Review

Analysis of Flooding Vulnerability in Informal Settlements Literature: Mapping and Research Agenda

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Abstract: The United Nations (UN) emphasizes the necessity of reducing the social and material losses imposed by water disasters, with an emphasis on protecting the most vulnerable social groups to achieve sustainable development goals (SDGs). Several objectives outlined under the SDGs including Goals 1, 11, and 13 concentrate on minimizing vulnerability to disasters and boosting resilience to extreme occurrences. Flooding is an increasingly challenging problem facing cities today, with consequences mostly felt in marginalized communities. Residents of informal settlements are particularly susceptible to the effects of flooding given that they are compelled to live in the most unsafe locations, such as floodplains. This study reviews the current status of flooding research from empirical perspectives globally and in South Africa through systematic literature and bibliometric analysis of 249 peer-reviewed articles on flooding, with a focus on informal settlements. We detect groups of keywords and major research themes. Our analysis shows that studies on flood modeling in informal settlements are inadequate. We synthesized the research to present a body of knowledge on floods in informal settlements. Future research prospects are identified in areas of upgrading housing and infrastructures, policies, integrating indigenous knowledge, and local participation.

1. Introduction

Climate change is expected to become more pronounced throughout the 21st century and beyond, and the effects could be significant. The frequency of extreme weather occurrences has increased due to climate change, such as strong rainstorms that produce widespread flooding across the globe. Over the coming years, flooding is expected to become one of the most common disasters owing to climate change and other man-induced activities. Each year, several million individuals are affected by flooding globally as one of the most expensive and devastating natural disasters (Desai et al. 2015; Kundzewicz et al. 2019). For instance, more recently in October 2022, Nigeria, a nation in West Africa, experienced its worst flooding in decades due to the emergency release of excess water from dams in both Nigeria and the neighboring country Cameroon (Khalid and Maishman 2022). An estimated 1.3 million people have been displaced due to this, and about a quarter of a million homes have been destroyed.

Similarly, in South Africa, on 11 September 2022, the Jagersfontein tailings dam located in the Free State province collapsed, releasing a tidal wave of tailings sludge and mudslides that swept through parts of Charlesville and Itumeleng villages, destroying homes, vehicles, and infrastructure. Four fatalities were reported, and dozens of injuries were sustained by residents of the affected villages. The sludge also destroyed vast swaths of farmland and grazing fields and swept away livestock (Motsau and van Wyk 2022).

Flood risks are a concern for South Africa as a nation, with the North-West, Eastern Cape, Limpopo, and Kwa-Zulu Natal provinces being the most vulnerable (Munyai et al. 2021). These provinces have experienced severe flooding, with the Eastern Cape and Kwazulu-Natal provinces experiencing the worst flooding in April 2022. Property destruction was catastrophic; nearly 400 people were killed, and approximately 50,000 people were displaced in Kwazulu-Natal due to landslides that swept away roads, bridges, and houses (Volgraff and Cele 2022). The Eastern Cape flood tragedy also resulted in severe infrastructure damage, as well as fatalities, which have a negative impact on the environment and socioeconomic situations (Dube 2022). Dube et al. (2021) contend that the increasing frequency of severe climatic conditions is concerning as it poses complex challenges to the socioeconomic development of communities in these areas, with the greatest impact being felt by the marginalized and vulnerable people (Dube et al. 2021). Considering that millions of people currently live in flood-prone areas worldwide and that this number is projected to rise sharply in the future, there is a high level of social vulnerability.

According to Dube et al. (2021), climate change has brought new challenges to urban areas along the coast. These areas are vulnerable to nature's wrath in the form of sea level rise, heavy rainfall, and, in some cases, tropical cyclones, as well as increased tidal activities and storm surges. Salami et al. (2017) maintain that because of dynamic land use patterns, unplanned growth, and the effects of climate change, urban human settlements have become increasingly vulnerable to flooding and other natural disasters.

Unfortunately, the deluge disproportionately affected the poorest people in South Africa, as the majority of those who died were living in shanty towns, also known locally as informal settlements (Sguazzin and Siwele 2022). As observed by Dube et al. (2021) floods are an urgent concern to the socioeconomic development of the vulnerable in Africa due to the loss of property, infrastructure, and human lives that arise from the occurrence. Consequently, the risk of flooding is recognized as a social construct in addition to a physical one. Hence, immediate sustainable interventions from developers, city planners, the government, and regular citizens are required to ameliorate or prevent its impact on the marginalized and vulnerable. Considering that the risk of flooding is a result of several factors interacting to create disaster situations, particularly in urban areas, combined efforts are required to implement measures that build the resilience of the vulnerable in informal settlements. We put these research questions forth to fulfill the study objective:

- What are the existing research trends in flooding among informal settlements globally?
- What have been the main domains of research, and how has flooding within this socioeconomic group been studied?
- What constitutes the key knowledge areas in South African informal settlements?
- What are the important research gaps and areas where further research is needed?

This study extends the field of knowledge by identifying the key knowledge areas of flooding in informal settlements to build resilience among these social groups.

2. Background and Theoretical Foundations

Setting the scene for this paper, we describe in this section an overview of the pertinent research studies and the theoretical underpinnings of the literature, which puts into perspective the complex political, economic, legal, and social elements that contribute to the legacy of spatial injustice and socioeconomic exclusion that underly South Africa's settlement pattern. The background section concludes by arguing for the need to take proactive measures to increase the resilience and adaptive capacity of the marginalized, especially in the informal settlement, to create a more inclusive society.

2.1. Historical Overview of South Africa's Informal Settlement and Marginalization

The legacy of spatial inequality and exclusion that underlies South Africa's current urban regions and fragmented development patterns is the result of numerous political, economic, legal, and social forces. The migration and urbanization patterns in South Africa during the past few decades have been influenced by a specific history. Towns and

cities evolved as economic and agricultural centers along crucial trade routes in Southern Africa before colonial authority (Van Wyk 2012). Some key occurrences beginning in the middle of the eighteenth century substantially disturbed the settlement patterns and means of subsistence of populations in southern Africa. The most notable factors leading to widespread forced migration were extended periods of ethnic conflict, severe droughts, and hunger (Seekings 2009). To increase political, economic, social, and geographical control, various Black communities were physically separated from one another and managed separately during the colonial era. Equally obvious is the role that the law plays in encouraging spatially inequitable settlement patterns, urban residential segregation, the prioritization of White minority property and economic interests, and the legalization of the forcible eviction of Black urban residents to remote locations outside the urban boundary (Pienaar 2002). People were subjected to oppressive policies, such as the well-known legislation that hampered the urbanization process (Turok and Borel-Saladin 2014).

The 1940s saw an increase in urbanization, which led to the spread of informal settlement and it implied that people had little access to properties and were compelled to live in homelands that were entirely of one ethnic group. As a result, the rural economy changed from being agrarian to being cash-based to accommodate numerous labor migrants (Zuma 2018).

