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Vulnerability and Adaptation to Flood Hazards in Rural Settlements of Limpopo Province, South Africa

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Abstract: Climate change has increased the frequency of extreme weather events such as heavy rainfall leading to floods in several regions. In Africa, rural communities are more vulnerable to flooding, particularly those that dwell in low altitude areas or near rivers and those regions affected by tropical storms. This study examined flood vulnerability in three rural villages in South Africa's northern Limpopo Province and how communities are building resilience and coping with the hazard. These villages lie at the foot of the north-eastern escarpment, and are often exposed to frequent rainfall enhanced by orographic factors. Although extreme rainfall events are rare in the study area, we analyzed daily rainfall and showed how heavy rainfall of short duration can lead to flooding using case studies. Historical floods were also mapped using remote sensing via the topographical approach and two types of flooding were identified, i.e., those due to extreme rainfall and those due to poor drainage or blocked drainage channels. A field survey was also conducted using questionnaires administered to samples of affected households to identify flood vulnerability indicators and adaptation strategies. Key informant interviews were held with disaster management authorities to provide additional information on flood indicators. Subsequently, a flood vulnerability index was computed to measure the extent of flood vulnerability of the selected communities and it was found that all three villages have a 'vulnerability to floods' level, considered a medium level vulnerability. The study also details temporary and long-term adaptation strategies/actions employed by respondents and interventions by local authorities to mitigate the impacts of flooding. Adaptation strategies range from digging furrows to divert water and temporary relocations, to constructing a raised patio around the house. Key recommendations include the need for public awareness; implementation of a raft of improvements and a sustainable infrastructure maintenance regime; integration of modern mitigations with local indigenous knowledge; and development of programs to ensure resilience through incorporation of Integrated Development Planning.

Keywords: flood risk; exposure; susceptibility; resilience; flood vulnerability index; adaptation

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1. Introduction

Floods are characterized as some of the most severe, dangerous and harmful natural hazards [1] causing loss of lives and livelihoods, disrupting socio-economic activities and damaging infrastructure. Floods may result from high run-off or a rise in water levels in a particular area that is more than what that environment can contain [2,3], and are regular and recurring risks to society [4]. They cause more economic losses in the world than any other natural hazard and are a major risk to Gross Domestic Product (GDP) [5]. Economic costs result not only from damages to infrastructure and property, but also include disaster relief efforts towards individuals and businesses. Some floods may also be compounded by poor drainage and culvert designs, poor siting, location of settlements and topographic forces, which are key determinants of vulnerability. Despite these factors, one of the immediate causes of flooding is the occurrence of extreme/intense rainfall in a short duration. Rainfall intensity, volume, timing, and antecedent conditions of rivers and their drainage basins, in addition to human encroachment into flood plains and lack of flood response plans increase the damage potential [6].

There is evidence that the numbers of people affected and economic damages due to flooding are rising at alarming rates [7,8]. This rise is exacerbated by global climate change, as severe storms associated with strong winds and flooding have become more frequent. Climate change has caused greater variability in precipitation patterns, increased intensification and frequent occurrences of natural hazards [9], increasing the risk of flooding in several regions. Floods are very contextual, suggesting that their impacts and social vulnerability depend on specific circumstances [10] and may vary from region to region, usually being more severe in developing communities [11]. This contextually emphasizes the great need for flood risk vulnerability assessments at all spatial scales.

South Africa is exposed and susceptible to flood hazards and the most vulnerable provinces are the Eastern Cape, Kwa-Zulu Natal, the North-West and Limpopo which are largely rural [12]. Zuma et al. [13] calculated the risk of flooding in South Africa and found an 83.3% chance of floods occurring in a given year. They also determined that levels of vulnerability are generally high mainly due to socio-economic and geographical factors. It has been found that rural settlements and infrastructure located in valleys and wetlands are more vulnerable to flood risks and disasters [3]. The effects of population growth, settlement developments and expansion of the rural-urban hinterland have also worsened the magnitude and frequency of flooding or ponding. Poor rural communities are more exposed and have become susceptible or sensitive to flood hazards. In some rural areas of South Africa, flood events disrupt transportation on gravel roads with downstream effects on several socio-economic activities [14].

We focus on the country's northern Limpopo province which receives most rainfall during the austral summer months [15,16], but for which the rainy season may extend from October to April. The main source of rainfall during this period is associated with moisture flux inflow mainly from the warm southwest Indian Ocean [17]. Most of the extreme rainfall events over the region are attributed to rain-bearing weather systems such as cloud bands, tropical lows, mesoscale convective complexes and cut-off lows [16]. Cloud bands form along tropical-temperate troughs (TTTs) that extend from the tropics to the mid-latitudes and produce nearly half of the seasonal rainfall over the summer rainfall region of South Africa [18]. Slow moving cloud bands can dump heavy rainfall as they propagate eastwards through Limpopo towards Madagascar via the Mozambique Channel. The occasional landfall of tropical cyclones (identified as tropical lows over land) over southern Mozambique during the late summer is also linked to heavy rainfall and flooding in the province.

Floods due to ex-tropical cyclone Eline in 2000 and continental tropical lows in 2011, 2013 and 2014 have raised various concerns regarding flood vulnerability and preparedness in South Africa's north-eastern interior. A more recent flood event occurred in Thohoyandou, northeast of South Africa during February 2019 after extreme precipitation (~300 mm/4 h) associated with a major cloud band [15]. A nearby shopping mall was inundated with flood waters such that some vehicles were stagnated, raising concerns of poor siting and drainage. It was found that the interaction of a low-level jet with a nearby mountain range compounded the heavy rainfall and flooding in the area [15]. Thus, this region is highly vulnerable to flooding from extreme rainfall, which may be exacerbated by climate change. It is also in the Limpopo Province that climate change models project a strong signal of warming in the future climate, e.g., [19,20]. The latest projections from the Intergovernmental Panel on Climate Change (IPCC) Assessment Report Six suggest (with high confidence) increased frequency of heavy precipitation over South Africa in future [20].

