Application of Analytic Network Process (ANP), Local and Indigenous Knowledge in mapping flood vulnerability in an informal settlement

Garikai Martin Membele (garikaimembele@yahoo.com)
University of Zambia https://orcid.org/0000-0003-1863-5533
Maheshvari Naidu
University of Kwazulu-Natal
Onismo Mutanga
University of KwaZulu-Natal School of Agricultural Earth and Environmental Sciences

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Abstract

In developing countries, informal settlements are mainly located in floodplains and wetlands, hence, they are frequently affected by floods. The objective of this study is to demonstrate a methodological approach that integrates the community members' local and indigenous knowledge and GIS-based Multi-Criteria Decision Making using the Analytic Network Process (ANP) in mapping flood vulnerability in an informal settlement. The study was conducted in Quarry Road West informal settlement located in Durban, South Africa. A mixed-method approach that involved a household survey (n = 359), interviews with key informants (n = 10) and focus group discussions (n = 2) were used in this study. The results of this study showed that there is a spatial differentiation of flood vulnerability in the study area. Households along the Palmiet River were highly vulnerable to flooding. A section of the settlement called Mcondo 1 was also highly vulnerable to flooding while maMsuthu had low flood vulnerability. The sensitivity analysis results showed that changing the indicator weights, correspondingly, affected the output of the flood vulnerability map. Therefore, this study can serve as a guide for decision-makers on how to elicit adequate community participation and comprehensively integrate local and indigenous knowledge with Geographical Information System in mapping flood vulnerability in informal settlements.

1. Introduction

A growing number of countries across the world have been affected by floods due to dense population, inappropriate land use planning and climate change (Cardona, 2004; Gandini et al., 2020; Lin et al., 2019; Myhre et al., 2019). Developing countries however are the most affected. This is due to their poor socio-economic conditions, inadequate financial resources, increased imperviousness, inadequate drainages, poor solid waste management and the construction of houses in flood plains and wetlands (Adelekan, 2010; Asiedu, 2020; Peters-Guarin et al., 2012). In developing countries, most informal settlements are located in sensitive and fragile environments, which makes them susceptible and vulnerable to flood hazards (Abunyewah et al., 2018; Mahabir et al., 2016). According to Roy et al. (2018, p. 283), close to 60% of the informal settlement dwellers in developing countries live in Sub-Saharan Africa and the UN-Habitat (2010) estimates that by 2050, the number of people living in informal settlements will increase to 3 billion. The UN-Habitat (2015) defines an informal settlement as housing areas where people build houses without complying with planning and building regulations, lack basic services and infrastructures and have no security of tenure. There is, therefore, a need to have a critical interest in reducing flood vulnerability in informal settlements, particularly in developing countries because informal settlements accommodate most of the urban dwellers (Duijsens, 2010; Flores et al., 2020; Zerbo et al., 2020).

A review of literature conducted by Membele et al. (2022a) shows that there has been a shift in the way flood vulnerability is considered in developing countries. Flood vulnerability is widely been considered to be integrated because it combines both physical and social vulnerability (Cutter et al., 2003; Ehsan et al., 2022; Paul & Routray, 2010). Integrated flood vulnerability is important because it takes a holistic and interdisciplinary approach crucial in facilitating a complete assessment of flood vulnerability (Barroca et al., 2006). Flood vulnerability is therefore considered as an interrelationship of exposure, sensitivity or susceptibility and adaptive capacity (Chen et al., 2021; Ehsan et al., 2022; Huynh & Stringer, 2018; Roy & Blaschke, 2013; Sahana & Sajjad, 2019). Exposure is defined as the predisposition of a system, community or physical items to impacts of floods due to location (Balica et al., 2012; Ehsan et al., 2022; Hung & Chen, 2013; Sadeghi-Pouya et al., 2017), while sensitivity is defined as the fragility or capacity of a system, individual or community to withstand the impact of flood hazards (Jha & Gundimeda, 2019; Roy & Blaschke, 2013; Yankson et al., 2017). Adaptive capacity is the ability of an individual, system or community to adjust, respond or recover from an adverse impact of floods (Borbor-Cordova et al., 2020; Kienberger, 2012; Roy & Blaschke, 2013). In our view considering flood vulnerability from an integrated perspective facilitates strategic policy formulation and implementation, which are important for sustainable disaster management.

According to Mazumdar and Paul (2018) locating vulnerable people in a community and identifying the reasons for their vulnerability has been a huge challenge for decision and policymakers. Mapping flood vulnerability especially at a local level is crucial because it helps to precisely locate where highly vulnerable people or households are, thereby helping in designing appropriate emergency alternatives and mitigation strategies (Bisht et al., 2018; Hoque et al., 2019; Mazumdar & Paul, 2018; Romanescu et al., 2018).

Therefore, this study was anchored on the ‘place-based’ approach to mapping flood vulnerability (Cutter, 1996; Cutter et al., 2008; Dintwa et al., 2019). According to Dintwa et al. (2019), the feedback mechanism embedded in place-based approaches where an increase or decrease in risk, leads to enhanced or decreased vulnerability, allows it to inform policy and mitigation interventions. Hung and Chen (2013) contend that mapping flood vulnerability is important because it helps to guide decision-makers on how they can prepare and deal with climate change impacts. Furthermore, mapping flood vulnerability enhances the participation of community members (Martin et al., 2018; Membele et al., 2022b; Scheuer et al., 2013; Wilk et al., 2018; Yen et al., 2019). Membele et al. (2022b) argue that local and indigenous knowledge help to foster community participation and the implementation of context-specific adaptation measures. Local and indigenous knowledge is however not the same.

According to Langill (1999), local knowledge is knowledge acquired or possessed by people because of living in a particular community or locality for a considerable period. Indigenous knowledge is a body of knowledge that is uniquely developed and rooted in the culture of a particular area. This knowledge is embedded in people’s way of thinking, skills, technology, culture and social practices and passed on from one generation to the next through repetition or demonstration (Fabiyi & Oloukoi, 2013; Sillitoe, 2007; UNEP, 2008).

However, the use of local and indigenous knowledge in mapping flood vulnerability especially in informal settlements remains underutilised (Dube & Munsaka, 2018; Membele et al., 2021, 2022a), mainly because some practitioners argue that local and indigenous knowledge cannot be scientifically validated. Chanza and De Wit (2016) contend that community members’ situational and experiential knowledge is crucial in mapping flood vulnerability at a local level. Hung and Chen (2013) further argue that the incorporation of local and indigenous knowledge in mapping flood vulnerability especially in developing countries has been a challenge. However, local and indigenous knowledge have been identified to be crucial in dealing with hazards like floods at local levels (Holley et al., 2011; Mavhura et al., 2013; Membele et al., 2021, 2022b; Ziervogel et al., 2016). In particular, the use of indigenous knowledge in helping to protect communities in high-risk areas to build resilience has also been underscored by the Sendai Framework for Disaster Risk Reduction (UNDRR, 2015).

Many strategies have been used to map flood vulnerability in developing countries. The indicator-based Multi-Criterial Decision Making (MCDM) using Analytic Hierarchical Process (AHP) and Geographical Information Systems (GIS) have been widely used in mapping flood vulnerability in developing countries (Abdullah et al., 2021; de Brito & Evers, 2016; Membele et al., 2022a; Rehman et al., 2021). The indicator-based approach is common in mapping flood vulnerability because of its flexibility, trustworthiness, transparency and ability to combine many elements that contribute to making people and places vulnerable to hazards like floods (Balica et al., 2009; Ciurean et al., 2013; Kappes et al., 2012; Nasiri et al., 2016). GIS-based MCDM approaches have been helpful in vulnerability mapping because they have an explicit, rational, spatial and efficient process that leads to justifiable and explainable choices, thus helping to enhance quality decision making (Abdrabo et al., 2020; Ferretti & Pomarico, 2013; Morea & Samanta, 2020).

