General Article

Systematic Evidence Mapping of Climate Change Impacts, Vulnerability and Adaptation in Informal Settlements in South Africa

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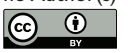

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Abstract

This study maps and analyses peer-reviewed evidence from 2015 to 2024 on climate change impacts, vulnerabilities and adaptation in South African informal settlements. The review is based on a sample of 23 studies from 1,282 studies that met the review inclusion criteria. The findings reveal that informal settlements are exposed to various climate hazards, with flooding, droughts and heat being the most documented. These hazards interact with infrastructure deficits and socio-economic and institutional factors to increase the vulnerability and limit the adaptive capacity of residents of informal settlements. Reported adaptation actions were mostly structural, involving physical changes to structures and systems to mitigate climate effects, and behavioural, with only one study reporting the use of nature-based solutions. Actors involved in climate adaptation operate at the household, community and city levels. Adaptation actions have been reported to be effective in improving safety and comfort, reducing biodiversity loss and improving energy efficiency in informal settlements. However, lack of funding and political will, and participation in decision-making and resource allocation are among the barriers to adaptation. These findings collectively highlight the urgent need for systemic, inclusive, scalable and sustainable adaptation solutions for informal settlements in South Africa.

Keywords

Adaptation, climate change, vulnerability, informal settlements, South Africa

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Introduction

Human settlements in South Africa stand at a critical juncture. Population growth and rapid urbanisation are driving the growth of informal settlements; at the same time, the country is grappling with the increasingly severe impacts of climate change (Engelbrecht et al., 2025). Approximately 12.2 per cent of South Africans live in informal settlements (Statistics South Africa, 2024). These informal settlements, a legacy of the apartheid-era spatial segregation and sustained by the failure of the post-apartheid government to address the apartheid legacy, are hotspots of human vulnerability. Rapid urbanisation, characterised by rural-urban migration, contributes to urban sprawl as people set up shacks (Jarstad, 2021). There were 4,297 informal settlements in the country in 2023, with the highest in Durban (590 settlements) (Kaunda, 2023), followed by Cape Town (464 settlements) and Johannesburg (210 settlements) (Comins, 2023). These informal settlements are largely located in climate-exposed areas such as floodplains, coastal areas and over steep and unstable land. Their vulnerability increases as they are exposed to climate hazards of increasing frequency, intensity and duration, including floods, droughts, storms and wildfires.

While there are common features across various informal settlements, they are not homogeneous. In South Africa's National Housing Code, for example, informal settlements are defined by the following factors: 'on the extent of their illegality and informality; their locations; the restricted public and private sector investment; high rates of poverty and vulnerability; and symptoms of social stress' (Department of Human Settlements, 2021). Informal settlements, such as Barney Molokwane in Khayelitsha, Cape Town, are highly vulnerable to climate impacts, first, due to their location near floodplains and wetlands, resulting in higher occurrence of fire and flooding, and second, due to various socio-economic challenges like limited access to services, high levels of unemployment, poor sanitation and poor infrastructure (Kunguma et al., 2025).

The impacts of climate change, which intersect with existing vulnerabilities, including poverty, inadequate sanitation, energy poverty, insecure land tenure and poor governance, exacerbate the precariousness of residents of informal settlements (Peirson & Ziervogel, 2021; Williams et al., 2018; Williams et al., 2019). Residents of informal settlements often lack basic services like water, sanitation and electricity, and live in conditions characterised by cramped housing shared by several families. A study of informal settlements in Western Tshwane showed very low residents' satisfaction, with evidence of poor sanitation, non-flushing toilets, low service delivery and inadequate housing (Shoniwa & Thebe, 2020). It is common that residents of these informal settlements do not pay for water or electricity. According to Jarstad (2021), this is partly because the country's constitution mandates the state to provide free basic services to citizens, but illegal connections to both electricity and water systems also exist. These informal settlements are known for high levels of crime and gangsterism because of poverty and unemployment (Lufuno & Steyn, 2021).

