions associated with heightened disaster vulnerability.

Table 1. Demographic profile of participants

Settlement Type	Male (n)	Female (n)	Age Range	Household Types Represented	Primary Livelihood
Urban	6	5	28–65	Nuclear, elderly-headed	Formal jobs, small business
Peri-urban	4	7	24–60	Single-parent, nuclear	Informal work, social grants
Informal	4	8	22–70	Child-headed, single-parent	Casual labour, subsistence
Total	14	20	22–70	Mixed	Predominantly low-income

This composition enabled analysis of intersecting vulnerabilities linked to gender, age, household structure, and livelihood conditions.

3.3 Data Collection

Data were collected between January and June 2023 using a qualitative multi-method strategy to capture household experiences in depth. Semi-structured interviews constituted the primary data source. Interviews lasted between 45 and 90 minutes and were conducted in isiZulu or English according to participant preference. The interview guide covered flood experiences, immediate and longer-term impacts, coping strategies, and perceptions of institutional response.

Three focus group discussions (FGDs) were also conducted, with one group in each settlement category. Each group included six to eight participants. The FGDs facilitated discussion of shared experiences and enabled identification of community-level patterns of vulnerability and resilience. Participants emphasised infrastructure disruption, including road damage and interruptions to water services, and highlighted the role of social networks and faith-based organisations in providing emergency support.

A document review complemented the primary data. Sources included municipal disaster management reports, national government assessments, NGO reports, and media coverage of the April 2022 floods. These materials provided contextual information on the scale of the disaster and the nature of institutional responses, supporting triangulation with household accounts.

Field observations were undertaken during site visits to affected areas. Observations focused on damaged housing, disrupted infrastructure, drainage conditions, and visible recovery activities. Detailed field notes were maintained to record environmental conditions, settlement layouts, and non-verbal cues relevant to interpreting vulnerability.

3.4 Data Analysis

Data were analysed using thematic analysis in accordance with Braun and Clarke's framework. All interviews and FGDs were audio-recorded with participant consent and transcribed verbatim prior to analysis. The analytical process involved six iterative stages. First, the researchers familiarised themselves with the data through repeated reading of the transcripts. Second, initial inductive coding was undertaken to identify recurring words, phrases, and patterns across the dataset. Third, related codes were collated into broader analytical categories, including loss of belongings, housing fragility, community solidarity, and institutional response. Fourth, these categories were organised into higher-order themes that captured key analytical patterns, such as housing and asset loss, differentiated household vulnerability, and disruption of essential services. Fifth, themes were reviewed and refined to ensure internal coherence and consistency across the three settlement categories. Finally, the themes were interpreted in relation to the study's conceptual framework (Figure 1), linking climate-related hazards, vulnerability, and adaptive capacity.

NVivo software was used to manage transcripts and support systematic coding and organisation of the data. Analytical credibility was enhanced through triangulation of interviews, FGDs, documentary sources, and field observations. Member checking was conducted with a subset of participants to verify the accuracy of preliminary interpretations, while peer debriefing within the research team supported reflexivity and reduced interpretive bias. An audit trail documenting coding decisions and analytical steps was maintained to enhance transparency and methodological rigour.

3.5 Ethics Approval

The study adhered to recognised ethical standards for research involving human participants. Ethical approval was obtained from the Durban University of Technology Institutional Research Ethics Committee (Reference No.

IREC/283/22). Participants received written and verbal information describing the study purpose, procedures, potential risks, and expected benefits. Written informed consent was obtained prior to participation, including consent for audio recording.

Confidentiality was ensured through anonymisation of transcripts and the use of pseudonyms. Audio files and transcripts were stored securely and were accessible only to the research team. Given the potential for emotional distress when recounting traumatic experiences, interviews were conducted in a sensitive manner. Participants were provided with referral information for psychosocial support services when needed. To support reciprocity, findings were shared with participants and local organisations through a community feedback workshop.

3.6 Methodological Limitations

Several limitations should be noted. First, the sample size of 34 participants limits statistical generalisability. This constraint is consistent with qualitative research, which prioritises depth of understanding over population-level inference. Second, the focus on eThekwini may not reflect experiences in all flood-affected areas of KwaZulu-Natal. Third, recall bias may have influenced accounts of events that occurred in April 2022.

Despite these limitations, the study employed multiple strategies to enhance trustworthiness. Triangulation across data sources, member checking, and peer debriefing strengthened credibility. Systematic documentation of analytical decisions further supported transparency.

4 Results and Discussion

The findings of this study are presented thematically, drawing on interviews, FGDs, document analysis, and field observations. Three interrelated themes emerged: (1) lived experiences of flood disasters, (2) social and economic vulnerability factors, and (3) community infrastructure impacts [38]. Each theme is supported by qualitative evidence from participants, complemented by descriptive tables and figures, and situated within relevant regional and international literature.

