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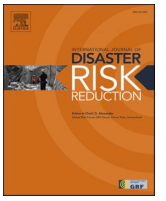

Disaster risk management in informal settlements: Household evidence from KwaZulu-Natal, South Africa

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ABSTRACT

Rapid urbanisation has intensified disaster risk in informal settlements. In South Africa, over two million households live in informal settlements, many in floodplains or high-risk areas. Often the only accessible land for low-income residents, these sites expose households to flood and fire hazards. Flood risk is intensified by climate variability, rainfall, low-lying terrain and poor drainage, while fire risk is shaped by dense layouts and combustible materials. These hazards interact with poor housing, limited services and low incomes, yet remain insufficiently captured by risk assessments.

This study examines how flooding and fire are experienced and managed in Khan Road informal settlement, KwaZulu-Natal Province, South Africa. It draws on 160 interviews by trained community researchers using a survey with closed and open-ended questions. The survey captured hazard exposure, housing and service conditions, impacts and responses.

The research contributes household-scale evidence showing how multi-hazard risk is experienced within dwellings and shaped by infrastructure failure, settlement morphology and informal response networks. Findings reveal multi-hazard exposure: over half reported flooding, nearly three-quarters fire, and two-fifths both hazards. Respondents linked flooding to terrain and drainage constraints, and fire risk to dense layouts and combustible materials. Unreliable water supply and shared sanitation intensified vulnerability and constrained recovery. Residents relied on neighbours and family for warning, response and support.

The findings indicate that disaster risk in informal settlements is co-produced through morphology, infrastructure deficits and social support systems. They show that community-generated data can strengthen disaster risk reduction and upgrading interventions in South Africa and other Global South cities.

1. Introduction

Informal settlements represent a critical interface between hazard exposure, infrastructure inequality, structural vulnerability and rapid urbanisation. Across the Global South, informal settlements are frequently located on environmentally marginal land such as

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floodplains, wetlands and unstable or steep slopes. This spatial pattern reflects structural exclusion from formal housing markets while simultaneously providing essential access to urban livelihoods [1,2]. Comparable patterns are evident across Latin America, where informal settlements are frequently concentrated in hazard-prone locations and where unequal access to land, housing and infrastructure contributes to differentiated disaster risk. Evidence from Costa Rica and Peru demonstrates how structural vulnerability and informal urbanisation interact with environmental exposure to produce persistent and, in many cases, multi-hazard risk [3–5].

In Sub-Saharan Africa, informal settlements are increasingly recognised as structurally embedded components of urban housing systems rather than temporary transitional spaces. As such, they require integrated responses that combine upgrading, community participation and incremental housing strategies [6,7]. Informal settlements are therefore not peripheral to urban development, but central to debates on climate adaptation, disaster risk reduction and inclusive urban governance [8–10]. In South Africa, this policy challenge remains substantial. Census 2022 recorded 17.8 million households nationally, while the General Household Survey 2024 reported that 11.7% of households lived in informal dwellings, underlining the continuing significance of informal housing in the national urban system [11,12].

The study is situated within disaster risk reduction research concerned with how exposure, vulnerability, household capacity and governance interact across scales [13–15]. It is also consistent with South Africa's disaster management policy framework, which emphasises vulnerability reduction, prevention, mitigation and community involvement in disaster risk reduction [16]. In informal settlements, climate-related hazards, infrastructure deficits, insecure housing and weak institutional support are experienced together within everyday living environments.

Recent research demonstrates that disaster risk in informal settlements is frequently systemic and multi-layered. Flood hazards, including increasingly intense rainfall events, are exacerbated by settlement density, drainage failure, poor infrastructure, lightweight and often combustible construction materials, and waste accumulation, generating cascading impacts across infrastructure systems, public health outcomes and household livelihoods [17–19]. Empirical evidence further shows that flood exposure and damage outcomes are shaped by micro-scale environmental and geomorphological conditions, including land cover, topography, slope and proximity to water bodies, reinforcing the importance of localised risk assessment approaches [20–22]. Recent evidence from rapidly urbanising Costa Rica further demonstrates how slope, terrain morphology, hydrological networks and flow accumulation influence the spatial distribution of landslide and flood risk [23]. In dense informal environments, fire propagation is strongly influenced by settlement morphology, building material flammability and emergency access constraints, producing settlement-level vulnerability even where emergency response systems are present [24,25]. This evidence indicates that disaster risk in informal settlements cannot be understood through single-hazard or area-wide assessments alone but must be examined through the interaction of environmental exposure, infrastructure deficits and everyday living conditions. Recent evidence from Colombia similarly demonstrates how flood, fire and other hazards intersect with settlement morphology, infrastructure deficits and socioeconomic conditions in informal urban environments. These studies reinforce the need to understand informal-settlement disaster risk as multi-hazard and systemic rather than as exposure to isolated hazard events [26,27].

At the same time, informal settlements demonstrate embedded forms of social resilience. Communities frequently act as first responders during hazard events and rely on local leadership, social networks and collective organisation to coordinate response and recovery processes [28]. At household level, preparedness and recovery capacity are shaped by access to economic, social and physical resources [13,29]. Usamah et al. [30] show that informal dwellers often show an inbuilt resilience perceiving disasters as part of everyday life. That study outlines that resilience is frequently rooted in strong social networks, mutual support systems, and adaptive coping strategies that enable communities to withstand and recover from shocks. Hazard perception and response behaviour are further shaped by local environmental knowledge and experiential learning, and may complement formal early warning systems, particularly where institutional trust is uneven [22,31,32]. Communication effectiveness similarly depends on trust and social proximity in dense informal settlements [33].

Despite these advances, significant methodological gaps remain in measuring disaster risk and resilience in informal settlements across multiple hazards at household scale. Conventional approaches rely heavily on remote sensing, hazard modelling and administrative datasets, which often fail to capture micro-scale variability and lived risk experience in rapidly evolving informal environments, particularly in-dwelling flooding, asset loss, material damage and household-level response practices [14,15]. While indicator-based resilience assessment frameworks provide practical alternatives in data-constrained contexts, they frequently lack integration of household-scale evidence, governance dynamics and community-generated data. Emerging hybrid approaches combining spatial mapping, participatory methods and indicator-based assessment demonstrate strong potential for improving context-specific resilience measurement [34,35]; however, empirical integration of these approaches at household scale remains limited.