The AHP developed by Saaty (2007) was widely used in mapping flood vulnerability in developing countries, due to its simplicity, flexibility and ability to structure the decision problem in a hierarchy (Das, 2020; de Brito et al., 2018; Hoque et al., 2018; Msabi & Makonyo, 2021; Roy & Blaschke, 2013). However, Aminu et al. (2014) argue that the AHP considers flood vulnerability elements as separate elements. It is our considered view that the 'separateness of elements' seldom happens in real life because flood vulnerability elements namely exposure, sensitivity and adaptive capacity are interwoven (Akukwe & Ogbodo, 2015; Ebi et al., 2006; Hung & Chen, 2013; Roy & Blaschke, 2013; Yuan et al., 2016). Ghorbanzadeh et al. (2018) further contend that the AHP does not consider multiple alternatives at a time.

One of the MCDM approaches that take into account interdependent elements is the Analytic Network Process (de Brito et al., 2018; Ekmekcioğlu et al., 2022; Esfandi et al., 2022; Ghorbanzadeh et al., 2018; Ghosh et al., 2021). However, studies that used ANP in mapping flood vulnerability, particularly in developing countries and informal settlements in particular are rare (Membele et al., 2022a). A few studies (de Brito et al., 2018; Ishtiaque et al., 2019) that used ANP to map flood vulnerability in developing countries, mapped flood vulnerability at a municipal level and sub-district level respectively, but not at a local and fine scale such as informal settlement. Furthermore, a few studies (de Brito et al., 2018; Ishtiaque et al., 2019) that have used the ANP to map flood vulnerability in a developing country context, used experts or decision-makers and not community members. Hoque et al. (2019) contend that mapping flood vulnerability at a local scale such as an informal settlement by using a multi-criteria analysis approach was crucial in providing detailed and accurate flood vulnerability information needed for decision-making. However, it has been argued that many MCDM studies especially in developing countries suffer from a lack of updated spatial data. To overcome this challenge, collecting accurate spatial data using field surveys were gaining traction in data-scarce environments like developing countries (Akukwe & Ogbodo, 2015; Huq et al., 2020; Lian et al., 2017; Muller et al., 2011; Sarkar & Mondal, 2019; Usman Kaoje et al., 2020).

Therefore, this study demonstrates the integration of community members' local and indigenous knowledge with a GIS-based MCDM using ANP to map flood vulnerability in an informal settlement. In particular, the study was conducted in an informal settlement called Quarry Road West located in Durban, South Africa. The study endeavours to answer the following questions: To what extent can an approach that integrates local, indigenous knowledge and GIS-based MCDM using ANP be used to map flood vulnerability in Quarry Road West informal settlement? How well does the ANP present flood vulnerability in the study area? What areas in the study experience low, moderate and high flood vulnerability? The novelty of this particular study lies in the operationalisation of indicators selected using community members' local and indigenous knowledge in mapping flood vulnerability in an informal settlement (Membele et al., 2022b). This study is also significant because it represents one of the first experiments that used the ANP to map flood vulnerability through the participation of community members living in an informal settlement

2. Methodology

2.1 Description of the study area

Quarry Road West informal settlement is located between Eastings 303250 and 303750, Northings 6701000 and 6701700 in the city of Durban. The informal settlement is about 31,250.84 m^2 in size. The informal settlement is positioned within the Palmiet River Catchment and the Palmiet River cuts across the settlement (see Fig. 1). Furthermore, the settlement is located between the M19 freeway and Quarry Road about 2.7 km from the uMngeni river (Sutherland, 2019). Quarry Road West informal settlement was established 36 years ago when the first occupants settled in a section called maMsuthu (Sutherland, Roberts, et al., 2019). In the early 2000s, the settlement expanded to the other three sections across the flood plain (Mazeka et al., 2019). Most of the people in the settlement were from rural parts of South Africa, mainly from the Eastern Cape and KwaZulu Natal Provinces (Williams et al., 2018). Sutherland, Mazeka, et al. (2019) contend that the people in Quarry Road West informal settlement were politically organised with strong social ties and identity. Like many other informal settlements in developing countries, the number of households in the informal settlement keeps on increasing.

According to Williams et al. (2018), Quarry Road West informal settlement had 931 households in 2017 and in 2019, the number increased to 1100 with over 2400 people (Mazeka et al., 2019). Using an aerial photograph, it can be seen that the number of households (building footprints) increased to over 1200 in 2020. Rapid urbanization in Durban and the effects of climate change have caused economic, social and environmental challenges in Quarry Road West informal settlement (Le Quéré et al., 2020; Williams et al., 2019). Flooding is one of the biggest challenges the informal settlement dwellers were grappling with (Le

Quéré et al., 2020; Mazeka et al., 2019; Williams et al., 2018). Increased impervious surfaces due to a high number of residential and industrial areas as well as the steep slopes in the Palmiet River Catchment exacerbate flooding in the informal settlement (Mazeka et al., 2019; Williams et al., 2018).

According to Williams et al. (2018), Quarry Road informal settlement (like the whole of Durban) experiences a subtropical and humid climate characterised by mild, dry winters and warm as well as wet summers. Mean annual rainfall is over 1000 mm but experts project it to go up by 500 mm.

2.2 Data collection and analysis

The data collection for this study started in October 2020 with key informant interviews. The virtual zoom online platform was used to conduct in-depth interviews with the key informants from the municipality (four) and local university (one). These key informants were selected purposefully based on their knowledge of managing floods in the study area. The zoom platform was used to conduct the interviews due to the Covid-19 restrictions which were implemented by the government in South Africa to reduce physical or human interactions.

In May 2021, physical interactions were allowed by the government hence, household surveys (359), face-to-face interviews and focus group discussions were conducted. Four trained research assistants living in the study area conducted the household survey using Google Forms loaded on mobile devices. The household surveys (359) were preceded by a pilot survey with 36 households. This was done to ensure that there were no distortions during translation from English to isiZulu (local language). The in-depth interviews with community leaders (three) and focus group discussions (two) were conducted face-to-face by the researcher in May 2021, and a trained research assistant translated words that were said in the local language. The focus group discussions were attended by seven community members composed of five females and two males. Although an equal number of males and females were invited in both cases, only two men attended the focus group discussions. This could be because most males were away looking for part-time and only came back home late in the evening. The interview with community members (two) to validate the flood vulnerability map was conducted in March 2022. The household survey, interviews and focus group discussions were conducted with strict adherence to all Covid-19 prevention protocols which included social distancing, sanitizing and wearing of a face mask.

Informed consent was granted by all the participants and the Humanities and Social Sciences Research Ethics Committee in South Africa granted Ethical approval for this study.

This study used mixed methods and the methodological approach applied eight steps. These steps included the identification of stakeholders, structuring of the problem, selection of flood vulnerability indicators, clustering and weighting of indicators, standardization of indicators, aggregation and mapping of flood vulnerability, sensitivity analysis and validation of the flood vulnerability map (see Fig. 3). These steps are explained as follows:

2.2.1. Identification of stakeholders

This step involved the identification of key stakeholders in mapping flood vulnerability in Quarry Road West informal settlement. Four of these key informants were from the eThekwini municipality. These were from the departments of Environmental Planning and Climate Protection, Coastal Stormwater and Catchment Management, Human Settlement and Disaster Management. One key informant was a researcher from the university. These key informants were identified because they have local knowledge of flood vulnerability challenges in Quarry Road West informal settlement as a result of their work. Three key informants were leaders in Quarry Road West informal settlement and two were community members. More community members from Quarry Road West informal settlement participated in the household surveys. The Community members and leaders were identified as crucial stakeholders in mapping flood vulnerability as they possessed both local and indigenous knowledge crucial for mapping flood vulnerability in the informal settlement because they were the ones who experienced the floods. The next step involved identifying the causes of flood vulnerability in the study area.