4.1 Theme 1: Lived Experience of Flood Disasters

The April 2022 KwaZulu-Natal floods had severe impacts on households, and participants reported extensive loss of housing, essential belongings, and community cohesion [39]. Damage was most pronounced in informal settlements, where poorly constructed dwellings made of corrugated iron, timber, and plastic were swept away by floodwaters. Participants described the distress of witnessing their homes collapse and losing essential possessions, including school materials, identity documents, and clothing.

One participant stated: “When the water came, it felt as if the whole ground moved. We lost everything—our house, our clothes, and my children’s school books. We had to run to the hall with nothing but what we were wearing.”

Displacement was a recurring experience. Many families sought refuge in community halls, schools, or relatives’ homes, often under overcrowded conditions [40]. The loss of housing security created additional challenges, including increased health risks in temporary shelters and reduced dignity associated with reliance on external support.

These findings are consistent with evidence from Ghana, where repeated floods in Accra have displaced households and destroyed housing and critical documents [41]. Similarly, research from Kenya’s Budalangi region highlights the psychological distress associated with repeated displacement from floodplain settlements. Table 2 summarises the household-level impacts reported by participants.

Table 2. Household-level impacts of the April 2022 KwaZulu-Natal floods ($n = 34$)

Type of Impact	Description	Frequency Reported (n = 34)
Loss of housing	Complete or partial destruction of homes	26
Loss of belongings	Household goods, clothing, school materials	30
Loss of documents	IDs, birth certificates, bank cards	18
Displacement	Relocation to shelters, relatives’ homes	22
Psychosocial trauma	Fear, anxiety, sleep disturbance	19

As shown in Table 2, nearly all participants reported loss of belongings, and 26 households reported complete or partial housing loss. Displacement was most common in informal settlements, where insecure tenure constrained access to insurance and formal recovery support. Figure 3 provides photographic evidence of collapsed dwellings and temporary shelter conditions observed in the study area.

These accounts highlight the interaction between physical and psychological vulnerability. Similar findings have been reported in the Philippines, where typhoon-related displacement resulted in both material losses and heightened emotional distress [42].

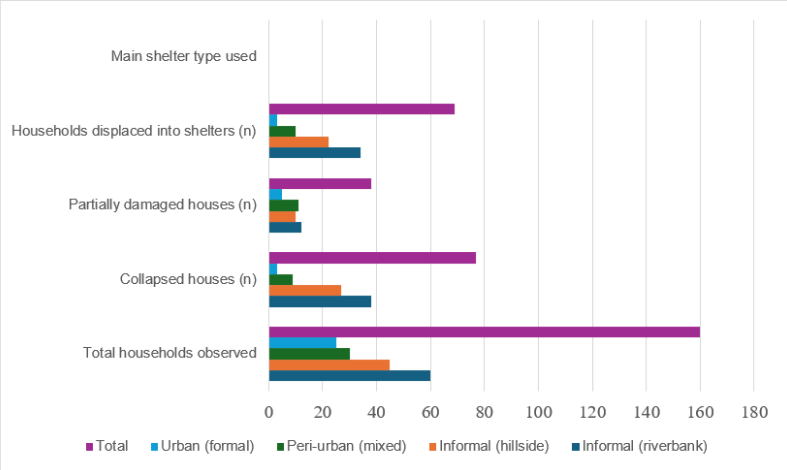

Figure 3. Collapsed and partially damaged houses across settlement types in eThekwini

4.2 Theme 2: Social and Economic Vulnerability Factors

In addition to immediate impacts, the floods exposed underlying social and economic vulnerabilities that shaped exposure and recovery. Poverty, insecure housing, and household structure emerged as central determinants of vulnerability and resilience.

4.2.1 Poverty and livelihood fragility

Participants emphasised that limited financial resources constrained recovery after the floods. Low-income households dependent on informal work or social grants were unable to replace essential items or repair damaged dwellings [43]. In the absence of savings or insurance, many relied on community donations or government relief, which was frequently delayed or insufficient. These findings align with studies in Ghana and Kenya that identify poverty as a primary driver of flood vulnerability.

4.2.2 Housing quality and land tenure

Housing quality strongly influenced the scale of loss. Informal dwellings constructed from lightweight materials were easily destroyed, whereas formal brick structures in urban areas generally remained standing, despite damage. Insecure land tenure further increased vulnerability because households occupying informal plots could not access post-disaster housing subsidies or reconstruction funds [44]. These patterns are consistent with South African scholarship linking apartheid-era spatial planning to contemporary risk exposure, particularly for Black African households living in flood-prone settlements.

4.2.3 Household structure

Household composition also shaped vulnerability. Single-parent households, particularly those headed by women, reported limited capacity to mobilise resources for evacuation or rebuilding. Elderly-headed households described challenges accessing shelters and relief due to mobility constraints [45]. Although fewer in number, child-headed households faced severe hardship due to limited adult support in securing assistance. Table 3 summarises vulnerability factors across household types.