In South Africa, informal settlement upgrading policy increasingly emphasises participation, co-production and community knowledge as key factors contributing to resilience building. However, empirical evidence linking household living conditions, community governance systems and disaster risk reduction outcomes remains limited, particularly in understanding how communities recover from repeated hazard exposure and transition from short-term coping to longer-term resilience [36,37]. This gap matters in relation to the Upgrading of Informal Settlements Programme (UISP) in the National Housing Code, which is explicitly framed around structured, area-based, participatory and incremental upgrading rather than relocation as a default response [38]. It also matters in relation to South Africa's disaster management policy context, which recognises rising risk associated with extreme weather, urbanisation and infrastructure deterioration [16].

This study addresses that gap through a case study of Khan Road informal settlement in KwaZulu-Natal, South Africa. It seeks to examine how flooding and settlement-related fire hazards are experienced, understood and managed at household scale within a high-risk informal settlement context, with particular attention to perceived exposure, underlying vulnerability conditions and community-

based response practices.

To achieve this aim, the study pursues the following objectives.

1. To assess household exposure to flooding and settlement-related fire hazards, including experiences of multi-hazard exposure.
2. To examine how housing characteristics and access to basic services shape vulnerability to hazard impacts at household level.
3. To analyse household and community response systems during hazard events, including the role of social networks, local leadership and informal support mechanisms.
4. To evaluate how community-embedded household data can strengthen disaster risk reduction evidence and inform policy and upgrading practice in informal settlement contexts.

This study provides household-scale evidence of how flood and fire hazards intersect with infrastructure deficits, settlement morphology, and social response networks to generate persistent multi-hazard conditions. It illustrates how disaster risk emerges from the interaction between dwelling conditions, infrastructure performance, and social organisation, and demonstrates the value of integrating structured survey data with community-generated evidence in informal settlement risk assessment. In doing so, it positions the household not simply as a unit of exposure, but as a critical site through which disaster risk is experienced, negotiated and managed in everyday urban life.

2. Literature review

2.1. Infrastructure deficits and household vulnerability

The impacts of climate change are likely to be felt disproportionately in countries of the Global South, where structural and developmental inequalities continue to shape vulnerability. Many of these countries face limited institutional capacity, governance constraints and high levels of socio-economic inequality, which reduce their ability to prepare for, respond to and recover from climate-related shocks [39]. These pressures are particularly acute in urban informal settlements, where hazard exposure is bound up with insecure tenure, inadequate infrastructure, poor service provision and constrained household resources [1,18].

Informal settlements often struggle to access and maintain safe, reliable and equitable basic services, including water, sanitation, energy and housing infrastructure. This reflects a combination of legal and tenure insecurity, exclusion from formal planning systems, underinvestment in basic services and distrust between residents and local authorities [40]. Households are therefore often compelled to rely on informal forms of provision that are less reliable and of poorer quality than formal systems, including unsafe water and sanitation arrangements [41] and housing that falls outside formal building and regulatory standards [40]. These deficits are not simply markers of poverty. They shape the way hazards are experienced at household level. Poor drainage, unreliable water supply, weak sanitation systems and precarious housing materials increase exposure, limit preparedness and make recovery more difficult when hazard events occur. Fragile infrastructure can also intensify cascading effects across basic services, particularly where water and sanitation systems are already under stress [42]. Infrastructure systems in informal settlements are closely interdependent, and disruption in one service can quickly generate failures or constraints in others. Drainage failure may lead to sanitation overflow, while interruptions to water supply can impede hygiene, cleaning and recovery following flood events [17,42]. These dynamics are especially evident in flood-prone urban settings, where drainage failure, settlement expansion into low-lying and environmentally fragile land, and the limited capacity of local infrastructure systems to absorb shocks can significantly intensify risk [21,43]. Evidence from tropical urban settings further demonstrates how geomorphological conditions interact with urban development and infrastructure deficits to shape vulnerability. For example, in the rapidly developing city of Santa Ana, Costa Rica, slope, landform and flow-accumulation characteristics influence landslide and flood susceptibility [20], while household-level research in a landslide-prone informal settlement in Manado, Indonesia, shows how inadequate solid-waste management can compound geological risk and existing settlement vulnerability [31]. At household level, this may result in in-dwelling flooding, damage to belongings, contamination of living space and repeated repair costs, all of which erode already limited coping capacity.

Climate hazards also place further pressure on housing affordability, infrastructure access and neighbourhood stability for low-income urban households [18,44]. In informal settlements, insecure tenure and exclusion from formal planning and housing systems deepen these pressures and restrict the ability of households to move to safer locations or invest in more durable living conditions [1,39,40]. Household vulnerability cannot therefore be understood only in terms of income poverty. It is produced through the interaction of insecure tenure, infrastructure precarity, hazardous location and repeated exposure to overlapping risks such as flooding, fire and service disruption.

2.2. Community-based response and informal governance

Public institutional responses to disaster risk in informal settlements are often constrained by weak coordination between communities and local government, limited resources, and delayed preparedness and response mechanisms [40,45]. Where cooperation is weak, communities may be excluded from decision-making, locally grounded knowledge may be overlooked, and disaster risk reduction measures may fail to secure settlement-level uptake or trust [40,46]. Evidence from Freetown illustrates this clearly: residents recognised local risks and vulnerabilities, yet their capacity to act remained limited by inadequate support, insufficient resources and weak institutional engagement [40]. Disaster risk management in informal settlements is therefore shaped not only by formal governance arrangements, but also by the quality of the relationship between communities and the state.

Land tenure insecurity adds a further constraint. Where households face the possibility of eviction or lack confidence in their long-term right to remain, they may be less willing or less able to invest in safer housing, service improvements or longer-term preparedness measures [47]. Informality thus affects more than exposure to hazard. It also influences the scope for household investment, collective organisation and local risk reduction both short and longer term. This is particularly important in settlements where decisions about construction materials, maintenance and service access are made incrementally and under conditions of uncertainty.