2.2.2 Structuring of the problem

Designing the decision problem is one of the first and fundamental steps in any decision-making process (Durga Rao et al., 2019). Therefore, with the goal of mapping flood vulnerability in Quarry Road West informal settlement using community members' local and indigenous knowledge, key informants particularly from the eThekwini municipality and the university selected some indicators they considered locally appropriate from the list of indicators that were generated from the literature. These indicators were then used for designing questions for the household survey. The household survey helped to generate the main factors responsible for causing flood vulnerability in Quarry Road West informal settlement. It is worth noting that this study was a continuation of the study conducted by Membele et al. (2022b) in which causes of flood vulnerability and indicators for mapping flood vulnerability were identified using community members' local and indigenous knowledge.

2.2.3 Selection of flood vulnerability indicators

The final set of indicators used for mapping flood vulnerability in Quarry Road West informal settlement was selected by community members during a focus group discussion. The community members used the factors that were found to be responsible for causing flood vulnerability in the study generated from a household survey. The discussants of the focus group discussion then used their local and indigenous knowledge to generate a list of indicators that could be used for mapping flood vulnerability in Quarry Road West informal settlement. Therefore, sixteen context-specific indicators were selected (Membele et al., 2022b). The selected indicators had to be clustered and weighted to establish the significance of each indicator in mapping flood vulnerability in the study area (See Table 2).

2.2.4 Clustering and weighting of indicators

Another focus group discussion was conducted to group the selected indicators into three clusters namely exposure, sensitivity and adaptive capacity. The meaning of each cluster was explained to the discussants. The discussants used their experiential and situational knowledge of floods in the settlement to show how the indicators were related to each other. This process led to the development of a structure to use for mapping flood vulnerability in Quarry Road West informal settlement (See Fig. 2). The links in the developed structure represented both positive and negative interactions. The interdependence of relationships between the indicators was shown by the direction of the arrows. Arrows with double directions showed mutual influence between clusters or indicators while a single arrow showed the dominance of one indicator over another. The loops in the structure indicated inner dependences among the indicators (See Fig. 2).

During the focus group discussion, the community members further used their local and indigenous knowledge of floods in the settlement to generate the influence of each indicator in causing flood vulnerability in the informal settlement. This was done by ranking or assigning percentages to each indicator (see Table 1). The percentages we noted after there was consensus among the discussants. When it was difficult to have consensus, the discussants voted and the majority carried the day. These percentages were later aligned to the ratio of 1–9 developed by Saaty (2007) for use during the pairwise comparison according to the Analytic Network Process. For instance, when comparing an indicator with 12% influence with another indicator with 2%, the number 9 (based on Saaty (2007)'s scale) was assigned to the indicator with 12%. This was because there was evidence that the indicator which had a rank of 12% was extremely important than the indicator which had a 2% influence. Furthermore, when comparing the indicator with 12% influence with another one with 9% influence, the indicator with 12% was assigned a number 3. This was because the indicator with 12% influence was much more important than the indicator with 9% influence. Equal importance was assigned to indicators that had the same percentages. For instance, when comparing proximity to roads and accumulated waste, the number 1 was assigned during the comparison. This was because both indicators had an 8% influence. Therefore, the two indicators contributed equally to the goal.

The ANP in Super Decision Software version 2.10.0 was used for weighting the indicators because it uses a network of feedback and interrelations (Saaty, 2007; Saaty, 2013). Flood vulnerability is also said to be an interrelationship of exposure, sensitivity and adaptive capacity (Akukwe & Ogbodo, 2015; Ebi et al., 2006; Hung & Chen, 2013; Roy & Blaschke, 2013; Yuan et al., 2016). Chang et al. (2015) argue that the ANP provides better results for assigning weights to criteria or indicators because it captures the interdependence of criteria. With the ANP, each cluster was compared against another cluster and each indicator was compared against the related indicator to ascertain the significance of each cluster and indicator over the other (see Fig. 2). Using the weights generated through the pairwise comparison, the unweighted supermatrix, weighted supermatrix, cluster supermatrix and the limit supermatrix were computed automatically in the Super Decision Software. At this stage, a sanity check was conducted in the Super Decision Software to make sure that there were no errors. This study had an average Consistency Ratio of 0.0427. Therefore, the matrix was acceptable because the Consistency Ratio of 0.0427 was less than the standard threshold of 0.1 (Chen et al., 2010; Ghorbanzadeh et al., 2018). The limit supermatrix was then normalized and priorities or weights for each indicator were generated (See Table 1). The cluster for exposure had a normalised weight of 0.61, a sensitivity of 0.27 and an adaptive capacity of 0.12. Because the indicators had different units, standardizing or normalizing them was required.

Table 1
Community members' indicator weights and weights generated using ANP

Cluster	Indicator	Community members weighting	Weight using Pairwise comparison (ANP)
Exposure	Proximity to river	12%	0.2207
	Nature of soil	12%	0.0372
	Amount of rainfall	9%	0.1854
	Flow velocity	9%	0.1814
	Proximity to roads	8%	0.0457
	Accumulated waste	8%	0.0390
	Slope	5%	0
Sensitivity	Type of building material	9%	0.1629
	Average income	5%	0.0093
	Level of education	4%	0.0034
	Land ownership	3%	0.0003
	Drainage system	2%	0.0481
	Population density	2%	0.0050
	Level of unemployment	2%	0.0004
Adaptive Capacity	Social ties	5%	0.0186
	Early warning information	5%	0.0426

2.2.5 Standardization of indicators

Standardizing the indicators is very important because it transforms the indicators with different measurement scales into common units thereby making the analysis meaningful (Shrestha et al., 2016).

Most of the spatial data used in this study were captured from the sampled households using a Global Positioning System (GPS) during fieldwork conducted in May 2021. The sampled households were spread across the four sections of Quarry Road West informal settlement. This was to ensure that updated and accurate data were captured for mapping flood vulnerability in the study area. This was also done to overcome the unavailability of high-resolution spatial data in the informal settlement (Hoque et al., 2019; Kienberger, 2012; Membele et al., 2022a).

A Spatial Join in ArcGIS Pro 2.6 was used to join the attributes from the GPS to the building footprints which were digitized from a very high resolution (0.01m x 0.01m) aerial photograph. Then the joined building footprints were spatially joined with a 1m x 1m fishnet which covered the whole study area. Then spatial queries were used to create vector layers for each indicator. The aerial photograph, soils and elevation data were provided by the eThekwini municipality while the rainfall data was provided by the South African Weather Services. The data from the municipality and the South African Weather Services were converted into one projection system (WGS 84 UTM Zone 36s) to have better results during the overlay analysis. The clip function in GIS was used to extract data for the study area.

The indicators were then analysed using various GIS operations. The spatial buffer was used for indicators like proximity to the river, proximity to main roads and drainage system. Flow velocity was generated by calculating flow accumulation from a Digital Elevation Model (DEM) and the reclass function was used to estimate the hydraulic radius. Then Manning's N was generated from a land cover dataset with a resolution of 10 x 10m raster pan-sharpened from the Sentinel 2 imagery (Kaplan, 2018). The Manning' N equation was then used to calculate the flow velocity of the study area (see Eq. 1).

$$V = \left(\frac{R_h^{\frac{2}{3}} * \sqrt{S}}{N} \right) \tag{1}$$

Where V is the Flow velocity, R_h is the Hydraulic radius, S is the slope in per cent and N is Manning's constant (Murwira et al., 2015).