Over the years, the government has implemented various policies and development initiatives to address the challenges of informal settlements, including the Breaking New Ground policy (Mkuzo et al., 2019), the Upgrading of Informal Settlements Programme (Parikh et al., 2020), and the National Upgrading Support Programme (Housing Development Agency, 2024), the Integrated Urban Development Framework (Department of Cooperative Governance and Traditional Affairs, 2016), and the Emergency Housing Programme (Cirolia, 2014). While these interventions demonstrate governmental attention to the issue of informal settlements, the integration of climate change considerations within them is fragmented, and there is an inadequate, cohesive and overarching strategy. Ineffective coordination could hinder the development of holistic solutions that address both the immediate needs of informal settlement residents and their long-term resilience to climate risks. A primary impediment to effective action in informal settlements also lies

in the absence of a comprehensive and synthesised understanding of the specific climate change impacts, vulnerabilities and adaptation dynamics (Hussainzad & Gou, 2024). Although the general vulnerability of informal settlements to climate change is well known, in-depth reviews and evidence-based research that clarify how climate variables interact with existing socio-economic, demographic and environmental vulnerabilities remain limited (Borg et al., 2021). Additionally, decision-makers in government and non-governmental organisations face difficulties in prioritising and allocating resources effectively, in the absence of a clear understanding of the most pressing climate impacts and risks faced by the most vulnerable populations in informal settlements (Kekana et al., 2023).

The urgency of understanding the vulnerability of informal settlements, the impacts of climate change and response options to the observed and projected impacts is underscored by recent climate-related disasters, including floods in KwaZulu-Natal in 2022 (Dlamini et al., 2024), the 'day-zero' drought in Cape Town (Shepherd, 2021) and projections of increasing frequency and intensity of extreme weather events (Mbokodo et al., 2020; Mengistu et al., 2024).

This review responds to the identified urgent need for a more comprehensive understanding by mapping and analysing the existing evidence on climate change impacts, vulnerabilities and adaptation in South African informal settlements. Adaptation effectiveness refers to how various communities respond, address and mitigate the impacts of climate change through a wide range of approaches, methods and strategies (IPCC, 2022). In this study, we identified key indicators of adaptation in communities, namely, adaptation actions, adaptation interventions, adaptation types, adaptation actors and adaptation scale (Table 5) and extracted evidence where studies reported actions as effective. These key indicators and the relevant sub-criteria were used to determine and identify adaptation measures.

By synthesising this body of knowledge, this article provides a consolidated resource for practitioners, climate experts, decision-makers and policymakers. The analysis offers crucial insights into how climate change is affecting informal settlements in South Africa. By exploring difficulties in accessing relevant information, coordinating efforts and implementing effective solutions, this analysis seeks to identify key barriers and opportunities for effective collaboration and action. Understanding the systemic challenges will pave the way for targeted recommendations for improvement.

Conceptual and Analytical Framework

This review is underpinned by the risk framework (IPCC, 2022). This is an analytical framework for understanding how the intersections among hazards, exposure and vulnerability create risk (IPCC, 2022). Hazards such as flooding, landslides, and extreme temperatures interact with exposure factors (e.g., location in flood-prone areas) and vulnerability (e.g., poverty) in informal settlements, thereby amplifying impacts. While they may differ in many respects, the vulnerabilities, hazards and exposures across informal settlements are similar.

The IPCC Sixth Assessment Report notes that the absence of basic services will increase vulnerabilities in informal settlements. The socio-economic and political contexts in which these informal settlements are located require context-specific responses. There are various entry points for developing adaptation measures in communities to significantly reduce risk. Some of these include ecosystem-based adaptation, early warning systems and risk management, strengthening social vulnerability reduction, urban planning, resilient infrastructure, governance and integrated planning (IPCC, 2023). Achieving these will require systematic and planned interventions by various structures, such as national governments and local authorities, while others will involve interventions by communities and residents, with the greatest impacts occurring where these are integrated.

Materials and Methods

This review maps and synthesises research conducted between 2015 and 2024 on climate change impacts, vulnerability and adaptation options in South Africa's informal settlements. The choice of this timeframe was to prioritise the Sustainable Development Goals, particularly Goal 11, which seeks to achieve sustainable cities and communities. We searched the Scopus Web of Science databases (see search strings and results in Table 1) using the following keywords: 'informal settlement*', slum*, 'climate change', 'climate impact*', 'shack dwelling*', 'global warming*', 'climate adaptation*' and 'climate variability*' (Table 1). Relying solely on 'South Africa' as a geographic search term may have excluded studies that refer only to specific cities, provinces or informal settlements without naming the country directly.