The literature on community-based disaster risk reduction often gives prominence to externally led or top-down interventions introduced by governmental and non-governmental actors [48]. Such approaches may improve preparedness, but they do not always recognise the capacity of communities to define priorities, mobilise support and develop locally appropriate responses. Studies of community-based flood mitigation show that public participation, local knowledge and involvement in early warning systems can strengthen resilience, although such efforts remain constrained by limited funding, bureaucratic delay, weak infrastructure and insufficient collaboration between communities and public institutions [49].

Recent studies suggest that community-led approaches are central to strengthening disaster resilience in informal settlements. In South Africa, a pilot study in Durban [50] shows how residents can successfully self-organise and co-design a locally relevant resilience strategy by combining low-cost technologies, community-based early warning systems, and participatory capacity-building initiatives. This approach combines technical and indigenous knowledge to strengthen the local community's resilience and promote self-reliance and reframes residents as co-producers of knowledge rather than passive recipients.

In informal settlements, community response should therefore be understood not as a substitute for formal disaster management, but as an immediate and necessary form of local governance operating within conditions of institutional neglect. This is especially relevant in dense settlements, where neighbours and kin frequently constitute the first line of warning, assistance and recovery.

2.3. Disaster risk management frameworks and household-level resilience

A persistent limitation in disaster resilience research lies in the mismatch between the scale at which evidence is collected and the scale at which policy is framed. Eriksen and Simon [51] note that much of the literature examines resilience at household and community level, while recommendations are more frequently directed towards actors at municipal, national or international level. Gaisie et al. [13] similarly show that resilience capacities and coping outcomes vary considerably at household level, where different combinations of human, economic, physical and social resources shape preparedness, impacts and recovery across the disaster cycle. This is especially significant in informal settlements, where households living in close proximity may nonetheless experience risk and recovery very differently.

At the same time, parts of the resilience literature continue to privilege financial security as the primary determinant of resilience, sometimes at the expense of other social and structural dimensions [52]. Eriksen and Simon [51] criticise this tendency for underplaying the role of intersectional factors such as gender and disability, while Mika [53] cautions that interventions framed too narrowly around financial support may overlook or even disrupt existing social networks, local knowledge and established coping practices. In informal settlements, where access to formal support is often limited, resilience is sustained not only through material assets but also through relationships of reciprocity, practical knowledge and informal organisation. This reinforces the need to conceptualise household vulnerability as multi-dimensional rather than predominantly socioeconomic. Disaster risk assessments in informal settlements have shown that risk emerges through the interaction of hazard exposure with social, physical and environmental vulnerability, including housing conditions, basic-service deficits and settlement location [5,54]. Similar evidence from Peru demonstrates how unequal access to land and services, housing and settlement conditions, and environmental exposure combine to produce differentiated and multi-hazard vulnerability in informal urban areas [3,4].

Household-level analysis is therefore essential for understanding how disaster risk is lived and managed in practice. It allows attention to be paid to the forms of loss and disruption that broader assessments often miss, including in-dwelling flooding, document loss, contamination of domestic space, temporary displacement and the uneven capacity to recover from repeated events. This is consistent with arguments for more context-sensitive resilience assessment in marginalised urban areas, including approaches that seek to move beyond aggregate indicators towards more grounded and measurable understandings of everyday risk and recovery [14,15]. Within informal settlements, household evidence is particularly important because it reveals how infrastructure deficits, resource constraints and social support systems combine in ways that are not captured adequately by municipal or spatial datasets alone.

2.4. Co-production of disaster risk and resilience

Recent work on participatory and community-led approaches has demonstrated the value of involving marginalised communities directly in identifying risks and shaping adaptation strategies [8–10]. Oliver et al. [48], through the Empower'22 project, show how participatory systems mapping can help communities and researchers identify context-specific climate risks and co-develop possible responses at household and community level. Their work also shows that awareness of risk does not in itself guarantee adaptive action, particularly where resources, technical knowledge or institutional support remain limited. The significance of co-produced approaches lies less in participation as an abstract principle than in their capacity to generate grounded accounts of risk that reflect the realities of place.

Other participatory approaches, including climate information services and scenario planning, have also sought to strengthen public engagement in adaptation and decision-making [55,56]. Yet, much of this work has been developed in rural or agricultural settings, and its transferability to dense urban informal settlements cannot be assumed. Informal settlements present distinctive combinations of exposure, including insecure tenure, deficient infrastructure, high density and overlapping hazards, all of which

require forms of analysis that are sensitive to settlement conditions and household experience.

For informal settlements, co-production is most valuable when it makes visible the contingent forms of risk that are routinely overlooked by conventional assessments. Flood depth at settlement scale, for example, does not capture what happens once water enters the dwelling, damages bedding and clothing, contaminates food, destroys documents or forces temporary relocation. Nor do administrative datasets adequately capture the role of neighbours, local leaders and family networks in warning, response and recovery. There is increasing recognition that hybrid approaches combining local knowledge, participatory methods and structured assessment can improve resilience measurement and planning in data-constrained settings [31,32,34,35]. Recent flood-risk studies demonstrate how such approaches can operate in data-scarce contexts. Participatory field surveys and freely available data have been combined with hydrological and hydraulic modelling in Mozambique, while citizen-science approaches in Vietnam have generated locally grounded data on residential flooding, land use and flood impacts where conventional datasets are limited [57,58]. High-resolution spatial approaches can further strengthen disaster risk reduction planning by integrating hazard, exposure and vulnerability at local and municipal scales. Recent studies in Costa Rica demonstrate the value of spatially explicit modelling for identifying differentiated climate-risk zones and assessing flood and landslide risk within rapidly urbanising municipalities [23,59]. Comparable international approaches demonstrate how locally focused flood-risk studies can generate lessons that extend beyond their immediate study areas. Research from South Sudan emphasises practical flood-risk reduction strategies in resource-constrained settings, while Bertilsson et al. [60] demonstrate how multi-criteria approaches can integrate flood resilience into wider urban planning and decision-making [60,61]. Even so, household-level empirical evidence remains limited, particularly in South African informal settlements exposed to repeated and overlapping hazards.

Flood and fire risks are often examined separately, yet in informal settlements they may be intensified by the same spatial, material and infrastructural conditions. Poor drainage, low-lying land and weak infrastructure shape flood exposure [17,21,43], while dense layouts, combustible materials and constrained emergency access intensify fire risk [24,25]. These conditions frequently overlap in informal settlements, making household-scale multi-hazard analysis necessary [14,15,18,19].