Since each indicator or data layer had different attribute classifications, units and values, they had to be converted into a common scale. Value functions also called fuzzy functions in ArcGIS Pro 2.6 of 0 (low flood vulnerability) to 1 (high flood vulnerability) was used to reclassify all the spatial data layers into a common scale. The assignment of value functions to the attributes was done during a focus group discussion with community members. An explanation was given to the discussants on the meaning of every attribute and how it increased or decreased flood vulnerability. The standardized vector layers were then converted to 1m x 1m raster files for subsequent aggregation and mapping of flood vulnerability.

2.2.6 Aggregation and mapping of flood vulnerability

This stage involved combining the 15 indicators to create a composite flood vulnerability map for the study area. The weighted sum in ArcGIS Pro 2.6 was used to combine the indicators based on their assigned weights (see Table 2). The weighted sum was used because it allows assigning negative and positive weights to indicators (Abdelkader & Delali, 2012). In this study, two indicators namely early warning information and social ties were given negative values during the aggregation process because the adaptive capacity (early warning information and social ties) reduces flood vulnerability, while exposure and sensitivity increase flood vulnerability hence they were given positive values. Therefore, the more adaptive capacity, the lower the level of flood vulnerability in that area (Kissi et al., 2015; Yankson et al., 2017). The final flood vulnerability map had values ranging from 0 to 1, where the low value represented low flood vulnerability and higher values corresponded to high flood vulnerability (see Fig. 4).

2.2.7 Sensitivity analysis

To ascertain the robustness of the flood vulnerability map, a sensitivity analysis was conducted. This was done by altering the weight of the indicators and then assessing the output of the flood vulnerability map. In particular, sensitivity analysis was conducted by assigning equal weight to all the indicators (see Fig. 5b). Another sensitivity analysis was conducted by assigning positive values to adaptive capacity indicators which were initially assigned negative values (see Fig. 5c).

2.2.8 Validation

This study used quantitative and qualitative methods to validate the final flood vulnerability map. The quantitative method involved overlaying the flood vulnerability map with the affected households on the 1:100 years flood line. The 1: 100 years flood line was provided by the eThekwini municipality. The qualitative method involved two community members who had lived in the informal settlement for more than ten years. These community members were independently availed with the final flood vulnerability map overlaid on the aerial photography. This was done to help the community members to have a proper orientation of the study area. Then an explanation was given of the meaning of the colours on the map. The community members were separately asked if the map represented the flood vulnerability situation of the informal settlement. Using their local and indigenous knowledge of floods in Quarry Road West informal settlement, the community members validated the maps.

3. Results

The spatial distribution of flood vulnerability in the study area showed that the area or households close to the Palmiet River were highly vulnerable to flood hazards (see Fig. 4). Using community members' local and indigenous knowledge in the weighting of indicators for mapping flood vulnerability in the study area revealed that the most influential or important indicators for mapping flood vulnerability in the informal settlement were proximity to river (22% of importance), amount of rainfall (19% of importance), flow velocity (18% of importance) and type of building material (17% of importance) (see Table 1). The results also showed that the effect of proximity to main roads, nature of soil and drainage system had a low to moderate influence on flood vulnerability in the settlement.

Table 2
Household levels of flood vulnerability in the four sections of Quarry Road West informal settlement

Section name	Low vulnerability	Moderately vulnerable	Highly vulnerable
Mcondo 1	35	207	119
Mcondo 2	135	253	80
maMsuthu	176	70	45
Mapondweleni	42	54	47
Total	**388**	**584**	**291**

Zonal Statistics conducted in Arc Pro 2.6, from the composite or final flood vulnerability map showed that a section of the settlement called Mcondo 1 had the highest number of households highly vulnerable to flooding. Mcondo 2 had the highest number of households moderately vulnerable to flooding, while maMsuthu had the highest number of households with low flood vulnerability (Table 2). The results also show that close to 50% of households in Quarry Road West informal settlement were moderately vulnerable to flood hazards and 31% of households had low flood vulnerability.

The results of the final flood vulnerability map (See Fig. 4 and Fig. 5a) were compared with results obtained from altering indicator weights during the sensitivity analysis. The results of assigning equal weight to indicators showed a huge increase in the number of households moderately vulnerable to floods. It also showed a decrease in the number of households with high and low flood vulnerability (see Fig. 5b). Assigning positive values to adaptive capacity indicators (social ties and early warning information) showed an increase in the number of households with low flood vulnerability (see Fig. 5c). The results also showed a decrease in the number of households moderately vulnerable to flooding. The results of the three flood vulnerability maps were therefore different.

The final flood vulnerability map was validated in two ways. The results validating the flood vulnerability map and the affected households on the 1:100 years flood line showed that 134 households in Quarry Road West informal settlement were outside the flood line. Of these, the majority (70%) of the households had low flood vulnerability and were mainly located in maMsuthu. The two community members who also validated the flood vulnerability using their local and indigenous knowledge expressed satisfaction with the output of the flood vulnerability map. They stated that Mcondo 1 indeed had the highest number of households highly vulnerable to floods and that maMsuthu had a low number of venerable households in Quarry Road informal settlement. They also stated that the map rightly showed that the main entrance to the settlement was regularly flooded and therefore the households around that area were also highly vulnerable to floods.

4. Discussion

The study has demonstrated how a methodological approach that integrates the participation of community members by using their local and indigenous knowledge with the GIS-based MCDM Analytic Network Process approach comprehensively mapped flood vulnerability in Quarry Road West informal settlement with a higher degree of reliability and legitimacy. The ANP approach was found to be very effective in modelling complex interrelationships of elements used for mapping flood vulnerability in Quarry Road West informal settlement. The feedback and dependences inherent in the ANP allow it to handle complex and multi-dimensional problems (Esfandi et al., 2022; Feyzi et al., 2019; Ghaemi Rad et al., 2018; Wu et al., 2018). Several scholars (Akukwe & Ogbodo, 2015; Ebi et al., 2006; Hung & Chen, 2013; Membele et al., 2021; Roy & Blaschke, 2013; Yuan et al., 2016) argue that flood vulnerability was multi-dimensional and was based on an interrelationship of exposure, sensitivity and adaptive capacity. Therefore, using the ANP approach provided a better opportunity to mimic what took place in the real world (Anand & Kodali, 2009), which in turn, provides better and more reliable results for mapping flood vulnerability in the study area. This could explain why de Brito et al. (2018) recommended the use of the ANP in mapping complex problems like flood vulnerability. However, Ghorbanzadeh et al. (2018) criticise the ANP for its high uncertainty and ability to marginalize community members due to its reliance on expert opinions. We are of the considered view that this weakness was overcome in this study by using community members' local and indigenous knowledge in the flood vulnerability mapping process. Ferretti and Pomarico (2012) argue that using the ANP helps to generate reliable results because stakeholders involved in using ANP tend to have a cautious reflection of the problem and priority of the mapping process.

Furthermore, this methodological approach successfully displayed the levels and spatial extent of flood vulnerability in the study area. This is crucial for monitoring the level of flood vulnerability over time and for implementing strategic decisions (Thanh Thi Pham et al., 2020). According to Hung and Chen (2013), interventions aimed at reducing flood vulnerability should be focused on areas that have the highest vulnerability or areas clustered spatially. Yankson et al. (2017) further argue that the lack of information on the levels of flood vulnerability in an area adversely affects the implementation of local adaptation plans. In this study, flood vulnerability reduction efforts should start with areas along the Palmiet River and the M19 bridge in Mcondo 1 as these were areas highly vulnerable to floods. This study, therefore, enhances the understanding of areas that need immediate intervention in terms of reducing flood vulnerability in the study area.