We identified 1,282 manuscripts from the two databases. All studies in the database were screened for inclusion (i.e., peer-reviewed publications between 2015 and 2024, and focus on climate change and informal settlements in South Africa) by at least two of the four authors. When there were conflicting decisions, the authors discussed and resolved the conflicts. After screening for relevance using our inclusion criteria, 46 manuscripts were identified as suitable for inclusion. During the full screening, 23 were excluded. Of these, the full manuscripts of 2 book chapters were unavailable, while 21 manuscripts were ineligible, resulting in 23 eligible manuscripts being included in this review. Figure 1 is the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram, which outlines the screening process. The use of a PRISMA flow diagram in this manuscript is intended solely to illustrate the literature selection process, but the study itself does not constitute a systematic review.

Findings and Discussions

Overview of the Manuscripts Included in the Reviews

This study aims to provide an overview of the body of evidence on climate change impacts, vulnerability and adaptation in informal settlements in South Africa. Although our focus spans 9 years (2015–2024),

Table 1. Search Strings and Results.

Databases	Search Strings	Results
Scopus	TITLE-ABS-KEY ((‘climate change’ OR ‘global warming’ OR ‘climate adaptation’ OR ‘climate impact*’ OR ‘climate variability’) AND (‘informal settlement*’ OR ‘slum*’ OR ‘shack dwelling*’) AND (‘South Africa’)) AND PUBYEAR>2015 AND PUBYEAR < 2025	41
WoS	‘climate change’ (Title) or ‘global warming’ (Title) or ‘climate adaptation’ (Title) or ‘climate impact*’(Title) or ‘climate variability’ (Title) and ‘informal settlement*’ (Title) or ‘slum*’ (Title) or ‘shack dwelling*’ (Title) and 2015 or 2016 or 2017 or 2018 or 2019 or 2020 or 2021 or 2022 or 2023 or 2024 or 2025 (Final Publication Year) and SOUTH AFRICA (Countries/Regions) and Article or Proceeding Paper or Book Chapters or Review Article (Document Types)	1,241
Total		**1,282**

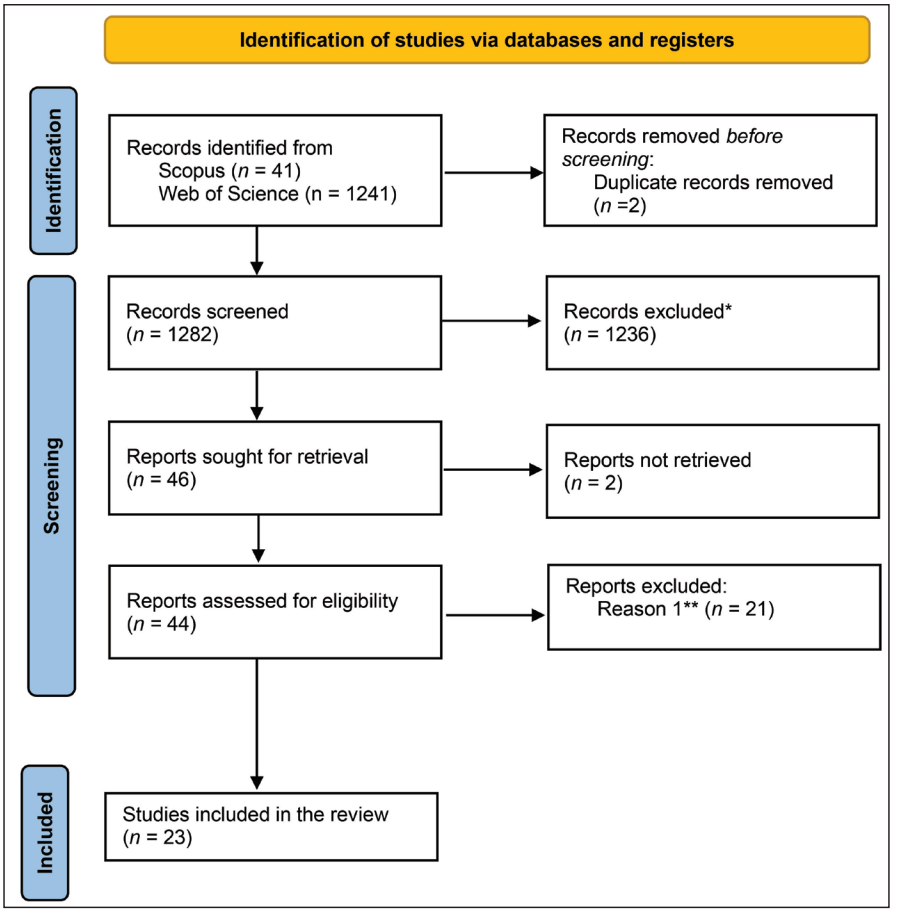

Figure 1. PRISMA Flow Diagram.