Existing research shows that disaster risk in informal settlements is shaped by hazardous location, infrastructure deficits, insecure tenure, settlement density and uneven access to social support [13,18,28,40]. Less clear is how these shared conditions are experienced at household level in settlements exposed to both flood and fire. Flood and fire are often analysed separately; infrastructure and service deficits are not always examined as active components of risk production; and household-scale evidence remains insufficiently integrated into disaster risk assessment and resilience measurement [8,9,14,15,17,24,36]. The present study addresses this gap by specifically examining household perceptions of flood and fire exposure, the influence of housing and basic services on vulnerability, and the role of community-based response systems in a flood-prone informal settlement in KwaZulu-Natal. This focus helps reveal how risk is experienced within the dwelling and through everyday infrastructure failure.

Fig. 1. Drone map of the Khan Road informal settlement.

3. Research methodology

3.1. Study design

This study uses a survey design based on a structured instrument combining closed quantitative questions with open-ended response fields. The instrument was developed as a pilot household assessment tool for the Khan Road settlement and was informed by prior community-based risk assessment approaches and informal settlement upgrading frameworks. The survey design was further shaped through collaboration with local partner organisations, including the Community Organisation Resource Centre (CORC) and YMAD, and through pre-fieldwork engagement processes. The design enables integrated analysis of hazard exposure, infrastructure and service conditions, household impacts, and response practices within a single dataset. This structure allows examination of how flood and fire hazards interact with infrastructure conditions and social response systems at household scale.

Prior to household data collection, drone mapping and collaborative participatory risk mapping exercises were undertaken to document settlement layout, environmental exposure zones and infrastructure distribution, as shown in Fig. 1. Insights from these spatial exercises informed survey structure and hazard-related questioning. Drone and participatory mapping supported alignment between reported household exposure and observed settlement morphology. This process informed the development of a community-led disaster response strategy [50] focused on participatory, community-led processes that empower residents to identify risks, generate knowledge, and co-design locally appropriate solutions.

In this study, these collaborative mapping exercises are used primarily to contextualise survey design and settlement conditions with first-hand community insights.

The analysis draws on a published community dataset on living conditions and disaster risk management in informal settlements in KwaZulu-Natal, South Africa [36]. Household-scale data were prioritised because they capture micro-level exposure pathways (e.g., in-dwelling flooding, document loss, temporary displacement) and response behaviours that are not visible in administrative or remote-sensing datasets. The dataset gathered through a pilot study has been published previously [36]; this article presents the substantive analysis.

3.2. Case study context: Khan Road informal settlement

The settlement was previously estimated to contain approximately 121 households and an estimated population of approximately 363 residents [36]. Formal infrastructure provision is extremely limited, including one communal standpipe and approximately five communal pit toilets. These service conditions shape both hazard exposure and the severity of hazard impacts.

The settlement experiences recurrent flood exposure linked to wetland overflow, surface water accumulation and drainage constraints (see Fig. 2). Periodic fire risk is also present, associated with dense dwelling layouts, flammable construction materials and electrical and cooking practices. Flood and fire hazards form part of everyday living conditions rather than isolated external events.

3.3. Data collection

Primary data were collected between August and September 2022 through face-to-face structured household surveys administered using mobile phone-based digital data collection via KoboToolbox [36].

The survey targeted the adult resident population of the settlement. Because more than one adult respondent could be interviewed from the same household, the dataset reflects adult respondent reports on household conditions rather than a one-respondent-per-household sample. A total of 160 interviews were conducted and included in the analysis. Valid n varies across variables because some respondents did not answer every question.

Data collection was undertaken by trained community researchers residing within the settlement. Fifteen community researchers were selected in collaboration with local NGOs and completed structured training prior to fieldwork (see Fig. 3). Interviews were

Fig. 2. Informal dwellings built in a floodplain in Khan Rd.

conducted orally in isiZulu and English, with responses digitally recorded using KoboCollect (see Fig. 4). The use of community researchers enhanced contextual sensitivity and trust, reduced response barriers, and improved the accuracy of documenting locally specific hazard experience, particularly where residents described recurrent flooding, in-dwelling damage and informal response practices. The survey instrument captured eleven thematic domains including household demographics, housing conditions, service access, flood and fire exposure, disaster response behaviour, community organisation, communication channels, skills development and livelihood activities. Hazard-related questions distinguished between exposure (whether households had experienced flood or fire), frequency of events, physical impacts (e.g., asset loss, structural damage, temporary displacement), and behavioural responses (e.g., evacuation, neighbour support, contact with authorities). The survey enabled assessment of hazard exposure, impact severity and response patterns within a single dataset.

A structured door-to-door approach was used to maximise household coverage during the study period. In the absence of an official household register, sampling was based on household availability at the time of fieldwork, with neighbouring households approached where residents were unavailable. This approach reflects common practice in informal settlement research where stable sampling frames are absent [8,9,37]. As more than one adult respondent could be interviewed from the same dwelling, the analysis is treated as respondent-reported household experience rather than as a one-respondent-per-household prevalence estimate. The findings are therefore interpreted descriptively and are not presented as statistically generalisable to all households in the settlement.

Participants were consenting adults aged 18 years and above. All responses were anonymised and reported using participant identification codes (IP1-IP160) to preserve confidentiality. Ethical procedures included informed consent, the option to decline participation or specific questions, and anonymisation of all qualitative excerpts. Full ethical approval for the study was granted by the University of KwaZulu-Natal Research Humanities and Social Sciences Research Ethics Committee (HSSREC) protocol number HSSREC/00004460/2022.

3.4. Data analysis

Data were analysed using a mixed-methods approach combining descriptive statistical analysis with structured qualitative coding, drawing on the dataset reported in Georgiadou et al. [36].

Closed-ended survey responses were analysed using frequency and percentage distributions following data cleaning and variable standardisation. Where relevant, medians and interquartile ranges were calculated for continuous variables such as household size and reported flood frequency. Exploratory analysis examined patterns of hazard exposure (flood and fire), multi-hazard exposure, and distribution of service access conditions across respondents.