The methodological approach used in this study also provides a participatory and comprehensive approach for mapping flood vulnerability in an informal settlement context by integrating community members' local and indigenous knowledge. de Brito and Evers (2016) argue that the participation of different stakeholders in mapping flood vulnerability especially in developing countries was fragmented. In South Africa, a literature review conducted by Membele et al. (2021) found that community participation in mapping flood vulnerability in informal settlement contexts was fragmented and mainly ended with community members responding to questions asked to them during interviews and questionnaires were administered to them. Therefore, this study has demonstrated how community members could adequately participate in mapping flood vulnerability. In this study, community members participated by using their local and indigenous knowledge in identifying factors that were responsible for making people vulnerable to flood hazards, selecting locally appropriate indicators, assigning weights to indicators and validating the flood vulnerability map. The participation of informal settlement dwellers who have for a long time been marginalized in mapping flood vulnerability in informal settlements, particularly in developing countries is crucial in promoting ownership, resilience and sustainable disaster risk reduction in informal settlements (Botha & van Niekerk, 2013; Hedelin et al., 2017; Membele et al., 2021; Scheuer et al., 2011; Wilk et al., 2018; Williams et al., 2018). Furthermore, reducing flood vulnerability in informal settlements is crucial because it contributes to achieving Sustainable Development Goals (SDGs), particularly number 11 which relates to making cities and human settlements safer, resilient and sustainable (United Nations Development Programme, 2022). It is our considered view that community participation in mapping flood vulnerability was enhanced by using the informal settlement dwellers' local and indigenous knowledge. In urban studies and informal settlements, in particular, indigenous knowledge has been underutilised in mapping flood vulnerability (Dube & Munsaka, 2018; Kasei et al., 2019). Furthermore, a review of literature conducted by Membele et al. (2022a) found that there was limited use of indigenous knowledge in mapping flood vulnerability in developing countries, yet the Sendai Framework for Disaster Risk Reduction 2015–2030 and the World Conference on Disaster Reduction held in Hyogo, Japan and have repeatedly called for the use of indigenous knowledge in disaster risk reduction even in urban areas (UNDRR, 2005, 2015). According to Bernatchez et al. (2011), local and indigenous knowledge provide an in-depth understanding of factors that influence flood vulnerability in a particular area, which helps decision-makers know what to do to improve people's adaptive capacity and resilience. Furthermore, unlike Ngie (2012) who independently analysed and compared the community's indigenous knowledge on floods and a flood vulnerability map produced using GIS in Diepsloot, Johannesburg, this study has demonstrated how the special attributes of local and indigenous knowledge could be combined with a GIS-based MCDM approach at once to map vulnerability in Quarry Road West informal settlement. Furthermore, to the best of our knowledge, this study is one of the first to comprehensively integrate local and indigenous knowledge in mapping flood vulnerability in an informal settlement context using the MCDM ANP approach.

This study revealed that the Quarry Road West informal settlement was highly exposed and sensitive to flood hazards and that the adaptive capacity of the people in the community was low albeit significant in helping people to reduce their flood vulnerability so a certain extent. This study also found that proximity to the river, amount of rainfall, flow velocity and type of building material significantly influenced the level of flood vulnerability in the informal settlement. In most studies, exposure is considered a major contributor to the vulnerability of people to flood hazards in many areas (Hoque et al., 2018; Hung & Chen, 2013; Sadeghi-Pouya et al., 2017). Ochola et al. (2010) also found that proximity to the river, amount of rainfall, flow velocity, soil type, elevation and type of building materials were influential in causing flood vulnerability in Kenya's Nyando River catchment. The study conducted by Ochola et al. (2010) differs from this study in that soil type and elevation were not considered to be highly influencing flood vulnerability in Quarry Road West informal settlement. This further speaks to the ability of the ANP to allow stakeholders to have a careful reflection and understanding of the decision problem, thereby selecting and assigning weights appropriately (Ferretti & Pomarico, 2012). de Brito et al. (2018) in Brazil found that households with improper building materials followed by the number of evacuation drills and training were the most important indicators for mapping flood vulnerability. Similar to this study, Aksha et al. (2020) conducted a study in Nepal that found that areas along the Sardu and Seuti Rivers had the highest level of flood vulnerability. This was because households and areas close to the river tend to be prone to increased flow velocity and erosion of the river banks, which caused the floodwater to enter the houses and in many cases made dwellings collapse (Membele et al., 2022b). Since many people in informal settlements, especially in developing countries live in fragile environments such as flood plains and wetlands (Adelekan, 2010; Asiedu, 2020; Peters-Guarin et al., 2012), the projected increase in the frequency and intensity of rainfall due to climate change (Cardona, 2004; Myhre et al., 2019) will make more informal settlements dwellers highly vulnerable to flood hazards. In Quarry Road West informal settlement, in particular, moderately vulnerable households will become highly vulnerable to flood hazards, particularly if nothing is done to increase the community’s adaptive capacity. Therefore, in an event that many people in the settlement became highly vulnerable to flooding, very few people in Quarry Road West informal settlement will be in a position to help their friends or neighbours during a flood. This situation will, in turn, weaken the strong social ties that the residents have for a long time used to deal with floods.

The results of this study showed that flood vulnerability in the settlement was spatially differentiated. A section called maMsuthu had a low number of households vulnerable to flood hazards. This is because, unlike the other three sections, maMsuthu was located on a mound that was not within the 1:100-year flood line (Mazeka et al., 2019). This explains why the first occupants of Quarry Road West informal settlement did not settle anywhere else in the settlement but they settled in maMsuthu. The results of this study also showed that there were other pockets or areas in the informal settlement with low flood vulnerability (see Fig. 4). Notwithstanding the locational advantage of Quarry Road West to economic opportunities for the residents (Mazeka et al., 2019), this situation (pockets of low flood vulnerability) could explain why some residents went back to the informal settlement despite them having been relocated to an area called Parkgate which had better housing. Furthermore, one of the main reasons why Mcondo 1 was highly vulnerable to flooding is that the section is close to the M19 bridge, and when the calvets under the bridge got blocked due to the accumulation of waste, the water easily found its way to Mcondo 1 (Membele et al., 2022b). Poor solid waste management has been identified as one of the major causes of flooding not only in Quarry Road West informal settlements but also in other informal settlements in many developing countries (Asiedu, 2020; Mazeka et al., 2019; Williams et al., 2018).

Updated and accurate spatial data in most developing countries was a challenge, especially in informal settlements (Hoque et al., 2019; Hoque et al., 2018; Kienberger, 2012; Membele et al., 2022a). Therefore, most of the spatial data used in this study were captured with a GIS while administering the household survey. This was to ensure that updated and accurate data were captured. Capturing spatial data this way could be expensive especially if the area was big, it is, however, one of the best ways for generating updated, accurate and fine resolution data (de Andrade & Szlafsztein, 2015; Kienberger, 2012).

The Sensitivity analysis helped to check whether or not a change in criteria weights affected the output (Chen et al., 2010; Crosetto et al., 2000; de Brito et al., 2019). According to Ferretti and Montibeller (2016) conducting a sensitivity analysis in mapping, flood vulnerability increased the transparency of the results. However, sensitivity analysis was lacking in most studies that mapped flood vulnerability in developing countries (Membele et al., 2021, 2022a). After conducting a sensitivity analysis, this study found that assigning positive values to adaptive capacity indicators (initially assigned negative values) and assigning equal weights to all indicators changed the output of the flood vulnerability maps. This showed that the flood vulnerability map was robust, reliable and accurate. It can therefore be used to support decision-making and formulation of policies and plans for reducing flood vulnerability in Quarry Road West informal settlement.