The apartheid regime looked at alternative approaches in the 1980s to deal with the effects of rapid urbanization and the influx of Black people into towns and cities, and thus proposals were included in the White Paper on an Urbanization Strategy for the Republic of South Africa (DOH 1997). With the introduction of this new approach to policy, steps were taken to guarantee that urbanization took place in areas of towns and cities designated for Black settlement, typically along the urban perimeter, in a planned and regulated way. Additionally, the plan permitted controlled squatting on the defined territory through the upgrade of invaded property or the planned redevelopment of vacant areas, particularly with the help of private industry engagement (Leduka 2008).

However, in actuality, the plan led to uncertainties concerning how to address informal settlement developments. Despite the end of White minority control in 1994, an apartheid policy that compelled poor Black individuals to live on the periphery of cities has not been remedied, and this has had a disproportionately negative impact on those vulnerable social groups (Sguazzin and Siwele 2022).

2.2. Legislative Framework on Human Settlement in South Africa

Nearly all Black people were prevented from owning land in regions designated for White people by the Group Areas Act No. 41 of 1950, which was passed by the apartheid regime. To keep Black people out of the most developed districts, which were reserved for Whites, a system of urban apartheid assigned racial categories to various residential and commercial portions of urban centers (Berrisford 2011).

The Abolition of Racially Based Land Measures Act, 1991 (Act No. 108 of 1991) came into effect and repealed many apartheid laws imposing racial restrictions on land ownership, and The Black Land Act of 1913 (formerly the Native Land Act), the Development Trust and Land Act of 1936 (formerly the Native Trust and Land Act), and the Group Areas Act of 1966 were among the laws repealed (Letsoalo and Thupana 2013). After the dismantling of apartheid in 1994, the ANC government embarked on the Reconstruction and Development Programme (RDP). The RDP sought to address the enormous socioeconomic problems caused by apartheid. Its specific goal was to alleviate poverty and address massive gaps in social services across the country. Between 1994 and the beginning of 2001, over 1.1 million low-cost houses were built and distributed to five million of South Africa's estimated 12.5 million people without proper housing (Guelke 2004). Poor housing conditions are the fundamental problem, in the opinion of RDP critics. According to one study conducted in 2000, only 30% of new houses met building codes. Critics also point out that new housing schemes are frequently drab in their planning and layout, to the point where they resemble the Apartheid government's bleak building programs of the 1950s and

1960s (Guelke 2004). The ANC government aimed to resettle families on 300,000 square kilometers of land through the RDP program, but only slightly more than 1% of this goal was met.

Very many South Africans continue to live in shacks and substandard housing, which makes them vulnerable to flooding and other adverse weather conditions.

Climate change is exacerbating the problems caused by urban flooding that poor people in African cities and towns face regularly. The detailed reports from the cities studied by Action aid confirm the general consensus in the literature on political ecology approaches, demonstrating, for example, that when confronted with flood risk, residents of marginalized but risky areas have only a limited set of adaptation options (Douglas et al. 2008).

Most vulnerable urban residents in African cities typically have less capacity and fewer resources to recover from disaster shocks as a result of the government's failure to build human security for poor African residents (Salami et al. 2017). Scholars have identified inadequate systems and policies for vulnerability assessment, as well as the competence to precisely measure, analyze, and assess the different vulnerabilities of people in affected communities as barriers to disaster risk reduction in Africa (Salami et al. 2017). Additionally, there is a growing fear that anthropogenic climate change will cause flood threats to change considerably in the future (Alfieri et al. 2016; Kundzewicz et al. 2014).

Although it is widely known that communities must now adapt to climate change-related risks such as flooding, the literature reveals that potential and chances for adaptation are not uniformly divided among them. In light of the foregoing, this paper aims to examine the current state of research on flooding in informal settlements as they are a community characterized by high vulnerability and risks of the impact of flooding. In fact, by 2050, flooding exposure is predicted to increase due to a rise in population and property in flood-prone locations (Jongman et al. 2012). Therefore, there is a need to be proactive in building resilience and adaptive capacity of the vulnerable, particularly in the informal settlements.

Sections 1 and 2 of this article started with the introduction and theoretical foundations. The remainder of the study continues with the methodology used to systematically compile the literature pool as discussed in Section 3 of this article. The findings of a bibliometric analysis of the retrieved publications are presented in Section 4, which gives information on the subject's current state on a global scale. Section 5 discusses the main sub-streams of study in the context of South Africa. Our discussion is informed by findings from a bibliometric keyword analysis that employs network science concepts to find interconnected groups of works. Our discussion is concluded in Section 6 by pointing out research gaps in the available literature and prospective paths for further investigation.

3. Materials and Methods

A dynamic methodology that combines the systematic literature review approach with the scientific mapping of bibliographic networks is used to achieve this objective. Pritchard created the term "bibliometrics" in 1969 to describe the interdisciplinary field of study that use mathematical and statistical techniques to quantitatively analyze all information carriers (Pritchard 1969). This dynamic analysis made it possible to identify important topics for further research and work. Making up the search terms was the first step in the investigation. Choosing keywords that enable finding all publications that are pertinent to the study's objectives is fundamental when performing database queries (Oakland 2015).

The following syntax was used to launch the query: "flood OR flooding AND *human AND settlement* OR *informal AND settlements* OR vulnerable OR marginalised AND interventions OR resilience OR mitigation OR adaptation AND (LIMIT-TO (OA, "all")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "ARTS")) AND (LIMIT-TO (LANGUAGE, "English"))". Selected articles from Scopus had the aforementioned terms in the title, keywords, abstract, or all three. The time period for publication was left unrestricted. At first, 1220 articles were found. We next narrowed

down our choices using precise inclusion and exclusion criteria so that only publications that conformed to the study subject would be included in our analysis.

Databases, Keywords, and Inclusion Criteria

The Scopus database was used to obtain the bibliographic information for this study because it not only adheres to the strict indexation standards (Donthu et al. 2020) but also due to the broader nature of the journals indexed in the Scopus database. A wide range of topics is covered by Scopus data, which is also the most important citation and abstract database and the most widely used search database (Owojori and Okoro 2022a). Furthermore, empirical comparisons have found that Scopus offers more comprehensive coverage of sources than the Web of Science for fields of study of social sciences research (Mongeon and Paul-Hus 2015). Additionally, Scopus's coverage of journals is wider, which leads to its coverage of citations being wider.

We obtained a total of 1220 papers from Scopus by executing the aforementioned queries (Figure 1). To determine which papers should be included in the final sample, we used the following criteria: (i) only academic articles written in English that have been peer-reviewed and (ii) only papers with a strong expressive focus on flooding were deemed relevant. Following the application of inclusion criterion #1, the relevance of the papers discovered was assessed by reviewing all of the titles and abstracts of the remaining publications to weed out those that did not satisfy inclusion condition #2. Finally, a valid sample of 249 publications was selected.