From season to season, the climate of South Africa's Limpopo Province is also influenced by remote phenomena from hot spots in the Indian and Pacific Oceans. The El Niño Southern Oscillation (ENSO) is a dominant phenomenon that regulates the occurrence of extreme events such as droughts, heat waves and floods in the region [17,21]. El Niño events over the equatorial Pacific Ocean are mostly linked to dry and hot austral summers over the northeastern interior of the country [22–24]. During this time, fewer cloud bands form, leading to below normal rainfall over the southern African subcontinent [15]. The circulation becomes largely anticyclonic characterized by subsidence induced a strong mid-troposheric Botswana High [25]. In contrast, most La Niña events have been linked to positive rainfall anomalies in the region [26], with enhanced moisture flux from the southwest Indian Ocean. Hence, the risk of flooding is enhanced during La Niña events in the northeast of South Africa. The occurrence of La Niña has also been linked to high/extreme streamflow events in several other regions in the tropics [27–29], which increase the risk of riverine flooding. Due to its warm climate, the Limpopo Province is also vulnerable to climate-sensitive diseases such as malaria, which often peak after a flood event. After floods, ponds create conducive conditions for breeding of *Anopheles arabiensis* mosquitoes, which are the common species transmitting malaria in the area [30,31]. Cholera outbreaks also occur in Limpopo following flood events as many rural communities do not have piped/reticulated water supply. Thus, flood events also put human health, lives and livelihoods at risk, as water-borne and vector-borne diseases become more likely. Tourism is a major economic activity in the province due to large areas of wildlife/game parks, including the renowned Kruger National Park and the Mapungubwe National Park. When floods occur, huge economic losses are incurred by the tourism sector mainly due to damage to infrastructure [32].

As a consequence of the vulnerability of the Limpopo Province to weather and climate extremes, several studies have detailed flood vulnerabilities, water pollution, impacts and adaptation in the province, e.g., [3,32–36]. However, the majority of the literature has focused on the Luvuvhu River Catchment, which is a major sub-catchment of the Limpopo River. This study focuses on flood vulnerabilities in Mopani, a district of the Limpopo Province which has not received adequate research attention.

Although studies have tackled floods from various fields and perspectives in the region, a paucity of vulnerability assessments for rural settlements to flood hazards remains. Several local communities have been declared vulnerable to floods, but little is known about the extent of their vulnerability. Our study of floods in rural South Africa is motivated by these vulnerabilities. Several indices have been developed to assess/measure levels of flood vulnerability at different spatial scales towards flood hazard management [37]. The more recent approaches have focused on geospatial techniques for vulnerability assessment [37]. Several studies have defined vulnerability as a measure of potential harm to communities caused by a natural hazard, e.g., [38–41]. A number of quantitative flood vulnerability indices have been developed to investigate the extent of potential harm due to exposure, susceptibility and resilience [42–46]. Tools and indicators have been documented linking theoretical concepts to strategy development, policies, decision making and adaptation [9,42] with all having unique and various responses to flood occurrences. This has been crucial for characterizing vulnerability indices and indicators relative to regions and focusing on physical, economic and social vulnerability [47]. Our study combines analysis of rainfall extremes, remote sensing and geo-spatial techniques with a vulnerability assessment using a Flood Vulnerability Index (FVI) developed and detailed in Balica et al. [42] and Balica and Wright [48]. The FVI calculates a single number based on social, economic, environmental and physical components in the water resource system [42].

Thus, the main aim of this study is to (a) assess the nature and extent of flood vulnerability and (b) establish adaptation strategies employed by three selected rural communities in Mopani District Municipality affected by the flood hazard repeatedly in recent years. The remainder of the paper is structured as follows: a study area description precedes the data and methods section, and the results are presented as subsections. A discussion and recommendations for flood management are offered at the end.

2. Materials and Methods

2.1. Study Area

Although this study deals with South Africa's northeastern Limpopo Province, it mainly focused on rural communities in the wetter western region of Mopani District Municipality (Figures 1 and 2) which are vulnerable to various natural hazards including floods, droughts and heat waves. The proximity of the study area to the warm South Indian Ocean (Figure 1) makes it vulnerable to tropical cyclones that reach land during the late austral summer [49,50]. The lowveld in the northeast is separated from the interior plateau by an escarpment, and our study sites lie in this transition zone, where rainfall is enhanced by orographic factors. The study focused on communities in Lenyenye, Nkowankowa Section B and C (in Greater Tzaneen Municipality) and Ga-Kgapane Masakaneng in Greater Letaba Municipality (Figure 2) which are largely semi-rural, while also providing labor to the *eucalyptus* and citrus plantations and urban areas of Greater Tzaneen.