Notes: *Studies excluded were those that did not focus on climate impacts, vulnerability and adaptation in informal settlements in South Africa.
**Studies not focused on informal settlements in South Africa

none of the 23 studies included in the review was published in 2015. Growth in the number of studies over this period has been slow, with 2020 and 2024 being the years with the largest number of studies (n = 4 each), while 2016 and 2017 accounted for the least (n = 1 each). As shown in Table 2, nearly all the studies (n = 20) covered residents of the settlement of interest with no dedicated focus on a particular subgroup (e.g., children or migrants). While some of the studies focused on a single case study, usually an in-depth examination of one site or location (Mazeka et al., 2019; Nyam et al., 2024), others focused on more than one informal settlement across a city or province utilising a comparative approach (Dlamini et al., 2024; Ngcamu, 2022; Peirson & Ziervogel, 2021; Teare et al., 2020). Furthermore, some studies included in the review are multi-country studies; for instance, Melore and Nel (2020) focused on the mountainous areas of Konso, Ethiopia, and QwaQwa, South Africa. The studies covered various provinces with the largest concentration in KwaZulu-Natal, the Western Cape, Gauteng and Tshwane. This is consistent with the reported distribution of informal settlements by the country's Department of

Table 2. Study Characteristics.

	Number of Studies	%
Year of Publication		
2016	1	4.3
2017	1	4.3
2018	2	8.7
2019	3	13.0
2020	4	17.4
2021	3	13.0
2022	2	8.7
2023	3	13.0
2024	4	17.4
Study design		
Qualitative	12	52.17
Quantitative	2	8.7
Mixed-methods	9	39.13
Data collection approach		
Interviews	9	39.1
Surveys	7	30.4
Focus groups	1	4.3
Secondary data	6	26.1
Others	7	30.4
Not specified	2	8.7
Not applicable	2	8.7

Human Settlements, which shows that Johannesburg, Cape Town and Durban metropolitan areas have the largest number of informal settlements (Comins, 2023). Despite progress, addressing the lingering problem of informal settlements remains part of the challenges limiting South Africa's progress towards achieving target 11.1 of the SDGs (Statistics South Africa, 2024).

More than half of the studies included in the review were qualitative, while mixed-methods comprised 39.13 per cent of the studies, underscoring the predominance of qualitative research on climate change and informal settlements in South Africa (see Table 2). Data were collected through interviews (39.1%), surveys (30.4%) and focus groups (4.3%). Other data collection methods used include learning exchange visits (Ndebele-Murisa et al., 2020), indoor temperature and/or humidity loggers (Naicker et al., 2017; Teare et al., 2020) and participatory community-based mapping (Mazeka et al., 2019).

Hazards and Impacts of Climate Change

Climate change hazards such as flooding dominate the discourse, with studies documenting extensive impacts on informal settlements in Cape Town and KwaZulu-Natal (Membele et al., 2021; Williams et al., 2019; 2018). Several climate-related hazards were reported (see Table 3), with flooding being the most reported (69.6%), followed by heatwaves (30.4%) and drought (17.4%). Only 1 study each reported cold spells (Teare et al., 2020), fire (Ncube et al., 2023) and storms (Ndebele-Murisa et al., 2020). The increasing frequency and severity of extreme flooding events are a growing challenge for South Africa (Pinto et al., 2022).

Table 3. Reported Climate-related Hazards in South Africa's Informal Settlements.