Table 3. Household structures and reported vulnerability factors

Household Type	Key Vulnerability Factors	Representative Quote
Single-parent	Limited income; childcare burden	"I had to choose between saving the children and saving our things."
Elderly-headed	Mobility constraints; health risks	"I could not run fast, so the water caught me in the house."
Child-headed	Lack of adult support; dependency on neighbors	"We just followed others to the shelter; no one told us what to do."
Nuclear family	Shared resources but limited income	"Even with two adults, we could not protect the house from the water."

Overall, the intersection of poverty, fragile housing, and household structure indicates that vulnerability is socially produced. This pattern supports the argument that disasters are shaped by structural inequality rather than hazard exposure alone.

4.3 Theme 3: Community Infrastructure Impacts

The floods disrupted critical infrastructure and basic services, which further intensified household vulnerability. Water and sanitation systems were damaged, leaving many communities without safe drinking water for extended periods [46]. Electricity supply was interrupted in several areas, affecting livelihoods and schooling. Road and bridge failures also isolated communities and delayed access to healthcare, markets, and relief distribution points. Figure 4 illustrates the infrastructure damage recorded during field visits.

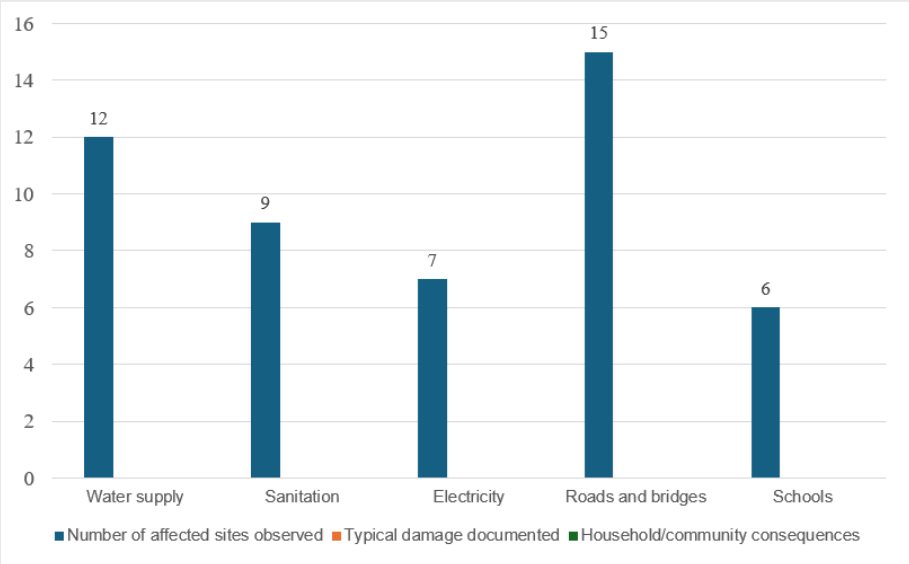

Figure 4. Number of infrastructure sites damaged during the KwaZulu-Natal floods

Participants described how infrastructure breakdown compounded post-flood hardship: "We survived the water, but afterwards there was no clean water to drink. Children got sick from the water we collected from the river."

These findings are consistent with disaster studies in Mozambique, where cyclone-related floods damaged transport and utility networks and constrained humanitarian access. In South Africa, previous studies similarly note that infrastructure deficits in informal settlements intensify the impacts of climate-related disasters. Table 4 summarises the community-level infrastructure impacts reported in this study.

Table 4. Infrastructure impacts and their consequences for households

Infrastructure Type	Impact Reported	Consequences for Households
Water supply	Damaged pipelines; reliance on unsafe sources	Increased diarrhoeal disease
Sanitation	Collapsed pit latrines; blocked drainage	Health and hygiene risks
Electricity	Extended blackouts	Disrupted schooling, livelihoods
Roads and bridges	Collapse of major access routes	Isolation, delayed relief delivery
Schools	Damage to classrooms and materials	Interruption of education

The collapse of infrastructure escalated the floods from an environmental hazard to a wider humanitarian crisis, intensifying health, education, and livelihood risks. Similar outcomes have been reported in the Philippines, where infrastructure failure prolonged recovery and widened inequality.

4.4 Policy Gaps in Disaster Preparedness and Resilience Planning

The findings also identified policy gaps in disaster preparedness and resilience planning. Participants reported that early warning systems were inadequate. Many households received no alerts prior to the floods, while others reported limited trust in official warnings due to previous false alarms [47]. This aligns with broader assessments of disaster management in South Africa, which highlight weak risk communication and limited community engagement.