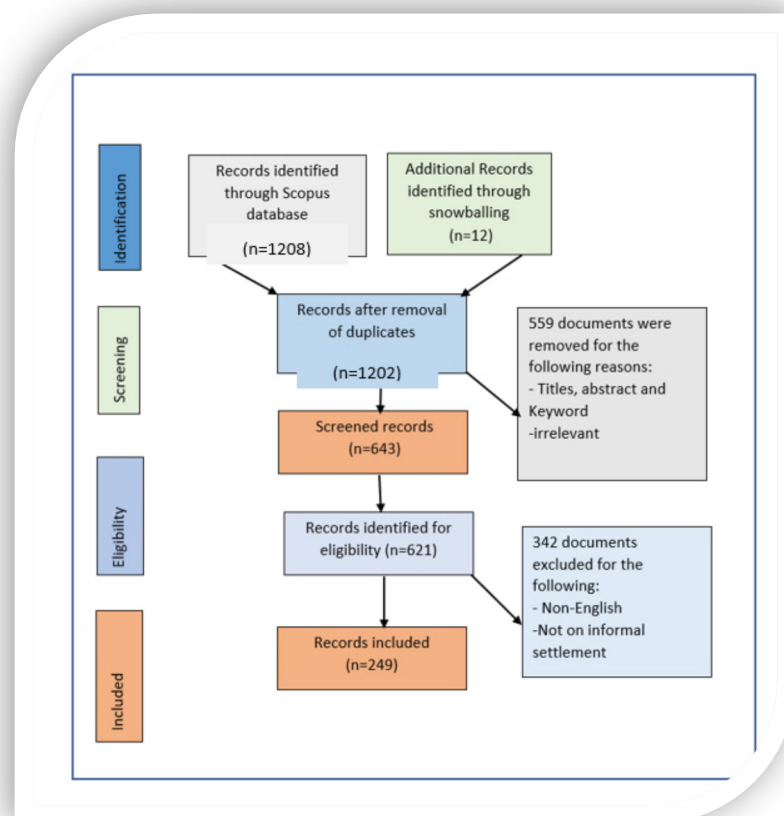**Figure 1.** Flow chart for the selection process.

Tools for analysis: The final sample of 249 publications' essential meta-data were exported to comma-separated values (CSV) file format for use in Excel. The VOSviewer was used to store the finished reference files (in CSV format) for bibliometric visualization. The text mining program VOSviewer was chosen for science mapping to display the view

of the keyword clusters. The software program, called VOSviewer, was created by van Eck and Waltman (2014). It is an extensive bibliometric analysis tool based on visualization of similarities (VOS) technology, which offers special advantages in clustering disparate knowledge from various domains based on their similarity and connectedness. For content analysis in NVivo, an electronic copy of the retrieved file was saved. Specifically, there were two bibliometric tests conducted:

(i) Evolution and yearly publication: it is important to illustrate the country-by-country distribution and yearly publications so that readers may immediately grasp the global research's spatial distribution and trajectory. (ii) Keywords Co-occurrence analysis: to visualize the keywords' co-occurring and group them into various study subjects. The knowledge structure is highlighted using network analysis of co-occurring keywords, which is also utilized to provide research hotspots and future research prospects (Owojori and Okoro 2022b).

An individual bibliographic item, such as an organization, nation, term, reference, etc., is represented as a node in the networks that have been depicted. The size of the node indicates how many times the evaluated item, such as a citation or an incident, has occurred. The relationship between two items is shown by a link, such as co-occurrence or collaboration. Total link strength, a parameter that measures how closely any two nodes in the produced networks are correlated, is outputted directly by the software. The greater the TLS value, the more significant and central the item is (Hu et al. 2019). High-similarity nodes were grouped and identified by colors from other clusters, and low-similarity nodes are wide apart as feasible.

4. Results

4.1. Global Mapping

Following the literature search and analyses, the Scopus database generated 249 documents regarding floods in informal settlements. The number of published articles on pertinent topics from 2008 to 2022 generally increased and can be split into three categories (Figure 2) Globally, from 2008 to 2014, there were fewer publications, and most of them focused on how residents experience floods, why they happen, how they cope with them, who is liable for lowering the risk of a flood, and what steps the community can take as a whole, as in scholars such as Douglas et al. (2008) and Adelekan (2010). They also take into account the elements that have contributed to the urban poor's increased vulnerability to flooding, such as the uncontrollable growth of the built-up area, the lack of supply of infrastructure, and the neglect of both expanding stormwater drainage and maintaining already-existing drainage systems (Sakijege et al. 2012; Zehra et al. 2019).
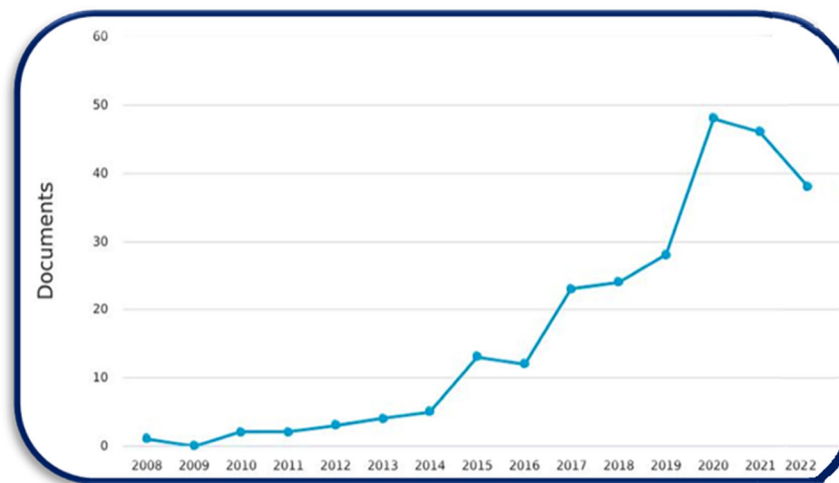

Figure 2. Annual publication distribution.

From 2015 to 2019, this stage's yearly publishing rate was stable and progressively rising. This trend is probably caused by the rapidly increasing significance of the climatic changes challenges that many nations are facing, especially in light of the Sustainable Development Goals document shared by UN member states, which emphasizes the significance of pre-disaster planning regarding the principal task of "social development". Moreover, the Sendai Framework for Disaster Risk Reduction 2015–2030 is a primary driver of the surge in research on disaster risk reduction (DRR), which is significant to the Sustainable Development Agenda (UNISDR 2015). Building the poor's resilience and lowering their exposure to climate-related catastrophes are only two of the numerous aims that expressly recognize the relevance of disaster risk reduction (DRR), which is directly or indirectly included in the framework of the SDGs (Target 1.5).

The third stage runs from 2019 to 2022 and shows a relatively fast trend in the growth of the literature. This could be because at this time, the world is receiving more attention, especially in light of recent reports predicting unprecedented flooding along with new records for global temperature increases and changes in land use, infrastructure, and population demographics, all of which are expected to lead to more intense events (Wilby and Keenan 2012; Tabari 2020). As a result, scholars started to focus on and actively advocate ways for mitigating flooding and planning for it.