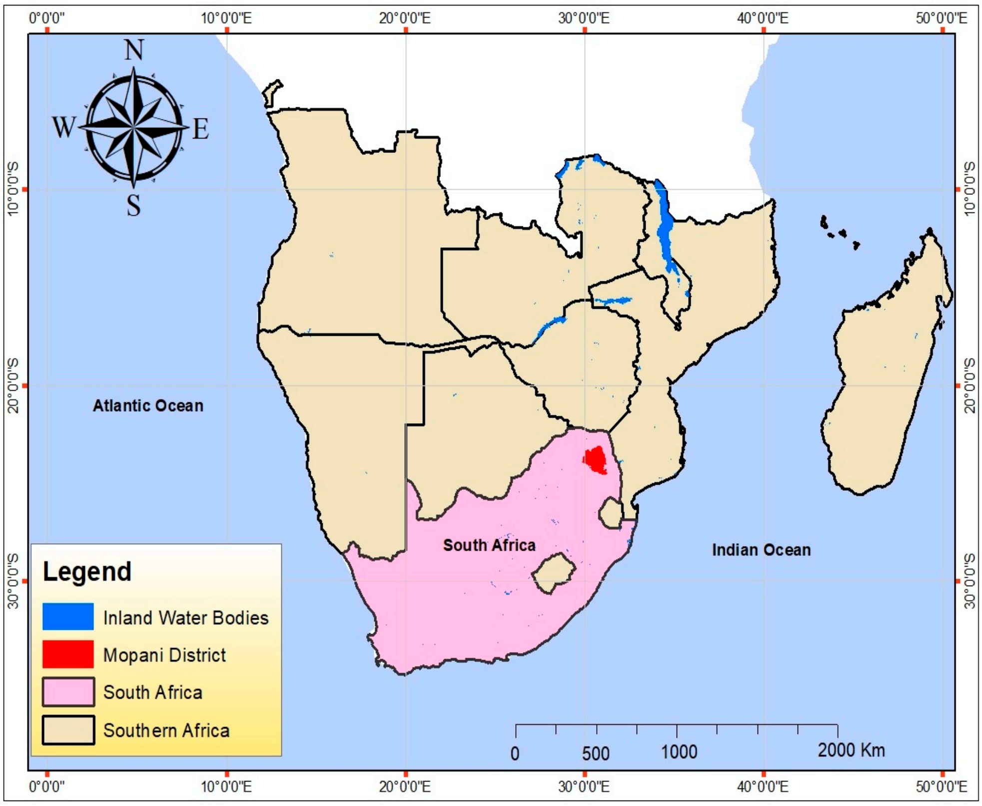


Figure 1. Location of Mopani District Municipality in the southern Africa region, northeast of South Africa. The district is in close proximity of the warm Indian Ocean in the east.

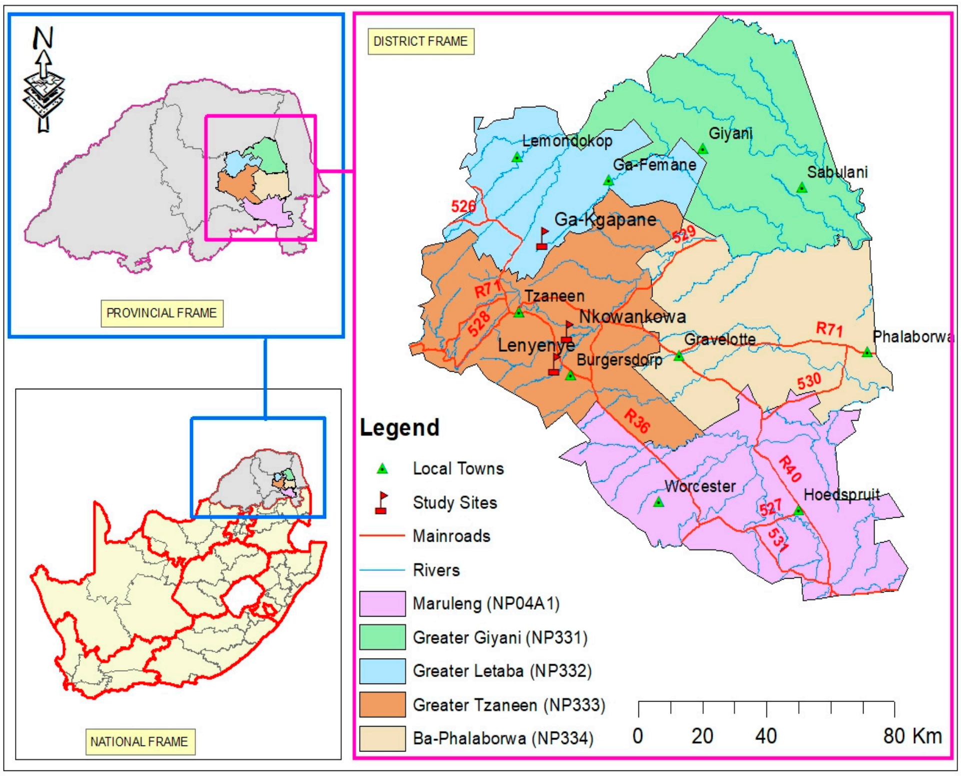


Figure 2. South Africa (national frame): Location of the three study sites (in red flags) in Mopani District's Greater Tzaneen and Greater Letaba municipalities.

The Mopani District Municipality in South Africa's Limpopo Province is made up of Maruleng, Greater Giyani, Greater Tzaneen, Greater Letaba and Ba-Phalaborwa local municipalities (Figure 2), which are variously exposed and vulnerable to flood hazards. Major flood events have occurred in Mopani during the past decade. In 2012, a total of 662 households were affected by floods, with Molalane village (east of the district, Maruleng Municipality) being the hardest hit [51]. However, it has been found that the most affected rural settlements in the Mopani District are Lenyenye, Ga-Kgapane and Nkowankowa Section B and C. These communities have been seriously exposed because they are located near rivers, while also being susceptible to high rainfall due to the proximity of the escarpment. The generally flat terrain and poor drainage in Nkowankowa Section B and C promote ponding to occur readily after a rainy day (Figure 3). The generally low socio-economic status of households has compounded the susceptibility of these rural communities to the natural hazard.

Figure 3. A flooded street in Nkowankowa, Greater Tzaneen Municipality due to both topography and poor drainage and culvert design [source: Field survey, 2016].

2.2. Data and Methods

This study was conducted using a mixed-method approach, mainly on a quantitative survey research design and supplemented by a qualitative survey. Quantitative data collection included an analysis of the occurrence of extreme rainfall and flooding using remote sensed data and also from questionnaires administered in the three study sites and target households.

As a background to the vulnerability analysis, we present a climatology of daily rainfall in the study area and analyze case studies of extreme rainfall which led to flood events. To identify and map flood events, high resolution rainfall data was analyzed in this study. We employed the Climate Hazards Infrared Precipitation with Stations (CHIRPS), [52] data for the recent period from 2000 to 2020. The CHIRPS data are obtained at very high temporal (daily) and spatial resolution ($0.05° \times 0.05°$) and derived from satellite infrared estimates and rain gauge observations [52]. The daily data are suitable for analysis of extreme events that may lead to floods. We also analyze the relationship between sea-surface temperature (SST) anomalies of the Niño 3.4 region (equatorial Pacific Ocean) and seasonal rainfall in the study region via correlation analysis.