Reported Hazards	Number of Studies	%
Flood	16	69.6
Heat	7	30.4
Drought	4	17.4
Cold spells	1	4.3
Fire	1	4.3
Storms	1	4.3

The climate hazards reported in the studies result in various impacts, with damage to houses being the most reported impact (34.8%). According to Dlamini et al. (2024), floods have caused widespread damage to informal settlements in South Africa. Similarly, flooding of people's homes was a recurring theme in Mazeka et al. (2019). The study by Ncube et al. (2023) found that in Sweet Home Farm, flood-related damages to homes were reported by most participants (81.5%). Impacts related to health and well-being also received sizeable coverage across the studies (Naicker et al., 2017; Nyam et al., 2024; Sekgobela & Sibanda, 2024; Teare et al., 2020). Naicker et al. (2017), for instance, examined the impacts of indoor temperature on health. For Ncube et al. (2023), climate-related water scarcity affected the community's health and sanitation practices, including being unable to take medication because of water scarcity. Another health-related challenge was linked to water contamination from floods (Naicker et al., 2017). In Quarry Road informal settlement in Durban, Williams et al. (2019, p. 167) found that flood severity 'determines whether, and to what extent, polluted water spreads' within the settlement. Participants in the study noted that flooding increases mosquito prevalence and vector-borne diseases. Respiratory illnesses resulting from increased dampness caused by flooding are another flood-related health impact (Williams et al., 2019). Other climate-related impacts reported in the studies include homelessness and poverty (Nyam et al., 2024).

Climate Change Vulnerability

The susceptibility of informal settlements to the impacts of climate change is a complex phenomenon, shaped by geographic, structural, socio-economic, health-related and governance factors. These factors interact at different levels, amplifying the climate risks faced by those living in informal settlements.

The location of informal settlements influences their extent of vulnerability to climate change. Informal settlements are predominantly situated in ecologically fragile and marginal areas, rendering their inhabitants highly susceptible to weather events such as floods (Anwana & Owojori, 2023; Pinto et al., 2022). A significant number of these settlements are located directly on floodplains and along riverbanks. Examples from the study show that Quarry Road West informal settlement in Durban is located on a precarious site on the floodplain of the Palmiet River (Williams et al., 2019). Likewise, the Mdantsane Township faces increased flood susceptibility due to land use changes (such as conversion of greenfield land for informal housing, illegal dumpsites and settlements on hazardous or undeveloped land) and environmental degradation (Membele et al., 2021). Similarly, Eerste Fabriek informal settlement in Mamelodi, Tshwane, is situated 'along the banks of the Pienaarsrivier, a low-lying area prone to flooding during heavy rains' (Nyam et al., 2024). In Durban, in KwaZulu-Natal, informal settlements are frequently constructed within 50–100-year flood lines on river and stream floodplains and in low-lying areas such as those in Prospecton, Isipingo, Sibongile, Ntuzuma and uMlazi (Dlamini et al., 2024).

In Mdantsane, an increase in built-up areas and a decline in vegetation cover between 1996 and 2016 have contributed to increased run-off and flood risks, and exacerbated vulnerability (Busayo et al., 2019).

Rapid urbanisation intensifies vulnerability, pushing people onto land deemed undesirable for formal development. As urban populations continue to grow, the pressure on available land escalates, leading to further encroachments into high-risk areas (including steep and unstable lands) (Williams et al., 2019). This expansion is frequently enabled by a lack of formal planning and regulatory enforcement (Vala & Malazaa, 2024).

The structural and infrastructural characteristics inherent to informal settlements amplify their vulnerability to climate hazards. Housing structures are usually constructed from rudimentary materials, such as wood, cardboard, metal sheets and mud, and often lack approved building plans, resulting in dwellings that are 'flimsily built' and have low capacity to withstand the impacts of fire or floods (Dlamini et al., 2024). For instance, Ncube et al. (2023) mentioned that Overcome Heights, a marginalised settlement in the Cape Flats of Cape Town, South Africa, is affected by 'recurrent fire outbreaks', a phenomenon partly due to their 'high density and haphazard pattern of homes'. Likewise, residents of Sweet Home Farm in Cape Flats 'endure drainage challenges and localised flooding induced by heavy rainfall and worsened by a rising water table'.

The lack of proper basic services and infrastructure directly escalates vulnerability in informal settlements in South Africa. Inadequate sanitation facilities also contribute to the rapid spread of communicable diseases. In Sweet Home Farm, Cape Flats, for example, the 'recurring flooding near community toilets, coupled with dumping and unmaintained drainage infrastructure, has created hygiene and sanitation challenges' (Ncube et al., 2023).