4.2. Spatial Distribution of Articles

In total, 62 nations have contributed to the body of knowledge about floods in informal settlements, according to the documents that were retrieved. Countries with the greatest number of contributions are the UK (36), USA (34), Germany (26), Netherlands (26), Australia (23), Italy (23), China (21), Ghana (12), Sweden (12), and Japan (11). Other articles from developing countries such as Nigeria (8), Ethiopia, (8), Kenya (7), Egypt (3), and South Africa (9) are also documented, but in few publications. According to the reports, people who are vulnerable to river floods are concentrated in particularly high numbers in parts of Europe, Sub-Saharan Africa, and East Asia. The high record is largely attributable to the fact that eight of the ten most significant weather and climate disasters over the previous ten years have involved flooding (Alfieri et al. 2016).

The United Kingdom and the United States of America have a high exposure but a low vulnerability, hence they do not have a high flood risk ranking. On the other hand, nations in West and Southern Africa with a high vulnerability are frequently more at risk even with considerably lower exposure levels. Currently, the majority of African cities and metropolitan areas are recognized as high-risk areas for flooding disasters (Baker 2012). Increased numbers of people living in floodplains as a result of unplanned urbanization in Africa have increased the number of fatalities from flooding in African cities (Baldassarre et al. 2010). Future extreme flood hazards are most anticipated to grow in Southeast Asia, South Asia, Oceania, and Sub-Saharan Africa. Therefore, there is a fundamental need to foster sustainable adaptive techniques and boost resilience within these informal settlements in these places.

4.3. Keyword Co-Occurrence

We examined keyword co-occurrence and subject trends of topics to determine the primary areas of knowledge inquiry. Researchers can easily grasp the research hotspots and upcoming research paths of an academic topic by studying the co-occurrence of keywords in that field. In this analysis, a term co-occurrence graph was made in VOSviewer, as seen in Figure 3. A keyword co-occurrence network analysis creates a network that highlights the words that are used most repeatedly in the topic of research. The network enables the exploration of concepts or subjects (keywords), thematic groupings, and even research gaps (Zupic and Čater 2014). Only 147 of the 2781 keywords fulfill our analytical criteria, which require a minimum of five occurrences of a term. A network of subjects and their connections in a scientific field is created via keyword co-occurrence analysis.

Figure 3. Keyword analysis of co-occurrences.

The number of times the keyword appears is shown by the size of the node in this map. The separation between two nodes and the width of the line connecting them determines how strongly two keywords co-occur. The color of the nodes denotes keyword clusters, which commonly include words that appear together and can be regarded as extensive research areas in the discipline (Gu et al. 2021; Owojori and Okoro 2022b). The thematic focus of interest in the extracted papers appears to be summarized in six main clusters, as seen in Figure 3 and shown in Table 1.

Table 1. Clusters and keywords.

Cluster 1	Disaster mitigation, risk reduction, flood vulnerability, land use planning, and resilience in human settlements
Cluster 2	Risk management, hydrological modeling, spatiotemporal analysis, risk assessment
Cluster 3	Adaptive management, vulnerability to flooding in informal settlements, knowledge, local participation, mapping methods, natural hazards, stakeholder and policy approach
Cluster 4	Global change occurrences, such as climate change and "sea level rise".
Cluster 5	Flood damage due to sea level rise, sea level change, coastal zone, and cost-benefit analysis
Cluster 6	Sustainable integrated method, climate change mitigation, urban development, urban planning, and coastal zone management in informal settlements.

Cluster 1: (Red cluster). Studies here showed that to raise their level of readiness for coastal flooding, communities employ several disaster risk reduction (DRR) strategies. Some strategies concentrate more on costly structural defenses, such as dikes or storm surge barriers, while others place more emphasis on non-structural measures, such as the development of early warning systems (Klijn et al. 2015). Some of the researchers reported the factors that determine the vulnerability and resilience-building capability of households

within the community which comprises the social, economic, human, physical, natural, and institutional capitals (Melore and Nel 2020; Williams et al. 2018). Inequality in access to open government, services, and economic opportunities is also discovered to be a major contributor to vulnerability (Adelekan et al. 2015). The research presented here links the idea of resilience as a social process that helps communities comprehend, plan for, and respond to environmental changes and natural disasters. This approach is characterized as social resilience (Amoako and Inkoom 2018).

Cluster 2: (Green cluster). Studies here evaluated the path of flood disasters through the understanding of real-time dynamics. Here, techniques including numerical modeling, remote sensing, geographic information system (GIS), and Lidar are used (Karamouz et al. 2017; Wong et al. 2017). Among these, numerical modeling is the primary research methodology and is frequently used to analyze coastal floods utilizing 3S (Remote sensing, RS; Geography information systems, GIS; Global positioning systems, GPS), and Lidar use has also expanded. The research in this cluster strives to create a dynamic systems model to simulate interactions and responses between urban flood risk reduction and social inequality in highly growing urban cities (Moulds et al. 2021). This study places a strong emphasis on flood modeling as a crucial approach for achieving integrated flood risk management in low-income cities and informal settlements (Tom et al. 2022; Moulds et al. 2021) and emphasizes the necessity of testing multiple models in various cities with varying contexts and with an integrated flood risk management focus in order to determine how well they function.

Cluster 3: The research in this cluster emphasized that greater vulnerability is linked to larger disasters when the coastal region has poor resilience. The studies here emphasized the necessity for community participation in the development of effective flood risk management, strategies, and infrastructure solutions (Zehra et al. 2019) and the use of indigenous knowledge (Gough et al. 2019; Membele et al. 2022). Researchers in this cluster (Membele et al. 2022; Amoako and Boamah 2015) argue that integrating local and indigenous knowledge as a strategy in flood vulnerability mapping in informal settlements can improve adaptive capacity in informal settlements in increasing their resistance to floods. The Sendai Framework for Disaster Risk Reduction 2015–2030, the United Nations International Strategy for Disaster Reduction (UNISDR), and the World Conference on Disaster Reduction (held in Hyogo, Japan, in 2005) all called for the integration of indigenous knowledge for vulnerability mapping. This is so that individuals living in high-risk areas, such as informal settlements, can develop resilience and be secure. This is attained by drawing on the knowledge and cultural understanding that emerge from an indigenous knowledge base

Cluster 4: In this cluster, it is highlighted that low- and middle-income societies' urbanized areas are in greater danger of flooding, storm surge, and sea level rise due to a lack of coping and adaptation capabilities. The works presented here address a wide range of topics, including decision making, governance approaches, institutional frameworks, and spatial planning. Additionally, the work here emphasized the importance of community and city-led initiatives to upgrade communities to serve vulnerable populations and increase community resilience to climate change hazards (Satterthwaite et al. 2020; Haque 2021). It is realized that decision makers and stakeholders can reduce exposure and susceptibility by taking adaptation measures such as risk mapping, building early warning systems (EWS), preparedness plans, and preventative risk strategies, particularly in informal settlements.