Relief efforts were frequently described as slow and uneven. Some participants perceived distribution as inconsistent and, in some cases, politically influenced. Households in informal settlements reported particular exclusion because insecure tenure limited access to reconstruction subsidies. NGOs provided essential support, but their interventions were fragmented relative to the scale of need [48].

Comparable gaps have been reported in Kenya, Ghana, and the Philippines, including weak preparedness, inequitable relief distribution, and limited integration of community perspectives. Evidence from regional case studies suggests that targeted interventions can reduce losses when implemented effectively. For example, community-based early warning systems using SMS alerts and local radio have been associated with reductions in disaster-related property loss in parts of Kenya and Mozambique. Similarly, evacuation drills and local disaster committees have been linked to improved household preparedness over time. Integrating such approaches into South Africa's disaster risk management system could strengthen accountability and improve measurable outcomes. Linking warning dissemination and preparedness activities to community-level indicators may also support a shift from broad policy commitments to performance-oriented resilience planning.

4.5 Synthesis and Implications

Overall, the findings indicate that the April 2022 KwaZulu-Natal floods were not only a consequence of extreme rainfall. Their impacts were mediated by social and infrastructural vulnerability [49]. Household losses were intensified by poverty and fragile housing, while infrastructure disruption converted the floods into a multi-dimensional crisis.

Comparisons with Kenya, Ghana, and the Philippines indicate recurring patterns of vulnerability in low- and middle-income contexts, underscoring the importance of inclusive, household-centred disaster risk reduction. The persistence of low resilience in KwaZulu-Natal, despite existing disaster risk reduction (DRR) frameworks, is consistent with social vulnerability theory. Resilience was constrained by structural factors, including insecure tenure, spatial injustice, and socio-economic exclusion, which limited households' capacity to anticipate, absorb, and recover from disaster impacts.

Although national policies such as the Disaster Management Act and the National Climate Change Adaptation Strategy are in place, implementation was frequently perceived as top-down and insufficiently responsive to marginalised communities. Similar challenges have been reported in Kenya, Ghana, and the Philippines, where resilience frameworks are less effective when governance systems do not address the structural drivers of vulnerability. In South Africa, these drivers remain historically rooted in apartheid-era spatial planning, which continues to shape settlement location and exposure to flood hazards. Consequently, resilience remains limited not because policies are absent, but because implementation does not sufficiently address the underlying conditions that generate vulnerability.

Policy implications include strengthening early warning systems, ensuring equitable access to relief irrespective of land tenure, investing in resilient infrastructure, and integrating community perspectives into resilience planning [50]. These priorities are summarised in Figure 5, which illustrates the cyclical relationship between early warning systems, resilient housing, community-based adaptation, and governance reform.

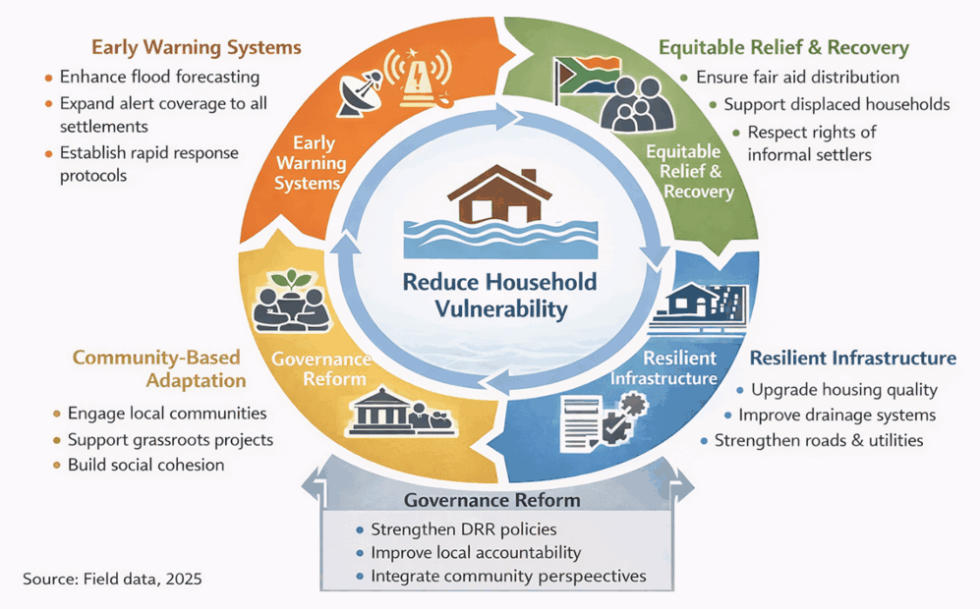

Figure 5. Policy framework for reducing household vulnerability to flood disasters in KwaZulu-Natal

5 Conclusion

This study examined the impacts of the April 2022 KwaZulu-Natal floods on vulnerable households using qualitative evidence from interviews, FGDs, document review, and field observations. The findings indicate that

the disaster was not solely the result of extreme rainfall. Instead, impacts were shaped by the interaction between climate-related hazards and long-standing social inequities.