The aerial extent and types of flood were mapped using geospatial and remote sensing data via the topographical approach to historical flood mapping. This is a process that analyzes the structure of the top layer of the Earth's surface to determine the areas that are prone to flooding and also provides a topographical explanation of historically recorded floods. The method for topographical drainage channel analysis involves an initial step which is to map the natural topographical drainage channels. This was undertaken using data from the Shuttle Radar topography mission (SRTM), which is accessible from NASA's database at 30 m resolution. This data is used to create a digital elevation model (DEM), which is the basis for this analysis. Using the ArcMap Hydrological tools toolbox, the DEM is filled for sinks and analyzed for flow direction from each cell using the D8 algorithm. This determines the direction in which water flows from every cell based on the proven motion of water that it always flows from a point of high elevation to a point of low elevation [53]. From the flow direction, the drainage basins are then clearly distinguished using the Basin Tool, after which the flow directions of each basis are analyzed for areas of greatest flow accumulation, into which most cells pour. For this study, the minimum number of cells pouring into a single cell was established to be 5000 because the interest was not only in perennial streams but also non-perennial runoff channels that only have water during rainfall events, as shown in Figure 4. The cell number threshold varies depending on the channel level as seen by Liu [54] and Theofanous [55], among others.

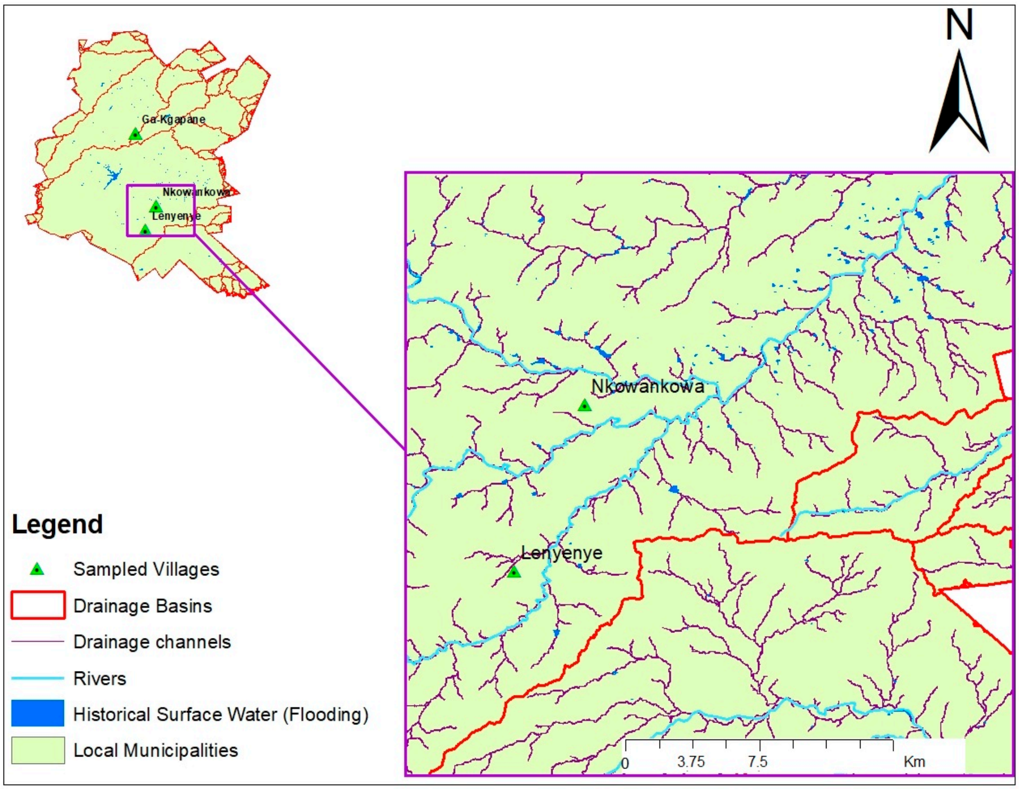


Figure 4. Study area flood locality map showing previously flooded areas relative to perennial rivers and drainage channels.

A limitation in satellite data when applied to flooding is a result of the fixed sensor temporal resolutions and revisit times, in addition to interference from upper atmospheric conditions [56]. Optical sensors cannot penetrate through clouds which are present during flooding events, creating a blind spot and, by the time the satellite revisits the same area in a few days, the flooding may be over or abated [56]. For most of the flooding dates observed in this study, there were no direct data due to these limitations. However, radar data provided a useful alternative because of its ability to penetrate through clouds, although the spatial resolution of Synthetic Aperture Radar (SAR) is at least 145 km [57]. Historical SAR-based surface water accumulation zones data were downloaded from the Copernicus hub and overlaid on top of the drainage channels on an aerial photograph of the study area for more visibility. The perennial rivers were also added and, interestingly, this revealed two distinct cases of flooding in the area.

In addition, qualitative data was provided by key informant interviews and focus group discussions using instruments mainly composed of semi-structured questions on indicators of vulnerability and the participation of authorities to mitigate flood impacts. Questionnaires were also distributed to target households to identify indicators and the extent of flood vulnerability. The questions included exposure, susceptibility and resilience indicators, and adaptation strategies/actions during floods (see Appendix A). The target households were sampled using the systematic random sampling method, a statistical method that is widely used in the social sciences research that employs a selection of components within an ordered sampling frame. The three settlements in Mopani District had total numbers of households as follows: Nkowankowa Section B and C—1860; Lenyenye—980; and Ga-Kgapane Masakaneng—706 [58]. Equivalently, 50% of the total households (which is the unit of analysis in each community) were systematically sampled in a quantitative order of one in every 20 households. The households' sample sizes were calculated as follows:

$$\text{Lenyenye} = \frac{Total\ number\ of\ households}{100} \times 50, \tag{1}$$

Systematic sample of every 1 in 20th of the 490 *households* = 25

$$\text{Nkowankowa C, B} = \frac{Total\ number\ of\ households}{100} \times 50 \tag{2}$$

Systematic sample of every 1 in 20th of the 930 *households* = 47

$$\text{Ga-Kgapane} = \frac{Total\ number\ of\ households}{100} \times 50 \tag{3}$$

Systematic sample of every 1 in 20th of the 353 *households* = 18.

Total number of questionnaires = 25 + 47 + 18 = 90.

It was decided to raise the number of questionnaires to 100 such that Nkowankowa received three extra questionnaires and Ga-Kgapane Masakaneng was allocated seven additional questionnaires to make a total of 100. With a sample size of 100 from a population of 1773, the margin of error of 7.99% was computed using the Raosoft sample size calculator (http://www.raosoft.com/samplesize.html, accessed on 15 November 2021).