The lack of accurate and updated spatial data has also been identified to negatively affect the validation of flood vulnerability maps in developing countries (Membele et al., 2022a). In this study, the 1:100 years flood line and two community members using their local and indigenous knowledge of flood in the informal settlement validated the final flood vulnerability map. Rincón et al. (2018) contend that validating flood vulnerability maps helped to enhance the legitimacy and usability of the maps. Mahmoody Vanolya et al. (2019) contend that validation increased the acceptance of the results by the general public. Membele et al. (2022a) contend that validating flood vulnerability maps was crucial if the maps were to inform decision-making. However, Fekete (2009) argues that independent datasets to use to validate flood vulnerability maps were scarce in many areas, hence many studies did not validate their maps. A few studies that validated their maps used various approaches. Roy and Blaschke (2013) used depth measurements to validate their flood vulnerability map, while Seekao and Pharino (2016) used actual flood events, de Brito et al. (2018) used expert knowledge and Hoque et al. (2019) used community members and other stakeholders. Mahmoody Vanolya et al. (2019) used Public Participation GIS (PPGIS) to validate GIS-MCDM results. Hoque et al. (2019) contend that qualitative validation of flood vulnerability maps by community members was also acceptable, especially in developing countries where high temporal and spatial resolution data was a challenge.

5. Conclusion

This study has demonstrated a novel and comprehensive methodological approach that integrates community members' local and indigenous knowledge with the GIS-based MCDM ANP approach in mapping flood vulnerability in an informal settlement in Durban South Africa. This approach jointly used the beneficial and inherent attributes of local, indigenous knowledge and the GIS-based MCDM approach to map flood vulnerability in the study area. The ANP approach was found to be effective in modelling the complex interrelationships of elements and indicators for mapping flood vulnerability. This led to the mapping of flood vulnerability reliably and transparently. It is, therefore, our considered view that the identification of households or areas vulnerable to flood hazards in Quarry Road West informal settlement should not be an end in itself, but rather it should enable decision-makers from the municipality and other stakeholders to work hand in hand with the community members in finding ways to improve people's adaptive capacity and resilience to flooding in the informal settlement. Failure to come out with any intervention will adversely affect many people as moderately vulnerable households will become highly vulnerable to flooding, especially due to the expected increase in the frequency and intensity of rainfall as a result of climate change. Furthermore, the study has revealed that flood vulnerability in Quarry Road West informal settlement in South Africa is spatially differentiated. This means that there are areas with low, moderate and high flood vulnerability. Therefore, any relocation programme in the settlement should take this into account to avoid decision-makers using a 'one-size-fits-all' approach. The methodological approach demonstrated in this study can be utilized in similar environments or adapted by selecting context-specific indicators and weights. Although used on flood vulnerability, this approach can be used for another type of hazard. Furthermore, this approach can be used as a tool for monitoring flood vulnerability, emergency preparation and spatial planning as well as flood risk management.

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Figures

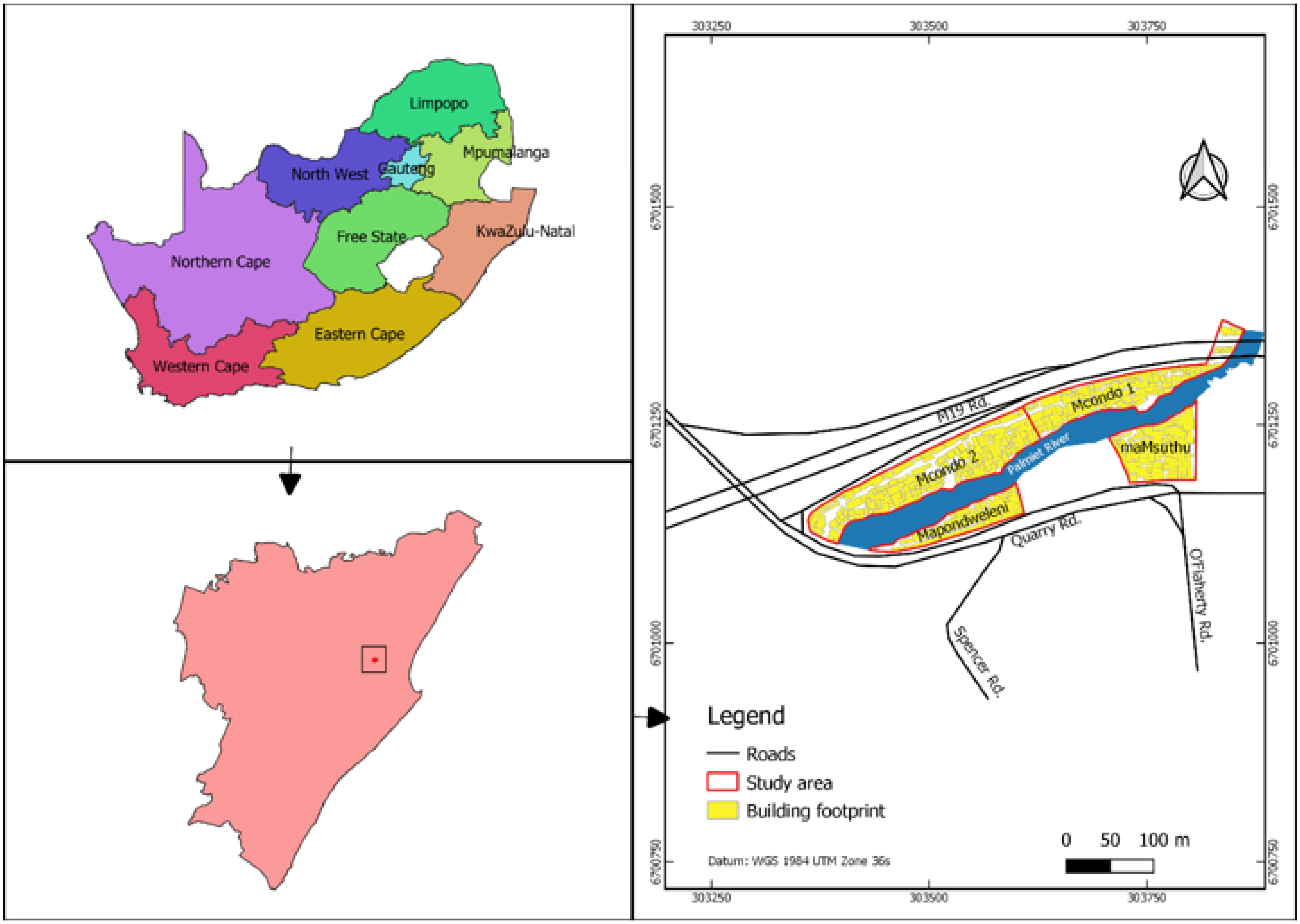

Figure 1

Quarry Road West informal and the three sections

(Source: Authors)