Cluster 5: The research presented here generally agrees that human-induced environmental constraints, such as water and air pollution, culture, institutional capability, physical environment, and supply of ecosystem services all influence vulnerability of settlements to climate change. Informal settlements are particularly vulnerable to climate change, according to many of the researchers who have focused on the factors that increase the risk of disaster, including the location on hazardous land, poor planning, a lack of infrastructure and services, and higher levels of socioeconomic vulnerability (Moser and Satterthwaite

2008; Morin et al. 2016). The cluster explores the harm suffered by these marginalized communities as a result of flooding, including the loss of dwellings, storm surges, erosion, poor water quality, fatalities, and injuries disruption of investment projects and livelihoods, damage to homes, assets, and public infrastructure, population displacement, and disease outbreaks (Moser and Satterthwaite 2008). However, studies in this area have alerted that if measures to make these communities more resilient are not timely adopted, flood disasters will aggravate the ensuing economic, public health, and economic repercussions (Tasantab et al. 2022; Zehra et al. 2019) It is almost clear that the costs of dealing with such disasters will be higher than the price of taking the necessary adaptive measures to prevent them.

Cluster 6: The research presented here provides novel systems understandings of local residents' experiences and perspectives of adaptation processes in low-income urban settlements and how those mechanisms may be positively impacted by combining bottom-up and top-down approaches. In informal settlements, which have historically been badly hit by floods and tropical storms, the social and political ramifications of using traditional risk management have been criticized (Sandoval and Sarmiento 2020). Community-based approaches, which are emerging as an alternative, see communities as essential actors in risk analysis, monitoring, and communication rather than as clients or outside consultants (Morin et al. 2016).

Here, it is established that community involvement is also necessary for the co-production of knowledge in systems of local governance for water management that is integrative and cross-disciplinary. This is especially crucial for formerly underprivileged groups living in informal settlements (Williams et al. 2018). Before beginning any upgrading, it is equally necessary to take a community-based approach to planning and to create suitable planning and technical standards.

4.4. Flooding in Informal Settlements of South Africa

Figure 4 shows that only a handful of studies have been annually published on flooding and informal settlements in South Africa. The studies published around the 2008–2022 period were recorded as 17 (Figure 4). Six articles were recorded in 2019, only one article was published in 2018, and none were recorded in the year 2020. This could be ascribed to the aftermath of the worldwide pandemic crisis, which would have negatively impacted research funding and research goals. Moreover, in 2021, three articles were published as opposed to none the year before. However, more are anticipated, largely because disaster management is receiving more and more attention.
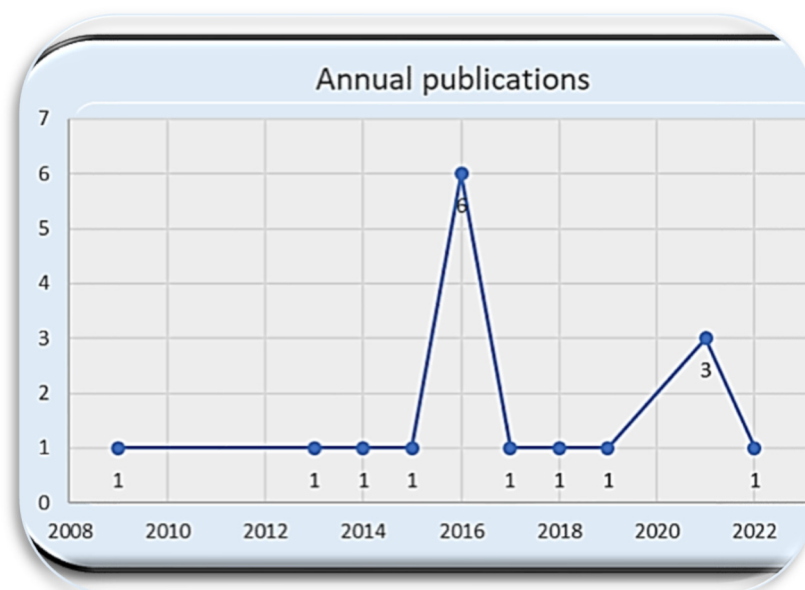

Figure 4. Annual publication trend.

According to statistics, South Africa lags behind developed nations in research on flood management even though it is well-established that there are impending issues with the state's disaster management in light of disaster prevention and climate change (Busayo et al. 2022). The South African government has, however, committed to stepping up disaster management to ensure that an efficient system is realized and put in place, with a focus on protecting those who are most at risk. However, it is still unclear how to adequately care for the marginalized population living in the nation's informal settlements in the event of flooding.

4.5. Keyword Co-Occurrence Analysis

To locate significant thematic clusters, we employed co-occurrence analysis. Each cluster is made up of several frequently recurring terms. Figure 5 displays the results of the analysis with a minimum threshold of five keywords. In terms of both frequency of occurrence and overall link strength, the following terms stand out: disaster management, knowledge, risk assessment, vulnerability, governance approach, local government, governance, drainage, indigenous knowledge, local participation, adaption, and coping strategy. Higher occurrence and link strength values for the term "informal settlements" are unsurprising since it was a part of the search term and the evaluation is centered on papers that looked at its connection to flooding-related incidents. Four main thematic clusters can be seen in Figure 5 and are shown in Table 2.
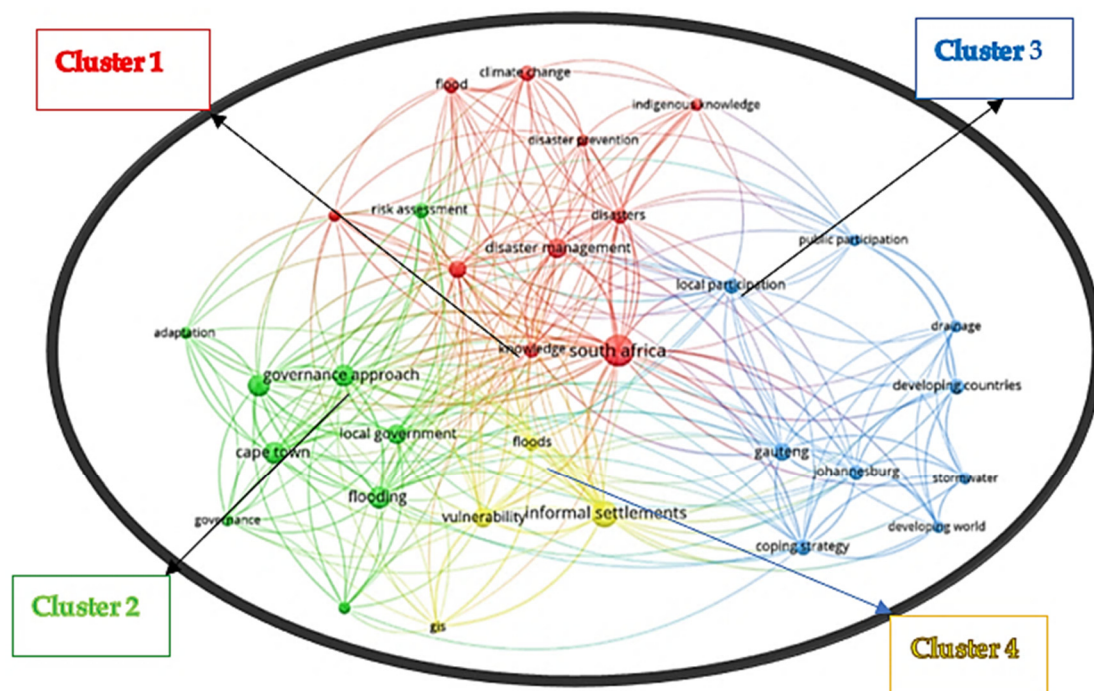

Figure 5. Analysis of keyword co-occurrence map.