Key informant interviews were conducted with a 'Risk Assessment Manager' of Mopani District Disaster Management Centre and two 'Storm Water Managers' of Nkowankowa Section B and C, Lenyenye and Ga-Kgapane Masakaneng. The informants were selected using the purposive sampling technique. This is a non-probability sampling method where investigated and selected units from a population are based on the subjective judgement of the researcher(s) [59]. Key informant interviews also included aspects of municipal adaptation strategies, information about indicators and flood impacts. To compute the FVI, both primary and secondary data sources were used in this study. Primary data were acquired through a quantitative questionnaire, a qualitative key informant interviews, and field observations; whereas secondary data were collected through Census, 2011 [60], South African Weather Service (SAWS) records and maps. The Mopani District Disaster Management Centre (MDDMC) was helpful in providing the majority of records, maps and information about relevant indicators for the FVI.

Questionnaire data from household surveys were analyzed through Microsoft Excel 2010 and Statistical Package for Social Sciences (SPSS) 23 spreadsheets. These data were coded and arranged, entered into Microsoft Excel 2010, and converted to SPSS 23 to create descriptive statistics. The entered data were summarized into percentages and frequencies, and key informant interviews' responses were analyzed using content analysis and arranged into themes. The themes and other responses were then grouped into identical categories, classified and synthesized, and the descriptive narrative technique was employed to discuss the results of key informant interviews.

The information collected from interviews, field observations, Statistics South Africa, SAWS observations and records were imputed into the FVI. The FVI is a parametric approach which is suitable to evaluate vulnerability to floods because it incorporates socio-economic and physical environment components. This index was used to measure the extent of flood vulnerability in the three study communities. Exposure, susceptibility and resilience are the three main factors of FVI, aligned with the social, economic and physical environment to reveal relevant indicators. Indicators were selected through a deductive approach and supported also by a preliminary survey for the relevancy of each indicator. Selected indicators were thoroughly reviewed and merged to be relevant in the three communities.

Exposure, susceptibility and resilience have different impacts on vulnerability. Resilience influences vulnerability negatively, whereas susceptibility and exposure positively influence vulnerability [61]. Exposure is a measure of predisposition to flooding due to the location; susceptibility measures the extent of exposure which may be related to awareness/preparedness; and resilience measures coping and recovery capacity during and after floods [48]. The general formula for FVI calculation uses categorization of the components into three groups of resilience, susceptibility and exposure indicators [47]. The formula used to calculate the FVI developed by Balica et al. Ref. [42] is:

$$FVI = \frac{E \times S}{R} \text{ or } FVI = (E + S) - R \quad (4)$$

where *E*—exposure, *S*—susceptibility and *R*—resilience

FVI is equal to the sum of exposure and susceptibility minus resilience. The index gives a number on a scale from 0 to 1, signifying low to high flood vulnerability respectively. FVI values greater than 0.5 are considered high vulnerability with very high vulnerability values from 0.75 to 1 [47]. FVI values lower than 0.25 are considered as small vulnerability to floods where recovery can be fast either due to high resilience or low economic development [47]. Interpretation of the FVI and descriptions of index value [47].

A high level of vulnerability to floods implies a high possibility of loss in any components [47,62,63]. The losses can be in a form of property, human lives, livelihoods, environment and others. High vulnerability to floods or other hazards has the potential to lead to catastrophes or natural disasters, especially in resource poor marginal regions of Africa. Normally, a very high vulnerability to flood is assigned to a system or circumstance in which there is a high probability of loss of life, whereas average vulnerability is assigned where there is a medium probability of harm to assets and lives of people. If a system or community is exposed to a small probability of harm and damage to the socio-economy and physical environment, a small vulnerability can be assigned. A "very small vulnerability to floods" is mostly related to a very small potential for damage to any system [47]. "Small vulnerability to floods" is normally due to the strong resilience of a specific community or system. Although a community may be exposed and susceptible to floods, the strongest determinant of vulnerability is its resilience capacity. Locations/households that are characterized by small vulnerability to a hazard mostly have a high resilience capacity [64].

3. Results

3.1. The Occurrence of Extreme Rainfall

Rainfall over the study area is strongly seasonal, occurring mainly during the austral summer months from December to February (Figure 5), although the entire rainfall season can span from October to April. Most rainfall over the study area is produced by cloud bands, connecting the Inter-Tropical Convergence Zone (northwestern end) to a cold front at its southeastern end. The rainfall here is also enhanced by the presence of a sharp topographic gradient (due to the north-eastern escarpment) such that the lowlands are more vulnerable. The annual cycle of daily rain shows that mean daily rainfall in the study area is below 10 mm/day (Figure 5; red line) which may be considered moderate. Although the occurrence of extreme rainfall is rare in this area [15], it is mostly linked to tropical continental lows and landfall of tropical cyclones from the warm Mozambique Channel and Southwest Indian Ocean [16]. It is also shown that the monthly mean for daily rainfall extremes can reach and exceed 50 mm/day during January and February (Figure 5; 97.5% percentile, green line).