Poor drainage was captured as a factor by 43.5 per cent of the studies (see Table 4). In the Murray informal settlements of Cape Town, the lack of, or unreliable access to, essential services such as water, sanitation, drainage and solid waste collection, rendering them unserviced and under-serviced, was identified as a critical vulnerability factor (Membele et al., 2021). Similarly, the Mdantsane Township faces major solid waste and sanitation problems, which contribute to blocked waterways and increased flooding, directly amplifying the health and economic impacts of climate-induced hazards (Busayo et al., 2019).

Climate-induced hazards impose severe health impacts on residents of such settlements. Flooding, for example, leads to poor water quality, injury, death and disruptions to livelihoods, population displacement and spread of diseases (Dlamini et al., 2024). Heat stress is also a critical concern in most informal settlements (Hugo & Sonnendecker, 2023).

Socio-economic factors represent fundamental drivers of vulnerability within informal settlements. These settlements are characterised by high levels of poverty, unemployment, low-income and inadequate access to basic services. Poverty was the most frequently recorded socio-economic factor (43.5%) in the studies (Table 4). Poverty and unemployment may manifest vulnerability through limited financial resources to cope with and recover from climate shocks, inability to invest in adaptive measures, increased food insecurity, and heightened susceptibility to health impacts. These factors may severely constrain people's ability to cope with or recover effectively from the outcomes of climate-related impacts (Membele et al., 2021). For example, in Mamelodi, Tshwane, the consequences of floods include loss of livelihoods, food insecurity, poverty and inequality (Nyam et al., 2024). Low socio-economic status correlates with limited adaptive capacity, hindering households' ability to effectively adapt to and cope with hazards. In the case of Sweet Home Farm, Ncube et al. (2023) reported that many residents cited a lack of funds to buy flood defence supplies such as cement and better building materials.

Table 4. Drivers of Vulnerability in Informal Settlements in South Africa.

	Number of Studies	%
Structural and infrastructural factors		
Poor drainage	10	43.5
Location near hazards	7	30.4
Others	4	17.4
Not applicable	2	8.7
Not specified	7	30.4
Socio-economic factors		
Poverty	10	43.5
Tenure security	4	17.4
Informal employment	1	4.3
Loss of employment	4	17.4
Others	4	17.4
Not specified	7	30.4
Institutional factors		
Lack of services	8	34.8
Weak local governance	7	30.4
Exclusion from planning	6	20.1
Others	2	8.7
Not applicable	1	4.3
Not specified	6	26.1

Effective climate change adaptation in informal settlements can be enabled or constrained by weak institutional and governance structures (Williams et al., 2019). Institutional factors, such as lack of services, were recorded by 34.8 per cent of the studies, followed by weak local governance (30.4%), as shown in Table 4. Governance is identified as a critical factor influencing flood risk and vulnerability, with ineffective governance structures and institutional challenges worsening the vulnerabilities experienced in informal settlements (Williams et al., 2019). For instance, Jordhus-Lier et al. (2019) mentioned that, in Green Park informal settlement in Cape Town, a local government flood intervention involving gravel platforms was contested and subverted by community demands for political recognition, proper housing and household electricity. In Quarry Road West, political capital, which encompasses transparency and trust in political actions, scored poorly. This was evident through reported political instability, violent protests, political pressure, corruption, a lack of understanding of decision-making processes and limited trust in law enforcement (Membele et al., 2021). In Murray's informal settlement, engagement between the community and local government was characterised by an 'us against them' mentality, with residents feeling excluded from decision-making by the local government (Membele et al., 2021). This situation hinders the integration of local and indigenous knowledge and the fostering of trust, thereby perpetuating the vulnerability of informal settlements. The absence of reliable monitoring data and challenges in enforcing existing legislation hinder effective flood adaptation. A critical challenge is the siloed approach of planning and environmental management departments, which leads to a lack of coordination and synergy in addressing climate change (Lah, 2025).

Vulnerability is not uniform across informal settlements. It is differentiated by various households and demographic characteristics, such as gender, marital status, house structure, education level,

household size, duration of residency, access to health, religious and recreational facilities, and living with an elderly person (Chumo et al., 2023). The differentiated vulnerability within informal settlements in South Africa, particularly age and gender-related, implies that intersectional, gender-transformative and age-sensitive development interventions are needed. The studies reveal that the socio-economic vulnerability in South African informal settlements is not only an issue of poverty but also complex, and an intergenerational consequence of interactions among several factors that continue to create and reinforce spatial and economic marginalisation (Williams et al., 2019).