Open-ended responses were coded iteratively to identify recurrent impact and response mechanisms evident in the dataset. Codes were derived from repeated descriptions in the dataset and included.

- In-dwelling flooding (water entering and accumulating inside the home)
- Water entering through the roof and/or floor level
- Destruction or damage to household belongings
- Loss or damage to identity documents
- Temporary relocation to neighbours during hazard events
- Reliance on neighbours as first point of contact
- Reported water pressure and access constraints

Coding was used primarily to contextualise quantitative distributions and clarify how hazard impacts occurred in practice. Qualitative excerpts are used to illustrate recurring mechanisms identified through coding. For questions where respondents could provide more than one answer, percentages are reported as multiple responses and therefore do not sum to 100%.

Fig. 3. Community researchers being trained to use the KoboToolbox app and collecting data.

Fig. 4. Community researchers being trained to use the KoboToolbox app and collecting data.

4. Results

4.1. Household and socio-economic profile

Table 1 summarises key demographic and socio-economic characteristics shaping household-level vulnerability. Household size averaged 3.0 persons per dwelling (SD 1.7; median 3; range 1 to 10; valid n = 159). Household income levels were low. The median reported monthly household income was ZAR 1000 (interquartile range ZAR 500 to 1500; valid n = 157). This income level suggests limited scope for structural improvements such as raising floor levels, reinforcing walls, replacing roofing sheets or improving electrical safety.

Although the mean suggests moderate occupancy, the upper range indicates that some single-room dwellings accommodate large household units. In structures without internal partitioning, higher occupancy may increase evacuation difficulty during fire incidents and intensify spatial congestion when floodwaters enter.

Moving to Khan Road was predominantly employment driven. Respondents consistently cited proximity to work, reduction of transport costs and access to informal labour markets as reasons for settlement choice. One participant explained:

> "I like it because this place is close to many things and I can save some money as I work, and I don't pay any money when I go to work because I just walk." (IP3)

Another described migration due to lack of employment in their area of origin:

> "I came here because there are no job opportunities in our area. I get piece jobs here, is not the same, its liveable." (IP5)

Proximity to services and institutions was also emphasised:

> "Things are available nearby such as shops, doctor, hospital, clinics, you can walk if you are looking for work." (IP6)

Table 1
Baseline household vulnerability indicators reported by respondents (Khan Road informal settlement).

Variable	Statistic	Value	Valid n
Total respondents interviewed		160	160
Household size (persons)	Mean	3.0	159
	Standard deviation	1.7	159
	Median	3	159
	Range	1–10	159
Monthly household income (ZAR)	Median	1000	157
	Interquartile range	500–1500	157
Accommodation status	Fully owned structure	86.7% (n = 137)	158
	Renting	13.3% (n = 21)	158

Affordability pressures further constrained mobility. As one participant stated:

"Because of the rent. Where I was staying the rent was high." (IP50)

Accommodation status data (valid n = 158) indicated that 86.7% reported owning their structure, while 13.3% reported renting. Ownership refers to self-constructed informal dwellings rather than formal tenure security. Environmental exposure remains shaped by location, drainage performance, settlement density and construction materials rather than tenure category.

These figures indicate that informal structure ownership did not equate to formal tenure security. Low income, employment instability and limited relocation alternatives reduce household capacity to invest in risk reduction and increase reliance on neighbourhood networks during hazard events.

4.2. Settlement flood and fire exposure

Hazard exposure was common and overlapping among respondents, as shown in Table 2. Of the 159 respondents with valid exposure data, 87 (54.7%) reported household experience of flooding, 116 (73.0%) reported household experience of fire, and 64 (40.3%) reported exposure to both hazards. The overlap is important because it shows that multi-hazard risk was not exceptional within the settlement. Rather, a substantial proportion of respondents experienced flood and fire as interconnected components of everyday vulnerability.

Flooding was linked to drainage blockage, low elevation and surface water accumulation. Respondents consistently described internal water entry affecting bedding, clothing, food and documentation, indicating direct in-dwelling asset loss rather than external surface pooling alone.

One participant stated:

"When it rains heavily, the water comes inside the house and everything gets wet." (IP23)

Another described dual entry pathways through roof and floor:

"The water was coming from the roof and the floor and there were leaks in the house, which hurt us a lot. The clothes we were sleeping in were wet, and the clothes we were wearing were wet and the food was wasted." (IP5)

Loss of identity documentation was also reported:

"*The floods ruined my stuff I had, the food and clothes all got wet like ID books." (IP6)*

Seasonal recurrence was noted. One respondent reported flooding in March, October and November within a single year (IP7), indicating cyclical exposure linked to recurring rainfall periods rather than singular extreme events. Fig. 5 shows the low-lying ground and poor surface drainage conditions adjacent to informal dwellings that contribute to recurrent water accumulation in the settlement.

Fire exposure was similarly destructive. Participants described rapid flame spread linked to dwelling proximity and combustible materials.

"When one shack burns, the fire spreads very fast because the houses are too close together." (IP14)

"By the time you see the fire, it is already spreading to the next houses." (IP102)

Material loss was frequently total. One respondent reported:

"The fire burned everything I had, clothes and bedding, cooking utensils. I manage to take out some important things like an ID book, but most of them were burned." (IP6)

In a severe case, a participant described fatal consequences:

"The incident of the fire was very painful because everything I had was destroyed, we didn't even have a place to sleep, my girlfriend also burned down and died." (IP3)

This evidence shows how reported flood and fire exposure translated into domestic loss, displacement risk and constrained recovery at household level.

Table 2
Reported flood and fire exposure among respondents.

Exposure category	n	%	Valid n
Reported flooding	87	54.7	159
Reported fire	116	73.0	159
Reported both flooding and fire	64	40.3	159
Flood only	23	14.5	159
Fire only	52	32.7	159
Neither flood nor fire reported	20	12.6	159

Fig. 5. Low-lying ground and poor surface drainage adjacent to dwellings rebuilt after a fire in Khan Road; unlike the original self-built shacks, these units are raised above ground level.

4.3. Housing and basic services conditions

Housing construction and service access directly influenced hazard entry pathways and recovery conditions.

Sanitation access was extremely limited and relied on a small number of shared self-dug pit toilets across the settlement. Flooding frequently triggered toilet overflow and contamination of shared spaces.