Three themes emerged from the analysis. First, households reported extensive losses of housing, essential belongings, and critical documents. Many families were displaced to temporary shelters and experienced prolonged insecurity. Second, social and economic vulnerability factors—including poverty, fragile housing, insecure land tenure, and constraints associated with single-parent, elderly-headed, and child-headed households—intensified exposure and reduced recovery capacity. Third, damage to community infrastructure, particularly water supply, sanitation, electricity, and roads, prolonged disruption and contributed to a sustained humanitarian crisis.

The findings further show that the most severe impacts were concentrated among poorer and marginalised households whose coping capacity was constrained by limited financial resources, weak social protection, and historical exclusion from equitable urban development. Evidence from Kenya, Ghana, and the Philippines suggests that these dynamics extend beyond South Africa and reflect broader patterns of vulnerability in climate-exposed contexts in the Global South.

The policy implications are therefore substantial. Early warning systems require strengthening to ensure timely, accessible, and trusted communication with at-risk households. Investment in resilient housing and basic infrastructure remains essential, particularly in informal settlements where exposure and service deficits are most acute. In addition, inclusive community-based adaptation approaches are needed to support preparedness, response, and recovery. Such approaches should draw on local knowledge, strengthen social networks, and incorporate participatory planning to improve equity and sustainability.

5.1 Recommendations and Future Research

The findings highlight several priorities for policy and future research. First, disaster resilience frameworks should be aligned with the lived realities of vulnerable households, particularly in informal and peri-urban settlements. National and municipal disaster management policies should explicitly address intersecting vulnerabilities related to poverty, gender, household structure, and insecure tenure. Relief and recovery mechanisms should also be designed to avoid excluding households that lack formal documentation or legal tenure.

Second, community-driven resilience strategies should be expanded. Community-based early warning systems, participatory hazard mapping, and locally governed disaster response committees can improve trust and strengthen preparedness. Evidence from other African and Asian settings indicates that these approaches can enhance effectiveness when they are contextually adapted and supported by institutions.

Third, longitudinal research is needed to document recovery trajectories over time. While short-term assessments capture immediate losses, longer-term social, economic, and psychological consequences may emerge gradually. Tracking households over multiple years would strengthen understanding of resilience pathways, persistent barriers to recovery, and the effectiveness of policy interventions.

Finally, comparative cross-country research could further strengthen disaster risk reduction knowledge and practice. Studies examining flood resilience across sub-Saharan Africa and other climate-vulnerable regions could identify transferable lessons and support regional cooperation in climate adaptation and disaster governance.

Author Contributions

Conceptualization, V.S. and R.B.; methodology, V.S.; software, V.S.; validation, V.S. and R.B.; formal analysis, V.S.; investigation, V.S.; resources, V.S.; data curation, V.S.; writing—original draft preparation, V.S.; writing—review and editing, V.S. and R.B.; visualization, V.S.; supervision, R.B.; project administration, R.B. All authors have read and agreed to the published version of the manuscript.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability

The qualitative data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to the confidential nature of interviews and focus group discussions, transcripts are not publicly shared to protect participant anonymity.

Acknowledgements

Grateful acknowledgement is extended to the community members in KwaZulu-Natal who participated in the interviews and focus groups, and to the local NGOs and municipal officials who assisted during data collection.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] K. Furtak and A. Wolińska, "The impact of extreme weather events as a consequence of climate change on the soil moisture and on the quality of the soil environment and agriculture—A review," *Catena*, vol. 231, pp. 1–15, 2023. https://doi.org/10.1016/j.catena.2023.107378

[2] M. M. Khine and U. Langkulsen, "The implications of climate change on health among vulnerable populations in South Africa: A systematic review," *Int. J. Environ. Res. Public Health*, vol. 20, no. 4, pp. 1–19, 2023. https://doi.org/10.3390/ijerph20043425

[3] F. A. Engelbrecht, J. Steinkopf, J. Padavatan, and G. F. Midgley, "Projections of future climate change in Southern Africa and the potential for regional tipping points," in *Sustainability of Southern African Ecosystems under Global Change. Ecological Studies*. Springer, Cham, 2024, pp. 169–190. https://doi.org/10.1007/978-3-031-10948-5_7

[4] P. Lombe, E. Carvalho, and P. Rosa-Santos, "Drought dynamics in sub-Saharan Africa: Impacts and adaptation strategies," *Sustainability*, vol. 16, no. 22, pp. 1–22, 2024. https://doi.org/10.3390/su16229902