Climate Change Adaptation

Most of the adaptation actions in the studies under review were structural (77.8%), referring to physical changes to systems and structures to mitigate the extreme effects of climate change, while others were behavioural (38.9%) and technological (16.7%) (Table 5). Autonomous adaptation interventions were 34.8 per cent, and planned adaptation interventions were 30.4 per cent of the reviewed studies (see Table 5). While nature-based solutions continue to gain prominence in adaptation actions, only one study in this review considered this approach. The adaptation interventions presented in the studies include natural ventilation (Teare et al., 2020) and reflective roofing (Hugo, 2023).

These different adaptations present broad categories within which stakeholders, both within and outside communities, develop interventions to better adapt and respond to climate risks and their

Table 5. Climate Change Adaptation in Informal Settlements in South Africa.

	Number of Studies	%
Adaptation actions reported		
Structural	14	77.8
Behavioural	7	38.9
Technological	3	16.7
Nature-based solutions	1	5.6
Not applicable	2	11.1
Not specified	1	5.6
Adaptation interventions implemented		
Natural ventilation	1	5.6
Reflective roofing	1	5.6
Others	7	38.9
Not specified	7	38.9
Adaptation types		
Autonomous	8	34.8
Planned	7	30.4
Others	1	4.3
Not specified	6	26.1
Not applicable	4	26.1
Adaptation actors		
Individuals	4	17.4
Communities	9	39.1

(Table 5 continued)

(Table 5 continued)

	Number of Studies	%
Local government	9	39.1
Provincial governmental	7	30.4
National government	5	21.7
NGOs/Civil society	5	21.7
Others	1	4.3
Not applicable	4	17.4
Not specified	4	17.4
Adaptation scale		
Household	7	30.4
Community	13	56.5
City-wide	4	17.4
Not applicable	5	21.7
Not specified	1	4.3
Adaptation effectiveness		
Improving safety	4	17.4
Improving comfort	2	8.7
Others	4	17.4
Not applicable	6	26.1
Not specified	7	30.4
Challenges/barriers to climate change adaptation		
Funding	9	39.1
Political will	5	21.7
Lack of participation	5	21.7
Others	2	8.7
Not applicable	1	4.3
Not specified	7	30.4

implications for policy and practice. Using these adaptations, the studies reviewed existing interventions utilised by residents of informal settlements, and the role of various stakeholders and groups in achieving adaptation and building resilience.

Adaptation Strategies, Actions and Actors

Structural adaptations in the studies included integrating climate change into planning and waste management (Ndebele-Murisa et al., 2020), improved disease management systems which include both government and private agencies that manage or deliver services to the public, such as hospitals or health services, waste management, water services, pharmaceuticals, laboratories and adequate sanitation (Sekgobela & Sibanda, 2024), and risk and GIS mapping (Mazeka et al., 2019). Behavioural strategies involved mainstreaming climate change at the city governance level and increasing engagement with the community (Mazeka et al., 2019; Ndebele-Murisa et al., 2020).

Another adaptation intervention reported is an Integrated Disease Management System (IDMS) involving both government and private agencies to ensure the efficient delivery of public services like

health, waste management, laboratories, pharmaceuticals and adequate sanitation. The IDMS uses advanced computational software to collect, process and analyse data to ensure an integrated healthcare response in managing the spread of epidemics (Hunter, 2000). It is a response to South Africa's reputation as a cholera hotspot due to a changing climate, its geographical location and other factors (Sekgobela & Sibanda, 2024). While authors like Joshi et al. (2014) state that South Africa's IDMS is adequate in comparison to other countries, failing to maintain and upgrade it will negatively impact the country's ability to respond to a full-blown cholera outbreak.

Risk and GIS mapping is another type of response reported in Mazeka et al. (2019). This has been deployed as part of developing community-based maps used in the Quarry Road West Informal Settlement in Durban. Developed in collaboration with the community, risk maps are used to understand how local communities perceive risk and risk areas in their settlements, while the GIS maps were developed to capture specific data on the informal houses within the settlement (Mazeka et al., 2019). These provide key benefits such as mapping community resilience to climate change, existing capacities to adapt to climate change and continued development of climate adaptation strategies.

Some other adaptation measures include the use of gravel platforms to elevate structures above flood levels (Jordhus-Lier et al., 2019), and the use of heaters, veranda shading and outdoor spaces to help regulate indoor temperatures, especially during extreme weather conditions (Hugo & Sonnendecker, 2023).