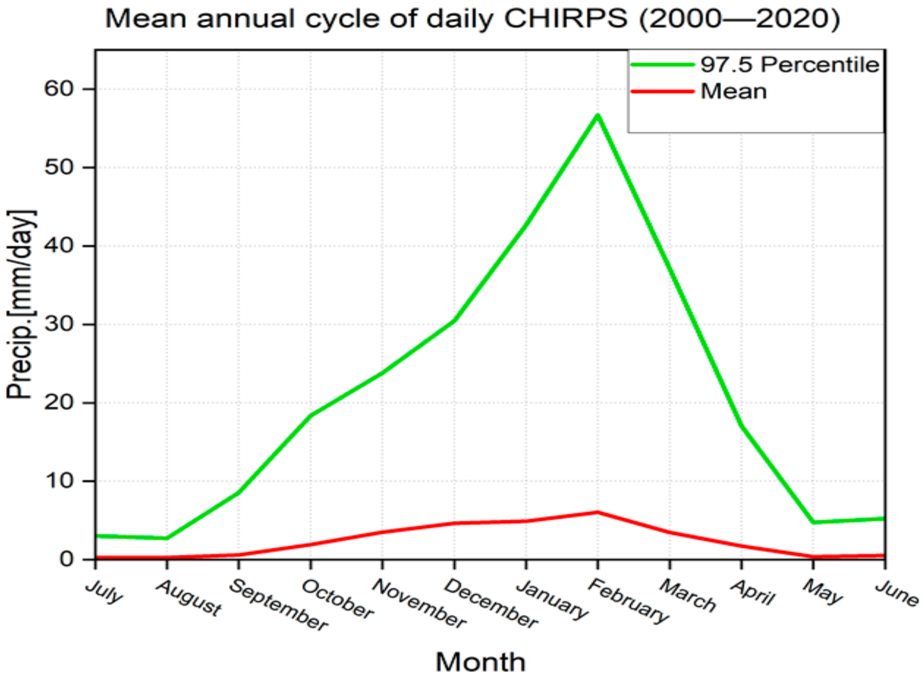


Figure 5. The mean annual cycle of daily CHIRPS rainfall over the study area (mm/day). The mean is shown in red and the 97.5% percentile is shown in green.

At inter-annual time scales, we show here that the study region has experienced heavy daily rainfall events several times during the past 21 years (2000–2020), which may be increasing in frequency due to climate change (Figure 6). In southern Africa, one definition of heavy rainfall events is when 24 h (daily) amounts exceed 50 mm [15]. The time-series in Figure 6 shows several distinct peaks with extreme amounts exceeding 100 mm/day during 2017 and 2018. Such events would most likely lead to ponding or flooding depending on other vulnerability factors such as drainage and terrain. It is also projected that sub-daily extreme rainfall events in southern Africa will become more frequent in the future [20,65], suggesting a corresponding increase in ponding, flash floods and fluvial flooding. These projections may imply increased future vulnerabilities in some areas.

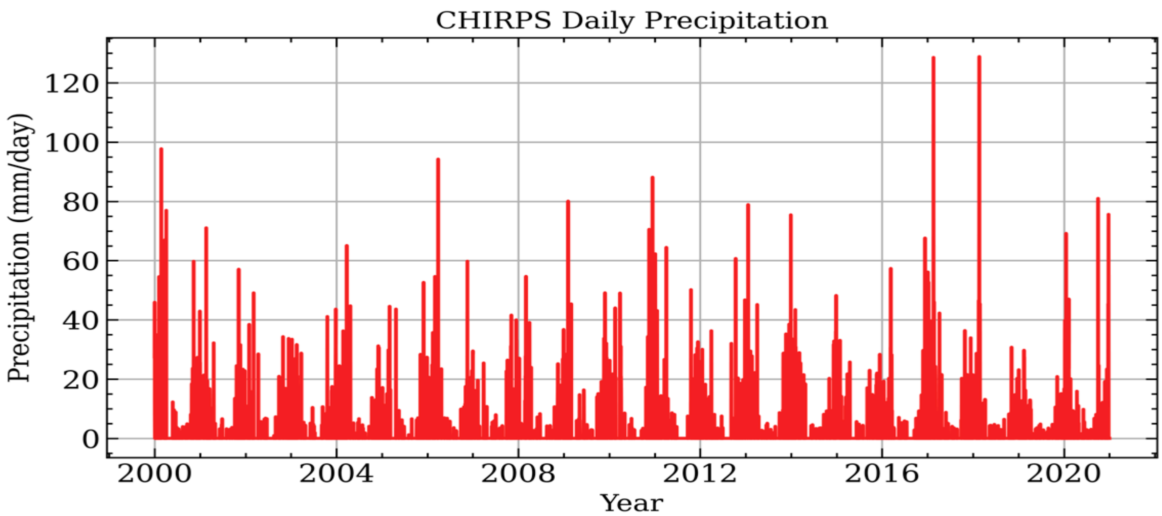


Figure 6. Inter-annual variability of CHIRPS daily precipitation over the Greater Tzaneen municipal area over the period from January 2000 to December 2020.

We also analyzed the link between the occurrence of extreme rainfall and the ENSO phenomenon and found a statistically significant ($p < 90\%$) relationship between SST anomalies over the equatorial Pacific Ocean and seasonal rainfall in the study area (Figure 7). El Niño events (positive Niño 3.4 SST) are mostly linked to drought and heat waves in Limpopo. The recent 2015/2016 El Niño, which is the most intense event, led to one of the most severe droughts that is comparable only to 1991/1992 and 1982/1983 (Figure 7; 17). Conversely, the heavy rainfall events that led to flooding in Mopani District during the 2012/2013 and 2013/2014 summers coincided with near-neutral weak La Niña events (Figure 7). However, although a statistically significant and negative correlation (R = −0.436; Figure 7) exists between Nino 3.4 SST anomalies and extreme rainfall in the area, the relationship is partial, suggesting a more complex climatic regime. This suggests that above normal rainfall in the region is more likely during La Niña, implying a link with flood events.