[5] H. Chikoore, M. J. Bopape, T. Ndarana, T. P. Muofhe, M. Gijben, R. B. Munyai, T. C. Manyanya, and R. Maisha, "Synoptic structure of a sub-daily extreme precipitation and flood event in Thohoyandou, north-eastern South Africa," *Weather Clim. Extrem.*, vol. 33, pp. 1–17, 2021. https://doi.org/10.1016/j.wace.2021.100327

[6] B. S. Ngcamu, "Application of the disaster management cycle and climate change: Studying flood disasters in South Africa," *Soc. Sci. Humanit. Open*, vol. 8, no. 1, pp. 1–19, 2023. https://doi.org/10.1016/j.ssaho.2023.100657

[7] B. R. Kuchimanchi, D. Nazareth, R. Bendapudi, S. Awasthi, and M. D'Souza, "Assessing differential vulnerability of communities in the agrarian context in two districts of Maharashtra, India," *Clim. Dev.*, vol. 11, no. 10, pp. 918–929, 2019. https://doi.org/10.1080/17565529.2019.1593815

[8] F. Cappelli, V. Costantini, and D. Consoli, "The trap of climate change-induced 'natural' disasters and inequality," *Glob. Environ. Chang.*, vol. 70, pp. 1–13, 2021. https://doi.org/10.1016/j.gloenvcha.2021.102329

[9] V. D. Banda, R. B. Dzwairo, S. K. Singh, and T. Kanyerere, "Hydrological modelling and climate adaptation under changing climate: A review with a focus in sub-Saharan Africa," *Water*, vol. 14, no. 24, pp. 1–26, 2022. https://doi.org/10.3390/w14244031

[10] M. Ganoe, J. Roslida, and T. Sihotang, "The impact of volunteerism on community resilience in disaster management," *J. Educ. Sci. Humanit.*, vol. 12, no. 3, pp. 199–213, 2023. https://doi.org/10.35335/jiph.v12i3.11

[11] Z. A. Elum and O. Lawal, "Flood risk perception, disaster preparedness and response in flood-prone urban communities of Rivers State," *Jàmbá J. Disaster Risk Stud.*, vol. 14, no. 1, pp. 1–10, 2022. https://doi.org/10.4102/jamba.v14i1.1303

[12] T. P. P. Sharma, J. Zhang, N. R. Khanal, P. Nepal, B. P. P. Sharma, L. Nanzad, and Y. Gautam, "Household vulnerability to flood disasters among Tharu community, Western Nepal," *Sustainability*, vol. 14, no. 19, pp. 1–19, 2022. https://doi.org/10.3390/su141912386

[13] E. Mudefi, "Disaster management 'deeds' in the context of April 2022 KwaZulu-Natal floods: A scoping review," *Int. J. Disaster Risk Reduct.*, vol. 98, pp. 1–21, 2023. https://doi.org/10.1016/j.ijdrr.2023.104122

[14] R. Jewkes, A. Gibbs, S. Mkhwanazi, A. Zembe, Z. Khoza, N. Mnandi, L. Washington, S. Khaula, S. Gigaba, J. Nöthling, N. Abrahams, and S. Willan, "Impact of South Africa's April 2022 floods on women and men's lives and gender relations in low-income communities: A qualitative study," *SSM-Ment. Health*, vol. 4, pp. 1–9, 2023. https://doi.org/10.1016/j.ssmmh.2023.100255

[15] J. Bouchard, T. B. Pretorius, A. L. Kramers-Olen, A. Padmanabhanunni, and N. Stiegler, "Global warming and psychotraumatology of natural disasters: The case of the deadly rains and floods of April 2022 in South Africa," *Ann. Méd.-psychol. Rev. Psychiatr.*, vol. 181, no. 3, pp. 234–239, 2022. https://doi.org/10.1016/j.amp.2022.07.004

[16] E. E. Ebhuoma, N. J. Nene, and L. Leonard, "Analysis of urban households' preparedness and municipal interventions to build flood resilience in Durban, South Africa: Implications for SDG 11," *Environ. Sustain. Indic.*, vol. 23, pp. 1–11, 2024. https://doi.org/10.1016/j.indic.2024.100454

[17] S. Dlamini, B. Nhleko, and N. Ubisi, "Understanding socioeconomic risk and vulnerability to climate change-induced disasters: The case of informal settlements in KwaZulu-Natal, South Africa," *J. Asian Afr. Stud.*, pp. 1–20, 2024. https://doi.org/10.1177/00219096241275398

[18] A. Van Straten and A. Ncube, "Assessing the spiritual and mental health of the KwaZulu-Natal flood disaster survivors," *Jàmbá J. Disaster Risk Stud.*, vol. 15, no. 1, pp. 1–5, 2023. https://doi.org/10.4102/jamba.v15i1.1435

[19] W. Thoithi, R. C. Blamey, and C. J. C. Reason, "April 2022 floods over east coast South Africa: Interactions between a mesoscale convective system and a coastal meso-low," *Atmosphere*, vol. 14, no. 1, pp. 1–23, 2022. https://doi.org/10.3390/atmos14010078