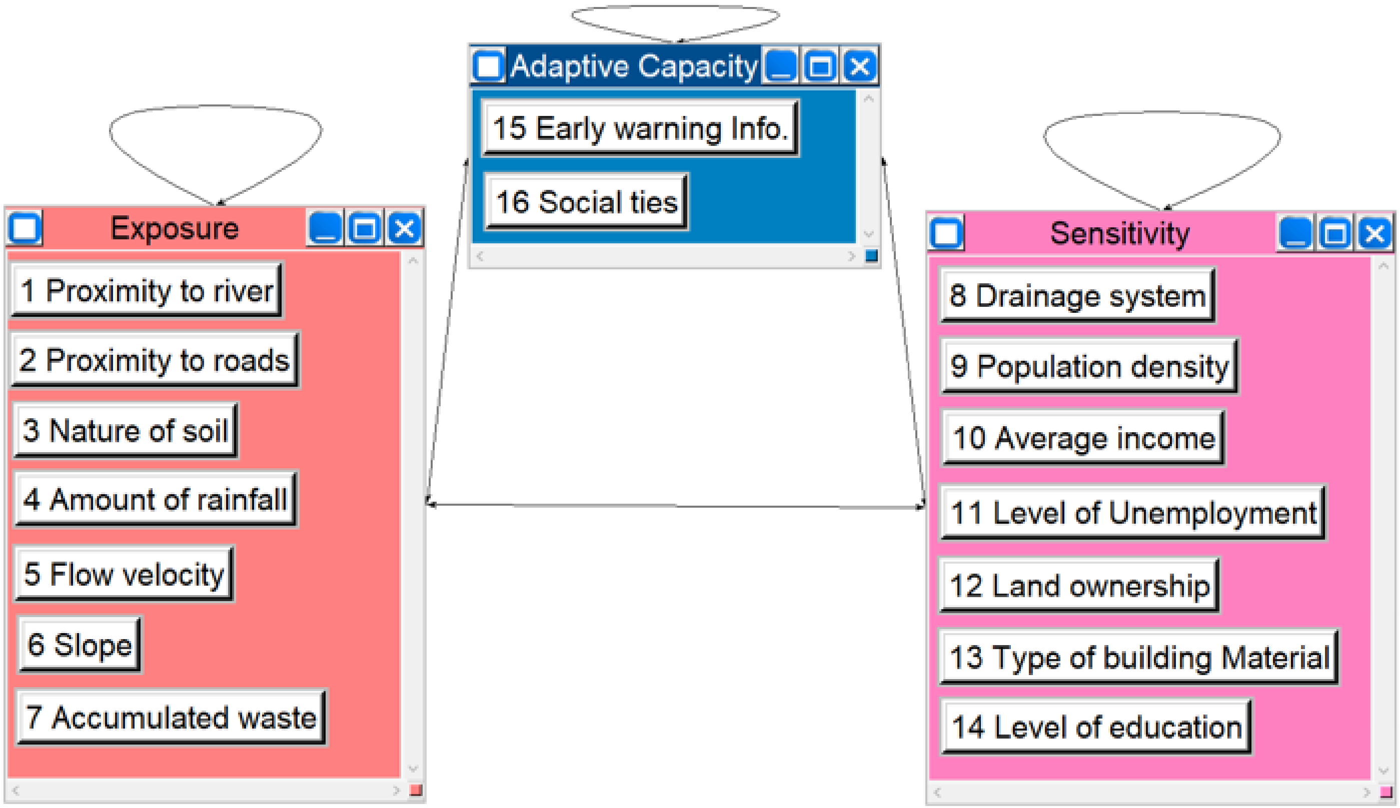

Figure 2

Analytic Network Process structure used to map flood vulnerability in this study

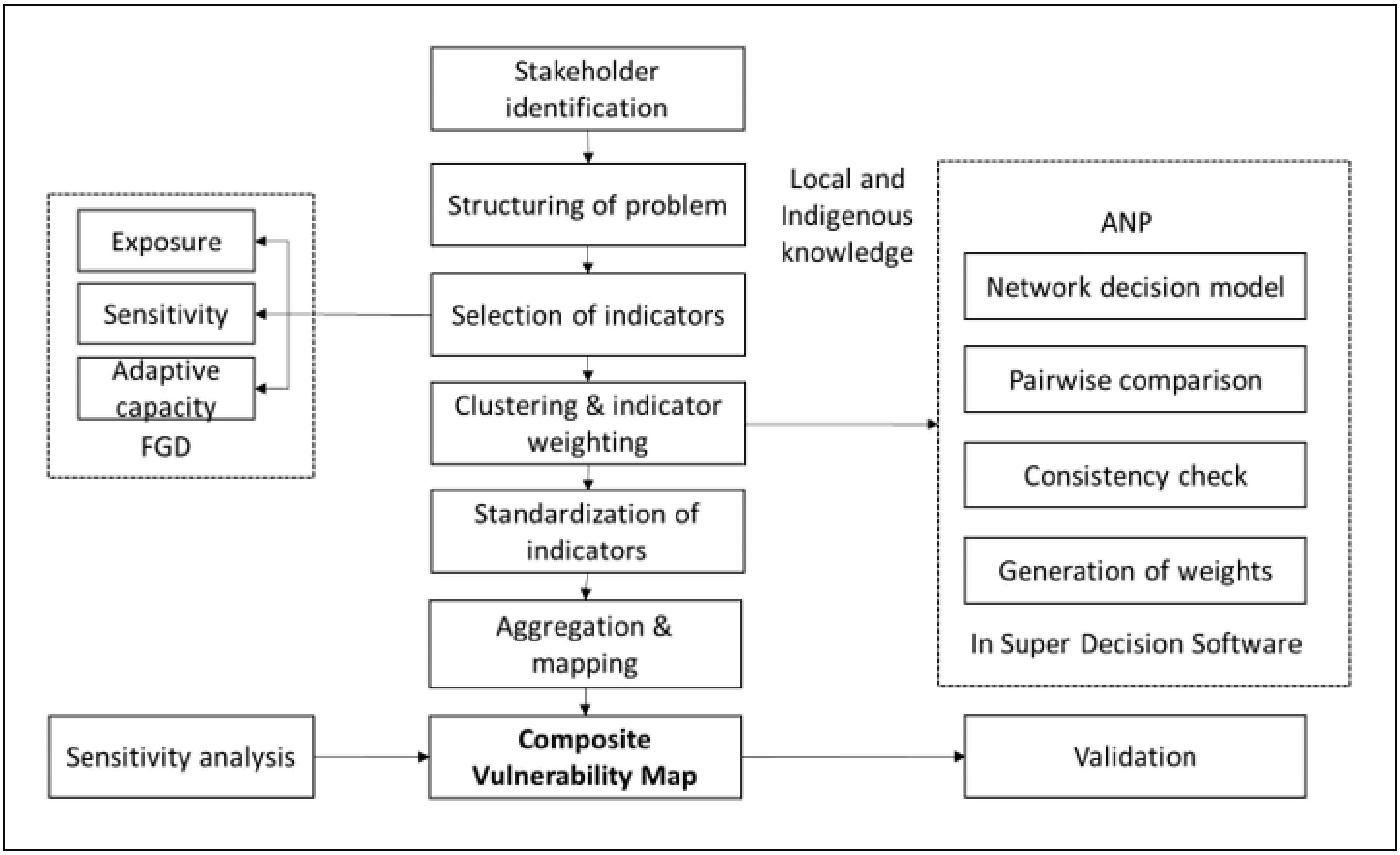

Figure 3

Schematic representation of the methodological approach applied in this study

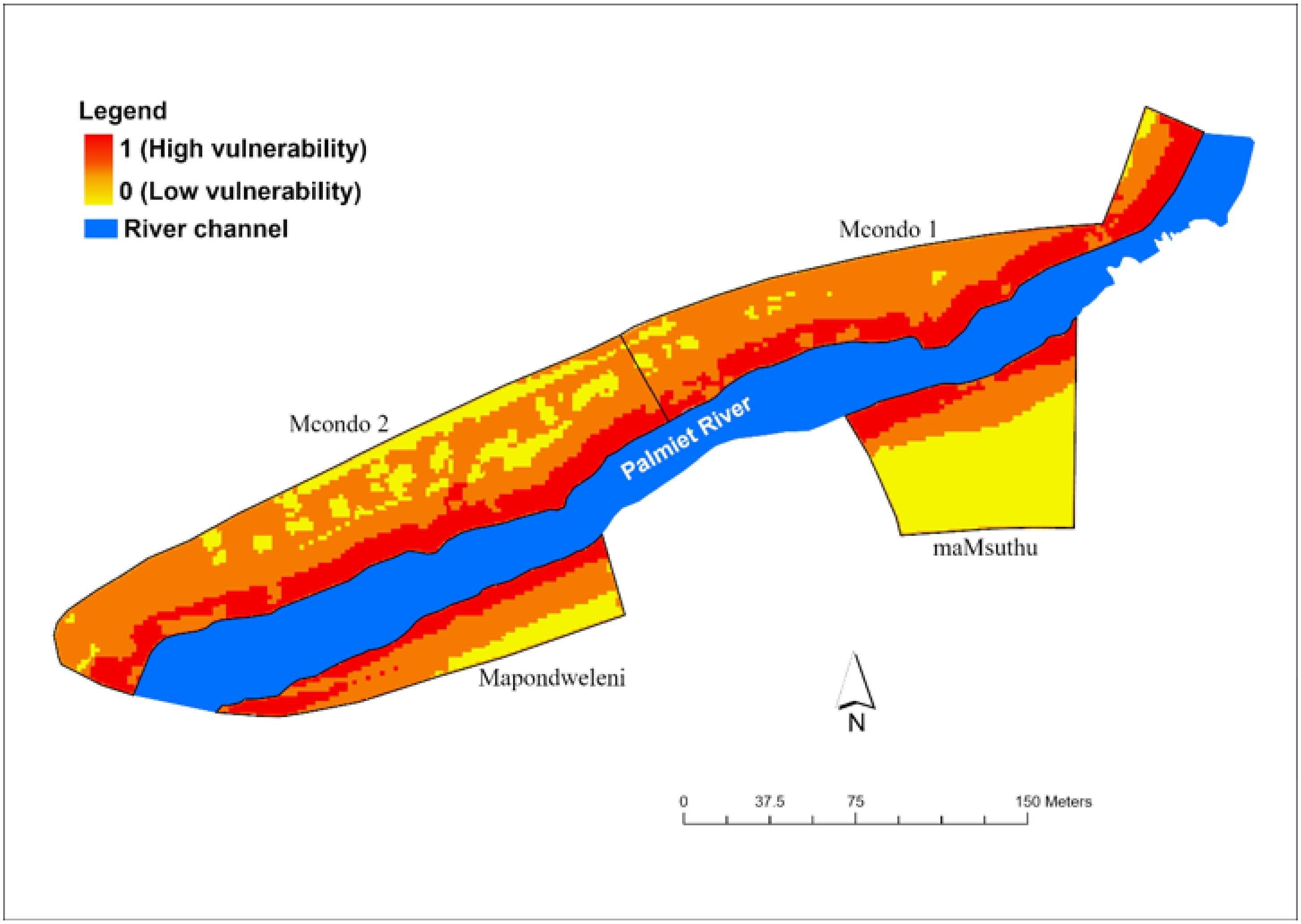

Figure 4

Final flood vulnerability map