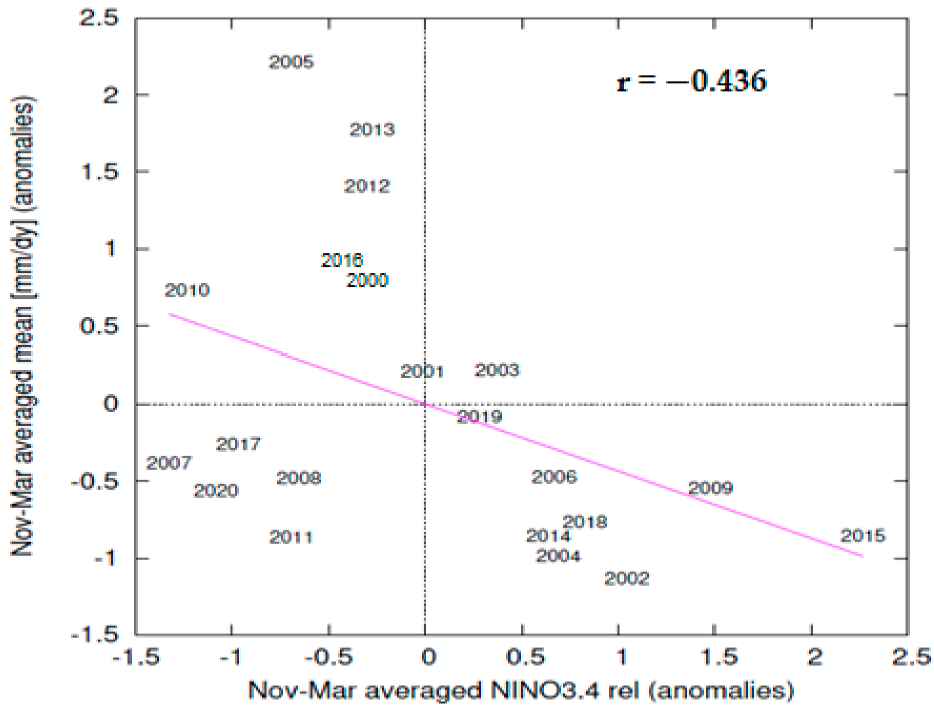
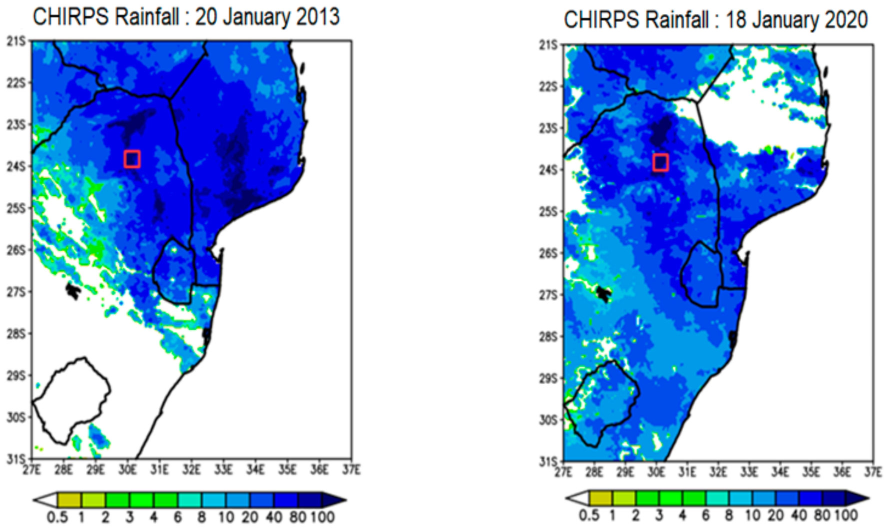


Figure 7. Correlation of Nino 3.4 SST anomalies with rainfall anomalies in the study area.

Several heavy rainfall events (exceeding 50 mm/day) that affected the area can be identified in 2000, 2006, 2007, 2011, 2013, 2014, 2017, 2018 and 2020, mostly in February (Figure 6). We focus on two of the more extreme events to show how intense rainfall affected the area and led to flooding: 20 January 2013 and 18 January 2020. It is shown that in both events, extreme rainfall amounts exceeding 100 mm/day were recorded in areas along the escarpment (Figure 8). Regarding the two events, although the general pattern is one of widespread precipitation across the province, there is a distinct west–east axis of extreme rainfall which shows the influence of orographic lifting in the northeastern escarpment in the study area (Figure 8).

The rainfall shown in Figure 8a was due to the influence of a tropical continental low-pressure system that developed and affected Mozambique, Zimbabwe, Botswana and South Africa. The slow movement of that tropical low coupled with a long life, which spanned the period 15–21 January 2013, resulted in extreme rainfall over the region. Several large areas of the Mopani District Municipality experienced floods, including the Kruger National Park, resulting in loss of lives and livelihoods [66]. The evolution of this weather system over the subcontinent in January 2013 and its impacts in Mopani District have been detailed in Webster [67].



(**a**) (**b**)

Figure 8. Daily CHIRPS rainfall during (**a**) 20 January 2013 and (**b**) 18 January 2020 over the study region. The location of the three communities in this study is shown in a red polygon.

The extreme rainfall of 18 January 2020 (Figure 8b) was associated with an upper air trough over the south of Botswana which allowed for an influx of moist tropical air into the study area. The upper trough developed ahead of a cut-off low-pressure system that affected the southwestern Cape of South Africa. Cut-off lows can occur throughout the year in South Africa, although with peaks during the austral autumn and spring seasons [68,69]. At the surface, a ridging anticyclone over the southeast coast of South Africa was driving moist and cold air from the Southern Ocean (not shown). The north eastern escarpment enhanced dynamical lifting resulting in heavy thunderstorms with rain over the study area. A combination of surface ridging anticyclones with disturbances in the upper air (such as a trough or a cut-off low) often results in severe weather and floods over South Africa, e.g., [15,70–73].

3.2. Mapping Flood Events

Our analysis reveals that areas that have been flooded historically are presently still vulnerable and may become more vulnerable to future flooding (Figure 9). The location of these areas relative to the drainage channels reveals two different types of flooding. Flooding Case A is when there is flooding on the surface away from drainage channels caused by an indented surface without proper drainage and culverts (Figure 9). Case B represents flooding occurring along the drainage channels that can be assumed to have been caused either by extreme rainfall or blockage in the drainage channels.

Although some floods can be attributed to topography, land modification through land use and land cover changes can create blockages in the natural topographical drainage channels that may result in flooding [74]. Land modification also creates planar surfaces in naturally steep regions and this interferes with the runoff towards the drainage channels, thus resulting in floods [75]. During fieldwork, we found that several gravel roads in the study sites do not allow for rainwater to drain away from the road, resulting in stagnant water and ponding.