Cluster 1 (Red): This research focused on themes including an investigation into the reporting of resilience and adaptation tactics in South Africa, which led to the identification of some assessment methods, particularly the application of geographical information systems (Gis) (Musungu et al. 2012; Siyongwana et al. 2015). They also discussed instances of applying indigenous knowledge in the improvement of informal settlements and the function of indigenous knowledge in interventions for disaster risk mitigation. An informal settlement's flood vulnerability can be better understood by utilizing local knowledge to choose criteria for flood vulnerability mapping. This provides decision makers and other interested parties with a perspective of adaptable policies that can be put into place to build people's resilience (Membele et al. 2022). Therefore, South Africa's capacity for adaptation

needs to be significantly developed to support the development of sustainable and resilient communities, particularly informal communities.

Table 2. Clusters and keywords.

Cluster	Keywords
Cluster 1	Vulnerability assessment and flood mitigation measures, building adaptive capacity for climate change, and preparing proactively for disasters
Cluster 2	Local government, social economic factors, inclusive governance, flooding, governance mechanisms, and governance system in informal settlements
Cluster 3	This cluster comprises studies on local participation, community participation, marginalization, and climate change governance
Cluster 4	This cluster centers on vulnerability, informal settlements, and flooding

Cluster 2 (green): The theme aims to reduce and mitigate risk and vulnerability, particularly in the poor and marginalized parts of society. There are some significant obstacles to collaborative urban flood risk management and governance, including the dominance of a bureaucratic approach, a lack of specialized skills, the difficulty of risk sharing, institutional contradiction, and short-termism. Failures in governance, a lack of communication and coordination, difficulties with social inclusion and planning, a lack of funding, a lack of operational skills, and an absence of community participation are also emphasized. (Ziervogel et al. 2016; Fatti and Patel 2013). Thus, it is acknowledged that all of these call for an understanding of the interactions among those involved in governance. It also necessitates understanding how various communities and groups may be impacted differently by climate change.

Cluster 3 (blue): They highlighted local community ideologies to address the complex flood risk brought on by climate change (Sinthumule and Mudau 2019; Drivdal 2016). The use of a sector response or a one-size-fits-all strategy is inappropriate in the majority of situations. The concept of community science is centered on engaging non-scientists in the process of describing and monitoring floods, typically under the guidance of a professional agency or expert (Drivdal 2016; Desportes et al. 2016). Citizen science is becoming more and more popular, which can be ascribed to its ability to produce inexpensive, current, and comprehensive disaster vulnerability information, as well as its associated social inclusion. The need for strengthening the community to lower their disaster risks has been highlighted by the adoption of frameworks such as the "Yokohama Strategy and Plan of Action for a Safer World", "Hyogo Framework for Action", and "Sendai Framework for Disaster Risk Reduction" (SFDRR). Community-based participation strives to enhance and empower communities to implement any projects of development including disaster prevention and mitigation, responding to the growing disaster risks within informal communities.

Cluster 4 (yellow): The term "vulnerability" describes a society, system, or entity's traits and conditions that make it vulnerable to the negative impacts of a disaster (UNISDR 2009). "Limpopo, North-West, and Eastern Cape" are South Africa's three most vulnerable provinces. However, this doesn't exclude other South African regions from vulnerability and susceptibility to floods (Munyai et al. 2021). There are few studies on South Africa's informal communities' susceptibility to climate-change-related flooding, and those that do tend to concentrate locally in rural areas (Musyoki et al. 2016; Williams et al. 2018). Flood disasters are occurring more frequently, and informal settlements have the most physical vulnerability to floods due to factors including obstructed drainage, poorly constructed homes, insufficient accessibility, washed-away unplowed roads, and weak sewage and storm-water infrastructure (Musungu et al. 2016). It is imperative to comprehend how vulnerable human communities are to flooding. The temporal keyword co-occurrence analysis identified areas of recent research interest in the topic of discussion as shown in Figure 6.
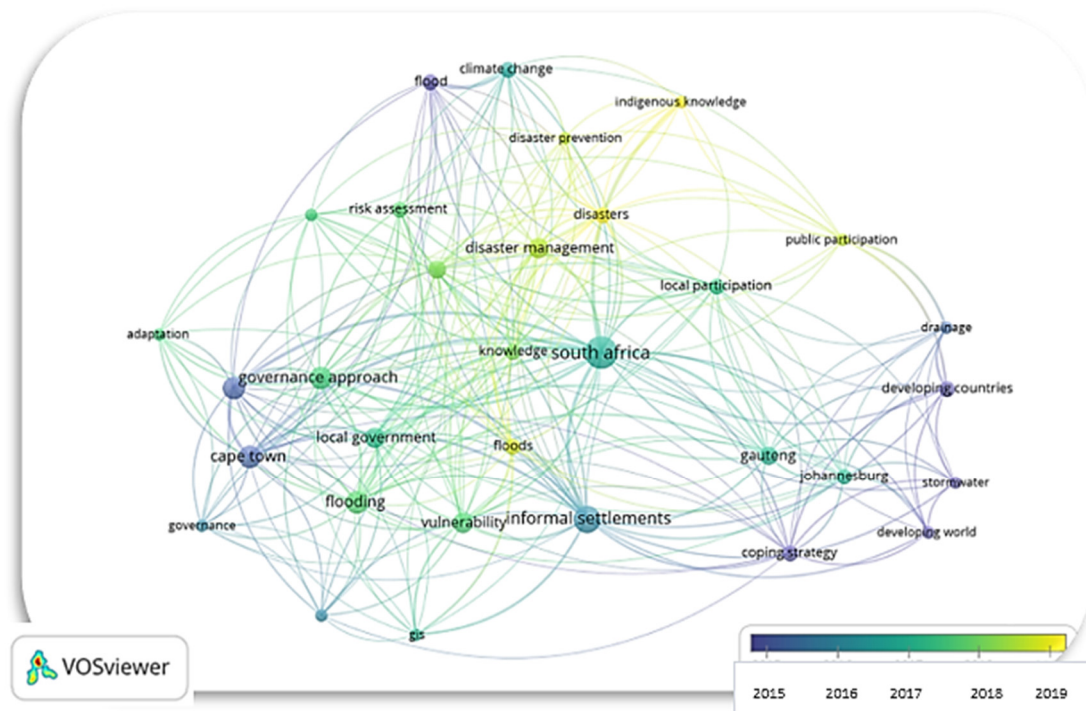
Figure 6. Overlay visualization of index keyword co-occurrence analysis.