Installation of water tanks, stepping stones, temporarily relocating to the homes of family and friends, digging trenches and making farrows to redirect floodwater and creating firebreaks are other reported adaptation actions (Ncube et al., 2023). Chamberlain and Potter (2022) note the provision of water tanks, sanitation packs and emergency responses, while Fox et al. (2021) identify reblocking of informal settlements and filling up rivers to divert floods from informal settlements as successful examples of adaptation. However, while filling up a river might be successful in diverting floods, it may be considered maladaptive as it undermines the various important ecosystem services offered by the river. All these adaptation strategies highlight the use of autonomous and community-inclusive measures.

Autonomous adaptation interventions were usually community engagements, initiated and driven by individuals, households and communities with little to no intervention from government. This is consistent with the IPCC Sixth Assessment Report, which noted the importance of community-based resilience and adaptation in reducing hazards, exposure and vulnerability (IPCC, 2023). The report also emphasises the need to solidify community-based decision-making structures to ensure accountability. The planned interventions involved policy and practical interventions by the government, mainly at the municipal and local levels. Key adaptation actors were identified in the studies reviewed (Table 5). Communities (39.1%) and local governments (31.9%) were the most common adaptation actors, while other actors included provincial government (30.4%), national government (21.7%), non-governmental organisations and civil society (21.7%). Individuals were also identified as adaptation actors (17.4%). Other adaptation actors are local community businesses (Ndebele-Murisa et al., 2020), traditional leaders (Melore & Nel, 2020) and academic researchers (Mazeka et al., 2019). The scale of adaptation rested mainly at the community level (56.5%) and within households (30.4%), with some studies identifying city-wide scales of adaptation (17.4%) (Table 5).

Although our study did not evaluate the effectiveness of the reported interventions, several studies included in this review described their interventions as effective. The studies reported that adaptation was effective in improving safety (17.4%) and comfort (8.7%) (see Table 5). The adaptations were effective in addressing other developmental challenges, such as biodiversity loss and water security (Ndebele-Murisa et al., 2020). Other key measures of effectiveness in adaptation include the development

of net-zero carbon buildings, which improve energy efficiency and encourage the use of renewable energy sources (Vawda & Hugo, 2022). In addition, building climate resilience and improving water governance are critical measures (Williams et al., 2018). Improving access to water and sanitation is also an effective adaptation response (Chamberlain & Potter, 2022).

Adaptation Challenges

The cited challenges to adaptation include insufficient funding (39.1%), lack of political will (21.7%) and lack of participation (21.7%) (Table 5). Other adaptation challenges include the absence of dedicated disaster management personnel in any of the three flood-affected municipalities of George, Knysna and Bitou (Kotzee & Reyers, 2016). Another challenge is the poor and insufficient maintenance and monitoring of IDMS subsystems such as waste management services, environmental reservoirs, inadequate medical facilities, inadequate access to quality drinking water and poor public hygiene practices (Sekgobela & Sibanda, 2024). The dispute between traditional leaders and local governments is another challenge in achieving adaptation (Melore & Nel, 2020). Ngcamu (2022) notes other challenges, such as the lack of reliable loss and damage data, the absence of updated early warning systems and flood prevention measures, the lack of climate change language in communities, geographical literacy, as well as communities' limited knowledge on climate risks and risk warnings, which makes it difficult for them to respond.

Conclusion

This evidence mapping shows that informal settlements in South Africa face a complex and interconnected web of vulnerabilities to climate change. The vulnerabilities are driven by their geographic exposure, the poor nature of their infrastructure, deep-rooted socio-economic inequalities and governance challenges. Recurrent hazards such as flooding, fires and heat stress are worsened by poor drainage, poor housing structures and persistent lack of essential services. Despite these challenges, the review demonstrates evidence of adaptation to climate impacts among residents of informal settlements in South Africa. However, these adaptation efforts are often at the individual/household level and are constrained by various factors, including inadequate funding, limited participation and poor governance. These findings collectively highlight the urgent need for systemic, scalable adaptation solutions that build on bottom-up innovations, are co-produced, strengthen governance frameworks and systematic approaches that ensure appropriate and targeted responses to the needs of informal settlements in South Africa. This also requires a strategic shift from temporary fixes to long-term solutions that address the root causes of vulnerability.

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