[20] K. Naidoo, N. P. Nzimande, and F. Morris, "Investigating the socioeconomic impacts of sewage spillages on businesses in the Umhlanga Rocks coastline area," *Jàmbá J. Disaster Risk Stud.*, vol. 16, no. 1, pp. 1–13, 2024. https://doi.org/10.4102/jamba.v16i1.1602

[21] E. Dube, O. Mtapuri, and J. Matunhu, "Flooding and poverty: Two interrelated social problems impacting rural development in Tsholotsho district of Matabeleland North province in Zimbabwe," *Jàmbá J. Disaster Risk Stud.*, vol. 10, no. 1, pp. 1–7, 2018. https://doi.org/10.4102/jamba.v10i1.455

[22] S. Ajodhia and T. B. Makhanya, "The lived experiences of displaced African single mothers in the aftermath of floods in KwaZulu-Natal," *Soc. Work*, vol. 60, no. 3, pp. 602–621, 2024. https://doi.org/10.15270/60-3-1349

[23] J. Vestby, S. Schutte, A. F. Tollefsen, and H. Buhaug, "Societal determinants of flood-induced displacement," *Proc. Natl. Acad. Sci.*, vol. 121, no. 3, pp. 1–10, 2024. https://doi.org/10.1073/pnas.2206188120

[24] A. Musyoki, R. Thifhulufhelwi, and F. M. Murungweni, "The impact of and responses to flooding in Thulamela Municipality, Limpopo Province, South Africa," *Jàmbá J. Disaster Risk Stud.*, vol. 8, no. 2, pp. 1–10, 2016. https://doi.org/10.4102/jamba.v8i2.166

[25] E. O. Anwana and O. M. Owojori, "Analysis of flooding vulnerability in informal settlements literature: Mapping and research agenda," *Soc. Sci.*, vol. 12, no. 1, pp. 1–21, 2023. https://doi.org/10.3390/socsci12010040

[26] N. James, "Commentary: The effects of climate change on informal settlements," *Town Reg. Plan.*, vol. 82, pp. 1–3, 2023. https://doi.org/10.38140/trp.v82i.6616

[27] R. Morrison, H. Tillermuir, L. Carboni, C. Hotchin, and H. Lal, "A holistic framework to improve urban flood management in cities with informal settlements," *Environ. Res. Infrastruct. Sustain.*, vol. 5, no. 1, pp. 1–15, 2025. https://doi.org/10.1088/2634-4505/adc32f

[28] R. U. Zzaman, S. Nowreen, M. Billah, and A. S. Islam, "Flood hazard mapping of Sangu River basin in Bangladesh using multi-criteria analysis of hydro-geomorphological factors," *J. Flood Risk Manag.*, vol. 14, no. 3, pp. 1–19, 2021. https://doi.org/10.1111/jfr3.12715

[29] T. K. Alain, B. T. Luc, D. Ali, D. Moumoni, I. Zongo, and F. Zougmoré, "Assessment of heavy metal concentration and evaluation of health risk of some vegetables cultivated in Loumbila farmland, Burkina Faso," *J. Environ. Prot.*, vol. 12, no. 12, pp. 1019–1032, 2021. https://doi.org/10.4236/jep.2021.1212060

[30] Y. Xu, J. Liu-Zeng, M. B. Allen, W. Zhang, and P. Du, "Landslides of the 1920 Haiyuan earthquake, northern China," *Landslides*, vol. 18, no. 3, pp. 935–953, 2020. https://doi.org/10.1007/s10346-020-01512-5

[31] S. Healey, S. Lloyd, J. Gray, and A. Opdyke, "A census-based housing vulnerability index for typhoon hazards in the Philippines," *Prog. Disaster Sci.*, vol. 13, pp. 1–12, 2021. https://doi.org/10.1016/j.pdisas.2021.100211

[32] T. A. Keya, A. Leela, N. Habib, M. Rashid, and P. Bakthavatchalam, "Mental health disorders due to disaster exposure: A systematic review and meta-analysis," *Cureus*, vol. 15, no. 4, pp. 1–13, 2023. https://doi.org/10.7759/cureus.37031

[33] G. T. Nigatu, B. A. Abebe, B. Grum, M. G. Kebedew, and E. M. Semane, "Investigation of flood incidence causes and mitigation: Case study of Ribb River, northwestern Ethiopia," *Nat. Hazards Res.*, vol. 3, no. 3, pp. 408–419, 2023. https://doi.org/10.1016/j.nhres.2023.04.009

[34] A. A. Shah, J. Ye, R. Shaw, R. Ullah, and M. Ali, "Factors affecting flood-induced household vulnerability and health risks in Pakistan: The case of Khyber Pakhtunkhwa (KP) Province," *Int. J. Disaster Risk Reduct.*, vol. 42, p. 101341, 2019. https://doi.org/10.1016/j.ijdrr.2019.101341