"When it rains, the toilets overflow and dirty water comes into the yard." (IP36)

"The toilet water mixes with the flood water, and it becomes dangerous for children." (IP88)

Flood impacts therefore extended beyond structural damage to include environmental contamination and increased health risk.

Water access was likewise highly constrained. The settlement relied on a single communal tap, meaning that water access was limited for all households and especially difficult during and after flood events. The location of this tap, far from many of the informal dwellings, also constrained immediate fire response and contributed to the severity of past fire damage, including an incident in 2021 in which around 50% of the dwellings were completely destroyed. Although 48.1% reported satisfaction with water supply and 31.3% reported dissatisfaction, qualitative responses indicated that dissatisfaction was closely linked to the inadequacy of this arrangement. Respondents repeatedly referred to the fact that the entire settlement shared one tap and described queues, low pressure, breakages, leakage and the distance of the tap from some dwellings. Limited water access reduced households' ability to clean, wash and recover after flooding.

"Sometimes there is no water for days, and during floods we cannot clean or wash anything." (IP57)

"After floods, the water is dirty, but we still have to use it." (IP119)

Housing structure further shaped exposure. Low floor levels and permeable roofing materials allowed water entry from multiple directions. Fig. 6 shows an interior domestic space with low floor construction, illustrating the exposure of the dwelling to water ingress during rainfall events.

"*The rain comes through the roof and also from the ground because the house is low." (IP44)*

Construction materials identified in survey responses, including corrugated iron sheets, timber and plywood, were lightweight and combustible. High dwelling density and narrow access routes increased fire spread potential and delayed emergency response, indicating that material vulnerability and settlement morphology jointly shape fire risk severity. As illustrated in Fig. 7, these lightweight and mixed materials increase exposure to both flood impacts and rapid fire spread.

4.4. Participation, training and disaster preparedness

Participation in formal settlement governance was limited. Only 8.9% of respondents reported involvement in community leadership roles. Seventy-six participants provided a response on social or community organisation membership. Of these, 39 (51.3%)

Fig. 6. Interior of a dwelling rebuilt in 2021 after a fire that destroyed approximately half of the Khan Road settlement, showing low floor construction and vulnerability to water ingress.

Fig. 7. Informal dwellings in Khan Road constructed from lightweight and mixed materials.

named a group or activity, while 37 (48.7%) explicitly reported no affiliation. This suggests that some associational life was present within the settlement, but it did not necessarily translate into formal disaster coordination structures. According to CORC officials, the settlement has a development committee of about six residents who reside in the settlement, as well as a representative of the ward committee structure. Other persons in the settlement are connected to South African Slum/Shack Dwellers International (SASDI) Alliance.

Formal disaster preparedness training coverage was low. Fifty-five participants provided a response to the training question. Of these, 41 (74.5%) stated that they had received no training, while 14 (25.5%) referred to some form of activity or learning. Participants described the absence of structured training clearly:

"No training has been received." (IP63)

"There is none." (IP140)

Although this item is based on a limited number of responses, the findings suggest that systematic preparedness initiatives were not widely embedded at household level. Preparedness knowledge appears to circulate informally rather than through regular municipal or organisational programmes.

Low leadership participation combined with limited training coverage indicates weak institutional embedding of disaster risk reduction at settlement scale, suggesting limited integration between community governance structures and formal disaster management systems. In response to this, CORC officials have implemented a Leadership Programme within the settlement since 2022, aimed at building local capacity and supporting young residents who are interested in taking on leadership roles within the community.

4.5. Household and neighbour-based response systems

Despite limited formal preparedness coverage, active response behaviour was widespread. Among the 87 respondents who reported flood exposure, 57 (65.5%) described a response strategy. These actions included lifting belongings, draining water manually, relocating temporarily and seeking assistance from neighbours.

One participant described immediate neighbour-based relocation:

"I ran to neighbours who were not affected by the flood." (IP92)

Another respondent explained reciprocal support arrangements:

"There are still neighbours we help each other." (IP5)

When asked who they would contact during flooding, 133 participants provided a response. Neighbours were mentioned most frequently (78 respondents, 58.6%), followed by family (55, 41.4%) and friends (46, 34.6%), while municipal officers were mentioned less often (14, 10.5%). This pattern reflects reliance on immediate social proximity during sudden onset events.

Fire response behaviour showed similar patterns. Among the 116 respondents who reported fire exposure, 86 (74.1%) described a response strategy. Actions included evacuation, alerting neighbours and contacting emergency services.

"I can call the fire brigade department." (IP18)

In severe cases, evacuation occurred under conditions of rapid escalation:

"I ran away from the place where there had been a fire and I came back after it was over." (IP5)

When asked who they would contact during fire incidents, 138 participants provided a response. Neighbours were again mentioned most frequently (71 respondents, 51.4%), followed by firefighters (59, 42.8%) and family (55, 39.9%). Although formal emergency services such as firefighters and police were mentioned, first response actions were typically undertaken at household or neighbour level. Immediate response capacity therefore operates through informal social networks rather than structured early warning systems.

4.6. Community knowledge and micro-scale hazard evidence

Interview responses revealed forms of hazard knowledge that are not visible in official datasets.

Participants emphasised internal dwelling impacts as the primary site of loss. Damage was frequently described in terms of bedding, clothing, food and identity documentation. A respondent noted that official mapping does not capture internal impacts:

"Flood maps don't show what happens inside the house, but that is where we lose everything." (IP75)

Residents also described awareness of spatial variation in flood patterns across the settlement.

"We know which houses flood first because we live here." (IP121)

This indicates accumulated spatial knowledge derived from repeated exposure to drainage pathways, elevation differences and seasonal rainfall patterns.

Survey data on flood frequency, affected months and damaged assets provide detailed micro-scale evidence of exposure pathways that are not captured in municipal hazard registers.

Household narratives demonstrate that internal dwelling conditions, sanitation performance and neighbour-based response practices are central components of disaster experience at settlement scale. They also show the value of household-scale data for informing locally targeted risk reduction planning.