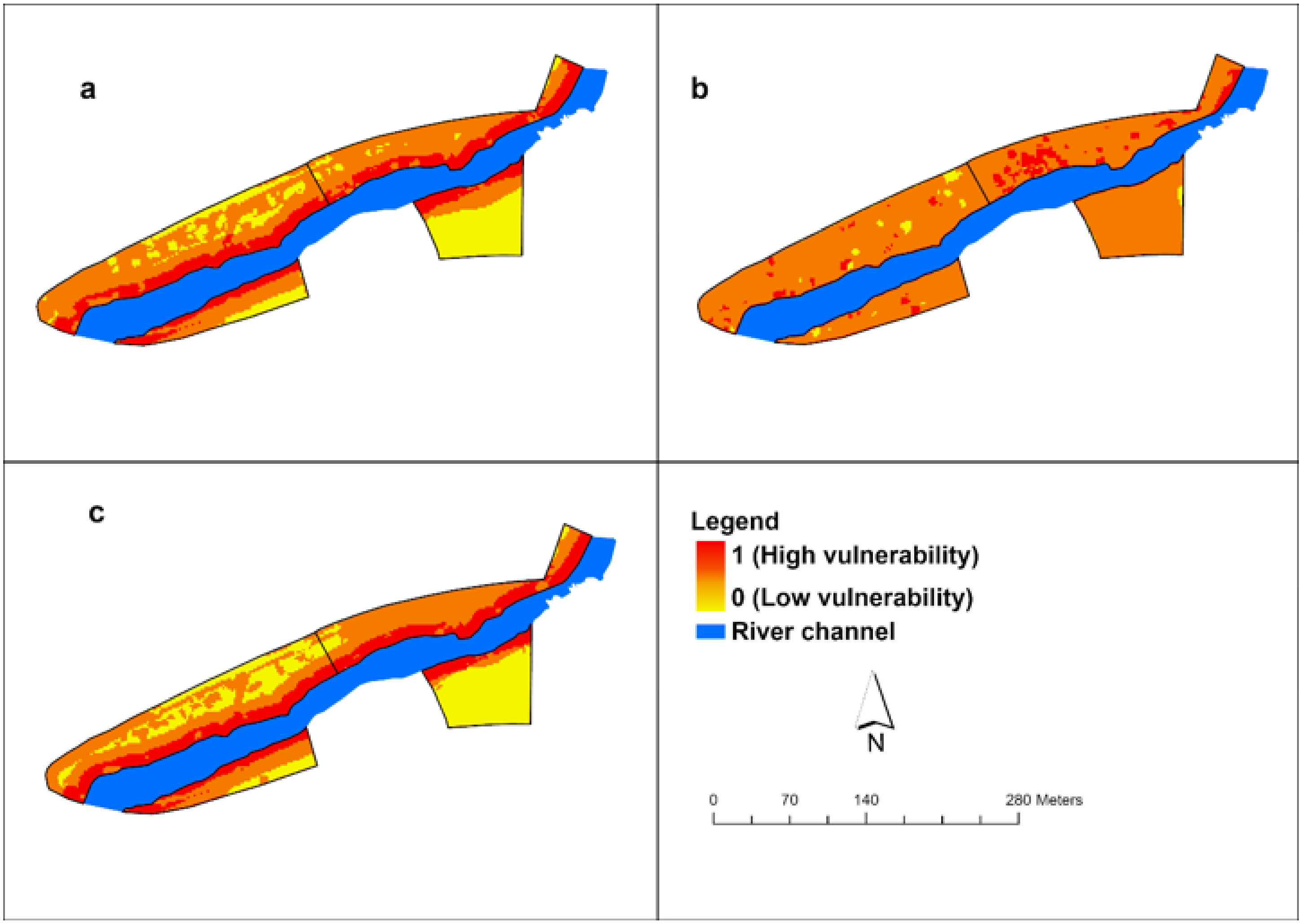

Figure 5

Sensitivity analysis of the flood vulnerability map. Figure 5a. Final flood vulnerability map with adaptive capacity indicators based on negative values for adaptive capacity. Figure 5b Flood vulnerability map based on equal weights and Figure 5c. Flood vulnerability based on using positives values for all indicators