The development of research terms is shown by a temporal overlay on a keyword occurrence map (keywords threshold of 2). The overlay representation provided by VOSviewer demonstrates how circles with cold colors (such as blue) represent research topics with average publication years that are older, while circles in hot colors (such as yellow) depict keywords with a more current average publication year. This is seen by the yellow cluster, where each node is made up of studies on the subject of disaster, disaster management, public participation, local participation, and indigenous knowledge.

Overview of the Connections between the Clusters

While the overall clusters' major topic is flooding and disaster risks, as seen in Figure 3, which shows relationships between clusters, the clusters still show a variety of research interests from different authors. Cluster 1 (disaster reduction, planning, and resilience) is the cluster with the most linkages to the other five while being placed from the center to the right side of the map. Despite being intriguing, Clusters 4, 5, and 6 are the least likely to occur together and have a weak connection to Clusters 1 and 2, and 3. Such a situation might be brought on by the lack of reports from vulnerable flood-prone informal settlements, despite the fact that these are the areas most likely to be at risk from the effects of human-induced climate change. The aspects of fewer keyword co-occurrence extreme events, sea level changes, and climate change are more closely related to this lack of reporting than one might think. Consequently, stronger links between Clusters 1, 2, and 3 (risk management, disaster risk reduction, and disaster management) are seen.

The major keywords in Cluster 1 may be grouped under the research theme "disaster reduction, planning, and resilience in informal settlements" and Cluster 2 under the theme "disaster modeling and risk analysis". Cluster 3 may be grouped under the theme "vulnerability, participation mapping, and policy approach", Cluster 4 under the theme "global changes in sea level and climate", Cluster 5 under the theme "flood damage due to climate and sea level change", and Cluster 6 under the theme "sustainable integrated methods for climate change mitigation".

In Figure 5, Despite the diversity of each author's research, Cluster 1's primary component is disaster management, the dominant element of Cluster 2 is the governance approach, the primary element of Cluster 3 is local participation, and the dominant element

of Cluster 4 is flooding in informal settlements. The focus of the clusters was placed on coping mechanisms and the governing approach prior to 2017, Adaptation and vulnerability to flooding gradually came into view from 2018–2020, and indigenous knowledge and disaster prevention from 2020, demonstrating the scholarly community's interest in flood disaster reduction in informal settlements.

5. Discussion

5.1. Strengthening the Resiliency of Informal Settlements

To strengthen the informal communities' resilience to flooding disasters, this section addresses important concerns around the highlighted theme. As a result of urban marginalization, which throughout time has continued to reflect a top-down autocratic approach, residents of informal settlements have learned to be resilient not only during natural disasters, but also to urban politics in general. Without a doubt, the government has strengthened its ties with the unorganized sector, but in practice, inadequate strategy and execution have left the urban poor dissatisfied with the lack of progress in acquiring housing (SERI 2018) The pathways laid out in the next section can be utilized by the government and other players to help the marginalized informal settlements become more resilient to flooding disasters.

5.2. Housing and Infrastructure Upgrading

As a holistic conceptual approach that connects individuals to mitigate climate-related calamities, resiliency is steadily gaining traction (Melore and Nel 2020). The usual government response to the requirement to strengthen resilience in informal settlements is to demand that residents invest in bringing their existing structures up to code and to pay for the expense of connecting such buildings to infrastructure and services (Satterthwaite et al. 2020). Governments can, however, increase the availability and lower the price of the essential elements, such as land and permits, building supplies (Rojas et al. 2022), connection to infrastructure (water, sanitation, drainage, and electricity), and services, while also enhancing access to formal housing. By collaborating with local governments to put "upgrading" programs into place, the informal settlements can successfully increase their resilience to the effects of climate change. Programs for upgrading buildings can raise their quality and safety while also providing infrastructure and public services (including healthcare, emergency services, and public transport). Governments can encourage companies to build less expensive "formal" housing and persuade banks to offer low-interest credit programs. One of the housing-related problems that is anticipated is the challenge of locating land to relocate individuals who reside in areas prone to natural disasters. State land must be made accessible for human settlement to be used for the construction of affordable housing and dwellings for rural development to solve the menace.

5.3. Mapping/Modeling Levels of Flood Vulnerability

In South Africa, modeling flood vulnerability at the local level is crucial to aid in understanding the localized interactions of factors that affect flood risk. The government and other actors can use this as a foundation to create suitable policies, initiatives, and services to mitigate flood vulnerability (Tom et al. 2022). This study found that little has been done to map the levels of informal flood vulnerability, which is alarming since various degrees of flood susceptibility exist within each community. Humans are more or less vulnerable to flooding depending on their coping and adapting skills, according to Nethengwe (2007). This makes it challenging to put into practice strategic initiatives meant to decrease flood vulnerability in a particular locality. Therefore, information on the actual occurrences of flood events, including their patterns, severity, and effects, is not available to further conduct a sensitivity analysis on the maps that are currently available.

In order to investigate the relationships between land uses, housing and population densities, household size and locational characteristics, flood dangers, and susceptibility in impacted informal communities, an appropriate GIS-based flood prediction model may be

constructed. This dataset might kickstart a more intelligent approach to managing flood risk than there is at the moment. A thorough flood risk and vulnerability map is required which accurately identifies various degrees of flood risks and vulnerabilities and can aid in predicting intensities and impacts as well as proactive evacuation planning.

5.4. Indigenous Knowledge and Mapping

Residents of informal settlements have developed their methods for coping with floods as a result of the infrastructure issues faced by the majority of them. This study found a gap in the approaches to mapping flood vulnerability. Flood technique has adhered to the traditional method of creating a flood hazard vulnerability map, which is based mostly on physical characteristics, flood vulnerability models, remote sensing data, and geographic information system (GIS) tools (Musungu et al. 2012; Ngie 2012). It is contended that GIS alone is unable to account for the human aspects that contribute to flood susceptibility. Opportunities must be made for local opinions to be heard, as well as meaningfully incorporated into whatever is being planned, including projects, policies, and processes. While technical-based ways to deal with flood risk are important, this study contends that incorporating knowledge local residents have accumulated through generations can offer a situation-specific and improved strategy to address the complex nature of flood vulnerability (Tran et al. 2009; Membele et al. 2022). The government must acknowledge, for instance, how native people combat floods using traditional means. Likewise, since the populace is familiar with them, the government should recognize the early warning systems developed locally. A more comprehensive and affordable understanding of the man-made-environment interaction of flooding vulnerability at the local level can be provided by merging indigenous knowledge with GIS, according to Mapedza et al. (2022). Thus, we believe that the combining of indigenous information and GIS can give contextual, pragmatic knowledge that is essential for comprehending and modeling informal settlements' vulnerability to flooding threats.

5.5. Green Infrastructure

Governments have historically used grey or engineering techniques to reduce the risks to flood disasters. However, as the negative effects of floods worsen, so does interest in a more comprehensive strategy for managing urban flood risk. Options for green infrastructure (GI) have become a crucial part of this comprehensive strategy (Douglas 2018). The creation of interconnected networks of green areas, such as parks, greenways, retention ponds, etc., that protect natural ecosystems and provide a range of social, economic, and environmental benefits, such as protecting habitats and maintaining natural services, is known as "green infrastructure" (GI) (US Environmental Protection Agency/USEPA 2010). Since residents of informal settlements are disproportionately affected by disasters such as floods, green infrastructure initiatives to reduce disaster risk will benefit them extremely. This paper promotes the idea that GI solutions need to be seriously considered as a component of strategies for managing urban flood risk in general.