5. Discussion

The findings indicate that flood and fire risk in Khan Road were produced through the same underlying settlement conditions rather than through separate hazard processes alone. Low-lying ground, constrained drainage, dense dwelling layouts, combustible materials, weak sanitation and restricted water access created a single risk environment in which different hazards generated overlapping effects. This is consistent with research showing that disaster risk in informal settlements is systemic and multi-hazard rather than single-hazard in character [3,5,17–19]. The Khan Road case adds to this literature by showing how these shared risk conditions were experienced at household scale. Flooding was not only a problem of standing water around structures, but of water entering dwellings, damaging bedding, food and identity documents. Fire was not only a question of ignition, but also a consequence of unplanned settlement layout, limited emergency routes, restricted access to water, restricted access for emergency vehicles and flammable materials, all of which intensified loss and constrained recovery. The significance of the case lies in showing how settlement-scale conditions were converted into domestic loss and disruption.

The findings also show that infrastructure deficits were direct mechanisms in the production of risk. Earlier studies have shown that weak drainage, unreliable water supply and inadequate sanitation can generate cascading effects across household health, hygiene and recovery [17,41,42]. The Khan Road evidence supports that argument and gives it clearer household-level expression. Restricted water access reduced the ability of households to clean and recover after floods. Sanitation overflows extended flood impacts into contamination and health risk. Low floor levels and permeable materials increased water ingress, while lightweight combustible materials and narrow access routes intensified the spread and severity of fire. This supports work showing that infrastructure weakness and built-form conditions in informal settlements are active components of disaster risk rather than background indicators of deprivation [18,26,27,40].

In Khan Road, resilience capacity was not equally developed across economic, physical, social and human dimensions. Gaisie et al. [13] argue that household resilience is shaped by the interaction of these dimensions, and the present findings broadly support that position. Economic capacity was weak, limiting households' ability to improve structures, replace damaged materials or invest in risk reduction. Physical capacity was constrained by poor drainage, weak sanitation, combustible housing materials and dependence on a single communal tap. Social resources were more evident, especially in the importance of neighbours and family during hazard events. Human and organisational capacity was less developed, as shown by low leadership participation and limited preparedness training. The findings therefore suggest that household-centred resilience frameworks remain useful, but in informal settlement contexts they need to account more explicitly for settlement-scale infrastructure and organisational conditions.

The social dimension of resilience was particularly important, but it also had clear limits. Neighbours and family were central to immediate response during both flood and fire events, which is consistent with work highlighting the importance of trust, social proximity and informal support systems in low-income settlements [28,33]. Yet, the Khan Road case also shows that neighbour support should not be equated with preparedness. Residents possessed detailed practical knowledge of where flooding begins, how water enters homes and how fire spreads through the settlement. This aligns with research on experiential knowledge and community-based hazard awareness [22,31,32]. However, that knowledge was only weakly translated into organised preparedness because leadership participation was low and training coverage limited. The issue was therefore not a lack of awareness, but a lack of stronger organisational structures through which awareness could be converted into coordinated risk reduction. In the absence of stronger individual and community leadership, informal communities are less able to organise timely preparedness, coordinate response and sustain risk reduction beyond the immediate event. This helps explain the continuous dependence on local authorities, whose interventions often become most visible after catastrophic events rather than through routine prevention and preparedness.

This has direct implications for the relationship between municipal-led and community-led disaster risk reduction. The findings do not support a simple contrast in which community action substitutes for state intervention, or vice versa. Community action was indispensable during hazard events, but it could not address the structural conditions that produced risk, including drainage, sanitation, water access, spatial layout and emergency access. Municipal intervention therefore remained essential. At the same time, formal systems appeared more visible after severe events than through sustained prevention or preparedness. The central problem was not the absence of either community capacity or state responsibility in absolute terms, but the weak connection between them. This is consistent with work on co-production and participatory upgrading, which shows that community knowledge becomes more effective when linked to formal planning, service investment and institutional support [8–10,36,37]. Key priorities to build community resilience in informal settlements include strengthening local leadership, particularly among youth, and establishing community disaster committees to improve preparedness and response. Informal communities should be meaningfully involved in risk assessment, planning, and decision-making processes rather than being treated as passive recipients of assistance [50].

These findings are directly relevant to South African policy. The Upgrading of Informal Settlements Programme is explicitly framed around structured in situ upgrading rather than relocation as the default response, with attention to tenure security and the progressive improvement of basic services. South Africa's disaster management policy framework similarly emphasises vulnerability reduction, prevention, mitigation and community involvement in disaster risk reduction [16,38]. The Khan Road findings show that these policy commitments cannot be realised through post-disaster response alone. They require routine investment in drainage, sanitation, water access, safer settlement layouts, emergency access and locally embedded preparedness. These findings also reinforce the importance of household-scale and community-generated evidence in disaster risk assessment. In Khan Road, residents' accounts made visible

in-dwelling flooding, service failures, material losses and neighbour-based response practices that are often missed by settlement-scale or administrative assessments.

Earlier studies have shown that conventional urban risk assessments often fail to capture in-dwelling flooding, domestic contamination, document loss and informal response practices in rapidly changing informal environments [14,15]. The present study supports this argument. Hazard maps may identify low-lying land or dense settlement form, but they do not readily show internal water entry, the contamination of domestic space, temporary movement to neighbours or the practical consequences of depending on a single communal tap. Household-level evidence therefore changes the scale at which risk becomes visible. This strengthens the case for participatory risk mapping, community-based early warning and other collaborative approaches that can bring local knowledge into formal planning processes [8,9,34,35,50]. Recent global research on flood early warning systems similarly highlights the importance of effective communication, preparedness and the capacity of communities and institutions to interpret and act on warnings alongside technological forecasting capacity [62]. This is consistent with recent flood-risk methodologies developed for data-scarce settings, which demonstrate how participatory field surveys, citizen-generated information and locally grounded data can complement technical assessment and strengthen disaster risk reduction planning [57,58]. It also suggests a practical role for digital tools. Mobile-based reporting and communication systems could widen access to information, reduce the repeated burden placed on residents to reproduce the same evidence, and improve the flow of locally generated data into municipal systems.