[35] S. K. Aksha, L. Juran, L. M. Resler, and Y. Zhang, "An analysis of social vulnerability to natural hazards in Nepal using a modified social vulnerability index," *Int. J. Disaster Risk Sci.*, vol. 10, no. 1, pp. 103–116, 2018. https://doi.org/10.1007/s13753-018-0192-7

[36] X. Huang, J. Yin, L. J. Slater, S. Kang, S. He, and P. Liu, "Global projection of flood risk with a bivariate framework under 1.5–3.0°C warming levels," *Earth's Future*, vol. 12, no. 4, pp. 1–19, 2024. https://doi.org/10.1029/2023EF004312

[37] R. Abegaz, J. Xu, F. Wang, and J. Huang, "Impact of flooding events on buried infrastructures: A review," *Front. Built Environ.*, vol. 10, pp. 1–8, 2024. https://doi.org/10.3389/fbuil.2024.1357741

[38] W. Wang, N. Z. Foutz, and G. Gao, "Huddling with families after disaster: Human resilience and social disparity," *PLOS ONE*, vol. 17, no. 9, p. e0273307, 2022. https://doi.org/10.1371/journal.pone.0273307

[39] M. B. Hahn, R. Van Wyck, L. Lessard, and R. Fried, "Compounding effects of social vulnerability and recurring natural disasters on mental and physical health," *Disaster Med. Public Health Prep.*, vol. 16, no. 3, pp. 1013–1021, 2021. https://doi.org/10.1017/dmp.2020.476

[40] A. Li, M. Toll, E. Martino, I. Wiesel, F. Botha, and R. Bentley, "Vulnerability and recovery: Long-term mental and physical health trajectories following climate-related disasters," *Soc. Sci. Med.*, vol. 320, pp. 1–19, 2023. https://doi.org/10.1016/j.socscimed.2023.115681

[41] M. Wang and X. Yin, "Construction and maintenance of urban underground infrastructure with digital technologies," *Autom. Constr.*, vol. 141, pp. 1–16, 2022. https://doi.org/10.1016/j.autcon.2022.104464

[42] M. Kaur, K. Hewage, and R. Sadiq, "Integrated level of service index for buried water infrastructure: Selection and development of performance indicators," *Sustain. Cities Soc.*, vol. 68, p. 102799, 2021. https:

//doi.org/10.1016/j.scs.2021.102799

[43] Q. A. Khan, A. Jan, S. Iram, I. Haider, A. Badshah, A. Khan, A. Hidayat, A. M. Farrukh, H. U. Ain, and R. Verma, "Impact of 2022 flood on socioeconomic and health status of people residing in flood-stricken areas of pakistan: A cross-sectional survey," *Ann. Med. Surg.*, vol. 86, no. 11, pp. 6465–6471, 2024. https://doi.org/10.1097/ms9.0000000000002402

[44] S. G. N. Ekpodessi and H. Nakamura, "Impact of insecure land tenure on sustainable housing development: A case study of urban housing lands in the Republic of Benin, West Africa," *Sustainability*, vol. 15, no. 21, pp. 1–29, 2023. https://doi.org/10.3390/su152115497

[45] R. Diaz, B. Acero, J. G. Behr, and N. S. Hutton, "Impacts of household vulnerability on hurricane logistics evacuation under COVID-19: The case of U.S. Hampton Roads," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 176, p. 103179, 2023. https://doi.org/10.1016/j.tre.2023.103179

[46] M. T. Chaudhary and A. Piracha, "Natural disasters: Origins, impacts, management," *Encyclopedia*, vol. 1, no. 4, pp. 1101–1131, 2021. https://doi.org/10.3390/encyclopedia1040084

[47] R. Dutta and S. Basnayake, "Gap assessment towards strengthening early warning systems," *Int. J. Disaster Resil. Built Environ.*, vol. 9, no. 2, pp. 198–215, 2018. https://doi.org/10.1108/ijdrbe-11-2016-0051

[48] J. Popay, "Understanding and tackling social exclusion," *J. Res. Nurs.*, vol. 15, no. 4, pp. 295–297, 2010. https://doi.org/10.1177/1744987110370529

[49] S. Grab and D. J. Nash, "A new flood chronology for KwaZulu-Natal (1836–2022): The April 2022 Durban floods in historical context," *S. Afr. Geogr. J.*, pp. 1–22, 2023. https://doi.org/10.1080/03736245.2023.2193758

[50] M. M. Al-Humaiqani and S. G. Al-Ghamdi, "The built environment resilience qualities to climate change impact: Concepts, frameworks, and directions for future research," *Sustain. Cities Soc.*, vol. 80, p. 103797, 2022. https://doi.org/10.1016/j.scs.2022.103797