5.6. Community Participation

For informal settlements to become more resilient and less vulnerable to flooding, there must be greater community involvement in managing flood hazards (Williams et al. 2018). This promotes a sense of community involvement and empowerment, which may ultimately result in more affordable, locally based, and long-lasting solutions to cope with flood vulnerability and reduction of disaster risk generally (Botha and Van Niekerk 2013). There is evidence that the need for community involvement in disaster risk problems is growing (Pandey 2018; Abunyewah et al. 2020), but this conversation is less prevalent in South Africa. The majority of the community mostly contributes to data collecting by responding to surveys or interviews that are conducted with them. The remaining stages are managed by "technical experts". Out of all the studies that have been reviewed, this is an aberration that demonstrates inadequate community involvement and inclusion in

the mapping of flood susceptibility. Thus, it poses an extreme challenge to include local knowledge and experiences to support disaster policies in informal settlements

5.7. Suggested Areas of Future Research

The research gaps and priorities for future research are presented in Table 3 based on the results of the bibliometric and thematic analysis. These suggestions are possible extensions of this research in the future.

Table 3. Themes for further research.

Theme	Further Research
Governance and policies	Investigate the effects of various institutional weaknesses on the system. More studies are needed to develop a more holistic perspective on the bottom-up approach for informal communities. Incorporating governance best practices from other jurisdictions to develop flood resilience techniques tailored to the local conditions
Upgrading of housing and infrastructure	studies on the upgrading of informal settlements through multi-stakeholder partnerships Assessing community needs and priorities, and using this data to garner support for future actions Research on private and public sector involvement in land accessibility
Indigenous knowledge	Additional research on local knowledge and experiences is needed to enhance flood disaster policies.
Flood mapping/modeling	More studies on spatiotemporal dynamics of vulnerability aspects. Application of socioeconomic vulnerability to flooding exposure models for extremely vulnerable locations Studies on multicriteria approach for risk assessment Mapping vulnerability by incorporating sensitivity analysis and validation in marginalized communities
Green infrastructure	Role of GI technologies in lowering flood risk in informal communities Challenges associated with implementing green infrastructure for flood mitigation Research to examine how much communities value the environmental and social advantages of GI Research to develop efficient GI design guidelines that are tailored to the regional ecological context
Community participation	Develop institutional capacity for social inclusion in improving flood resilience in detail. Evaluating public participation in depth in flood-prone neighborhoods utilizing quantitative and qualitative methodologies

5.8. Summary

To evaluate the state floods research, we quantitatively assessed the major study areas within the informal settlement socioeconomic group and the key knowledge areas in South African informal settlements, as well as the important research gaps. Given the status of the research in this area, our quantitative approach is exploratory but offers new information on flooding in informal settlements and interventions.

Given how ubiquitous the informality policy and inequality dilemma are in South Africa, as reflected in the theoretical background, one might have anticipated wider metadata on intervention measures, but the metadata we were able to collect ultimately reflect the dearth of interventions for flooding-prone informal communities currently. Our analysis is timely because the majority of this research was just lately conducted, which implies

a spike in interest in this subject. Future research will surely constructively expand on this, and systematic evaluations of formalization approaches will be able to concentrate on a more coherent set of findings as the metadata scope grows. However, this also necessitates that policy actions targeted at reducing informality and flooding vulnerability among these socioeconomic groups be subjected to a careful evaluation by researchers.

The limited information on actual flood events, including their patterns, severity, and impacts, prevents additional sensitivity analysis from being performed on the available mappings. As a result, there are few warning or rescue systems or models for predicting floods. Therefore, information on the exact incidence, intensity, and effects of flood disasters is sparse.

The characterization, collection, and digitization of spatial, infrastructure, and socio-economic information will be a crucial first step in developing an integrated flood mitigation framework for informal communities in South Africa as a response to the data gap mentioned above. Future data accessibility will be impacted by new information technologies as well.

Poor training and development of technical competence to facilitate local involvement in exercises or mainstream hazard mitigation issues at the local levels is a major cause of the absence of indigenous knowledge input on local vulnerabilities at informal settlements. The comparatively limited population of these settlements presents a chance to start inter-community conversations and planning for integrated flooding mitigation, nevertheless.

From the foregoing, some other policy questions are of prime significance: what is known about which type of "flooding intervention" works? From the literature reviewed, resettlement, housing, and infrastructure upgrades were among the measures that were mentioned. However, we should be able to keep track. Does the vulnerability and adaptability to flooding differ in the short and long term? Do these informal settlements have varied effects on various measures? Is "formalizing" or upgrading easier?

Last but not least, as urbanization is a national concern, the government can support long-term risk reduction through urban planning policies. State-level policies should therefore concentrate on directing strategies for developing localized information on flooding vulnerabilities and developing institutional capacity for social inclusion in enhancing flood resilience in detail.

We propose that a policy and information-based approach will help improve disaster reduction and mitigation within the investigated socioeconomic group by better connecting policymakers with the realities of informal settlements at the local level. Clear policies for the informal sector are essential for addressing informal settlement issues and building institutional capacity for social inclusion in flood resiliency. As a result, given the lack of critical policy attention on the ground, it is essential also to adopt appropriate policies from other settlements that share the same characteristics of inequality as SA to strengthen the informal settlements' resistance to floods. By offering a systematic analysis of the available data, we contend that implementing appropriate policies on the growth of informal settlements may aid in resolving some of the identified issues.

5.9. Limitations

The limitations of this study are similar to those of relevant academic investigations. Only the Scopus database was used for the study's data. Future attempts at extracting bibliographic data may make use of more databases, such as the Web of Science.

6. Conclusions

This bibliometric analysis attempts to examine the current state and future directions of research on flooding in informal settlements. Keyword Co-occurrence and spatial and evolution analyses of the 249 bibliographic records which were collected from the Scopus database were undertaken to examine and visualize the current state and trends of flooding and informal settlements globally and locally in South Africa. In terms of the theme clusters of flooding and informal settlement research, climate change, disaster management,

knowledge of disasters and disaster prevention, indigenous knowledge among informal settlements, flooding governance, adaptation, local government approach to flooding, local and public participation, coping strategies, stormwater drainage, and vulnerability of informal settlements to flooding obtained the most bibliographic records. Knowledge gaps were found in the areas of upgrading housing and infrastructure, indigenous knowledge, Flood mapping/modeling, green infrastructure, and community participation. The future research agenda was highlighted in light of these knowledge gaps, as indicated in Table 3. For researchers, the community, and practitioners, this study provides an in-depth review of the current status, gaps, and future outlooks of floods in an informal settlement. Following the suggested research gaps, researchers could close knowledge gaps and add to the body of knowledge on flooding among the marginalized informal communities.

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