A further implication concerns the treatment of multi-hazard risk in informal settlements. Flood and fire are often addressed through separate institutional and technical responses, yet the Khan Road findings show that the same settlement conditions intensified both. Poor drainage, dense dwelling layouts, flammable materials, restricted access routes and weak service provision all contributed to overlapping vulnerability. Comparable multi-hazard research in rapidly urbanising environments demonstrates that different hazards can share common environmental and urban drivers, including topography, hydrological conditions, land use and patterns of urban development [23]. This supports the need for multi-hazard assessment and for practical guidance on infrastructure and the built environment that addresses flood and fire together rather than through separate interventions [17,24,63]. In informal settlements, drainage improvement, safer water and sanitation provision, spatial access, construction guidance and preparedness planning need to be treated as connected elements of risk reduction.

The findings also have implications for household resilience frameworks. Gaisie et al. [13] identify economic, physical, social and human resources as central to household resilience. The Khan Road case supports that framework but also shows that the physical dimension requires fuller attention at settlement scale. Physical vulnerability in this study was not confined to the dwelling unit alone. It was produced through the combination of low-lying ground, weak drainage, constrained water access, inadequate sanitation, combustible materials and dense spatial layout. The findings also show that social support, while important, did not by itself amount to preparedness capacity. Leadership structures and training mattered because they determined whether local knowledge could be translated into collective action and linked to formal systems of support. In informal settlements exposed to multiple hazards, resilience was shaped not only by household resources and social relations, but also by settlement infrastructure, built form and the organisational capacity that connected community action to municipal intervention. The study therefore indicates that disaster risk reduction in informal settlements cannot rely on household coping alone. It must also address settlement infrastructure, the built conditions that intensify multiple hazards, leadership development, and a more balanced relationship between community action and municipal intervention that strengthens community self-reliance.

6. Conclusions

This study examined household-scale disaster risk management in Khan Road informal settlement, KwaZulu-Natal, focusing on how flooding and settlement-related fire are experienced, understood and managed through everyday dwelling, infrastructure and social conditions. The findings show that disaster risk is produced through the interaction of hazardous location, weak drainage, constrained water and sanitation access, dense dwelling layouts, combustible housing materials and limited organisational capacity. Flood and fire did not operate as separate threats. They were intensified by the same underlying settlement conditions and were experienced through in-dwelling water ingress, contamination of domestic space, loss of household essentials, restricted response options and uneven recovery capacity. The research therefore contributes household-scale evidence showing how multi-hazard risk is lived within the dwelling and shaped by everyday infrastructure failure, rather than only at settlement scale or through event-based hazard assessment.

The findings also show that neighbour and family support remain central to immediate response, but that informal support alone does not constitute preparedness. Residents held detailed practical knowledge of where flooding begins, how water enters homes and how fire spreads through the settlement. However, this knowledge was only weakly connected to organised preparedness, leadership structures or formal training. The study therefore indicates that household resilience in informal settlements is shaped not only by economic conditions and social networks, but also by the interaction between community knowledge, leadership capacity, infrastructure conditions and institutional support. Disaster risk reduction cannot rely solely on household-level coping practices where the physical and organisational conditions that produce risk remain unchanged.

The implications for policy and practice are clear. More effective disaster risk reduction in informal settlements requires stronger alignment between municipal intervention and community-driven action. Community-based early warning, participatory risk mapping and locally embedded preparedness systems should be linked more directly to routine municipal investment in drainage, sanitation, water access, emergency routes and safer building conditions [50]. Flood and fire should also be addressed through a more integrated multi-hazard approach, since the same settlement characteristics intensified both. Nature-based Solutions could provide a complementary component of these interventions, particularly through measures that support flood regulation, stormwater

management, erosion control and wider urban resilience, while recognising the need for appropriate governance, monitoring and long-term maintenance [64,65]. Digital tools may help support this process where they widen access to information, improve local reporting and reduce the repeated burden placed on residents to reproduce the same evidence for different institutions. In relation to the wider international literature, the findings support evidence that infrastructure deficits and settlement form are central drivers of disaster risk but extend this by showing how these conditions operate simultaneously across flood and fire hazards at household scale. The study also qualifies assumptions that strong informal social networks necessarily translate into preparedness. In Khan Road, neighbour support and local knowledge were important during response, but remained limited without stronger leadership, training and links to formal institutions. The contribution therefore lies not simply in identifying familiar risk factors, but in showing how they interact within everyday household experience and across multiple hazards. Although grounded in the Khan Road case, these findings have wider relevance for under-serviced and rapidly urbanising settlements where formal risk data are limited, and infrastructure deficits intensify multiple hazards. The study therefore supports the wider applicability of household-scale evidence, participatory risk assessment and integrated multi-hazard planning in other vulnerable urban contexts, while recognising that their implementation must remain sensitive to local institutional, environmental and social conditions.

The study is based on one informal settlement and a cross-sectional household dataset, and its conclusions should be interpreted in that context. The findings are not intended as direct statistical generalisations to all informal settlements, but they do offer analytically useful insight into how disaster risk is produced and managed in dense, under-serviced urban environments. Further research should extend this work through comparative studies across settlements, longitudinal analysis of how leadership, preparedness, infrastructure upgrading and institutional support shape risk and recovery over time, and closer attention to how gender, age, disability and other forms of social differentiation shape household disaster vulnerability. Additional work is also needed on how community-generated and mobile-based data can be incorporated into formal planning and disaster management systems without shifting responsibility away from the state. The Khan Road case shows that disaster risk in informal settlements is inseparable from the conditions of everyday life. Reducing that risk requires more than post-disaster response. It requires routine prevention, stronger community leadership, better infrastructure and closer integration between household knowledge, community organisation and municipal systems of support.

CRediT authorship contribution statement

Maria Christina Georgiadou: Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Priti Parikh:** Writing – review & editing, Validation, Resources, Methodology, Formal analysis, Data curation. **Claudia Loggia:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mariam Zaqout:** Writing – original draft, Visualization, Methodology, Formal analysis. **Viloshin Govender:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation.

Declaration of generative AI

During the preparation of this work the authors used ChatGPT in order to assist with language editing and proofreading. The tool was used solely to improve readability, grammar and clarity. After using this tool, the authors reviewed and edited the content as needed and take full responsibility, the author reviewed and revised all content independently and take full responsibility for the final version of the manuscript.

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

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Data availability

The data supporting this study are available on Zenodo: https://zenodo.org/records/10108308. Additional information can be made available upon request.

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