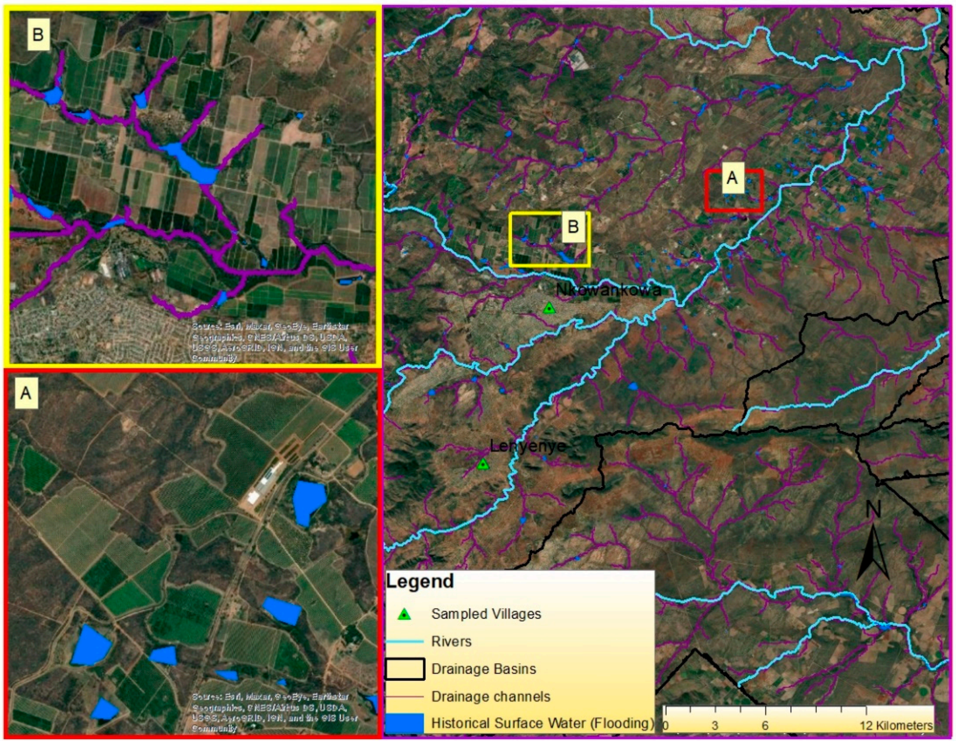


Figure 9. Close aerial view of sampled sites, showing different types of flooding cases in the Nkowankowa study area.

3.3. Indicators of Flood Vulnerability

In this section, we employed the FVI [42] to measure levels of flood vulnerability in three dimensions, namely social, economic and physical environment for each study site. Based on the surveys, Table 1 shows the important indicators, components and factors, and their function or relationship with flood vulnerability.

Table 1. Flood Vulnerability Index; selected indicators in Nkowankowa section B and C, Lenyenye and Ga-Kgapane Masakaneng [source: Field survey, 2016].

Indicators	Components	Factors	Function/Relationship with Vulnerability
Frequency of Flood Occurrence	Physical	Susceptibility	Higher number of occurrences/year, higher vulnerability
Evaporation Rate	Physical	Susceptibility	Higher evaporation, lower vulnerability
Unemployment	Economic	Susceptibility	Higher%, higher vulnerability
Dwelling quality	Economic	Susceptibility	Poor quality (mud material), high vulnerability
Infrastructure quality (e.g., roads, storm drainage)	Economic	Susceptibility	Higher% of good quality infrastructure, lower vulnerability
Preparedness/Awareness	Social	Susceptibility	Higher number of people aware, lower vulnerability
Education level	Social	Susceptibility	Higher number of people uneducated, higher vulnerability
Disabled People	Social	Susceptibility	Higher number of disabled, higher vulnerability
Number of days with heavy rainfall	Physical	Exposure	Higher number of days, higher vulnerability
Topography	Physical	Exposure	The flatter/low lying area of the slope, higher vulnerability
Household income	Economic	Exposure	High household income, low vulnerability

Table 1. *Cont.*

Indicators	Components	Factors	Function/Relationship with Vulnerability
Maintenance of Infrastructure	Economic	Exposure	High maintenance, lower vulnerability
Population Density	Social	Exposure	Higher number of people, higher vulnerability
Population Growth	Social	Exposure	Fast population growth, higher vulnerability.
Dam and storage capacity/quality	Physical	Resilience	Higher capacity, lower vulnerability
Floods Recovery Time	Physical	Resilience	High recovery time, less vulnerability
Dam and storage capacity	Economic	Resilience	Higher capacity, lower vulnerability
Economic Recovery	Economic	Resilience	High economic recovery, less vulnerability
Response team	Economic	Resilience	Effective response team, lower vulnerability
Early Warning System (EWS)	Social	Resilience	Having EWS reduces the vulnerability
Emergency Service (ES)	Social	Resilience	Efficient ES, lower vulnerability
Evacuation Route	Social	Resilience	Better quality of roads, improve quality evacuation
Past experience (PE)	Social	Resilience	Higher number of people with PE, lower vulnerability.

Twenty-six indicators were selected in the three study sites; information about indicators was collected from the Mopani District Disaster Management Centre (MDDMC), Director of MDDMC, Greater Tzaneen Disaster Management Section, Greater Letaba Disaster Management Section, SAWS, household questionnaires and Census 2011. It was found that data or information about soil moisture and ground-water level indicators were mostly not available, and this is not unique to the study sites. These two indicators were unable to be included in the FVI computation regardless of their significance. The study employed the deductive approach, adopted from Balica [4] and Veenstra [76], which was supplemented by a preliminary field survey for relevancy of selected indicators. The following equations show the key variables considered for the physical, economic and social components of the FVI:

$$\text{FVI}_{\text{Physical}} = [\text{FO, Er + H, FH, T}] - [\text{DSC, FRT}] \quad (5)$$

where FO: Frequency of Flood Occurrence; Er: Evaporation Rate; H Rainfall: FH Number of days with Heavy Rainfall; T: Topography; DSC: Dam and Storage Capacity/quality; FRT: Floods Recovery Time.

$$\text{FVI Economic} = [\text{Um, Dq, Iq + Hi, Mi}] - [\text{DSC, Ecor, Rt}] \quad (6)$$

Um: Unemployment; Dq: Dwelling quality; Iq: Infrastructure quality; Hi: Household income; Mi: Maintenance of Infrastructure; DSC: Dam and Storage Capacity/quality; Ecor: Economic recovery; Rt: Response Team.

$$\text{FVI}_{\text{Social}} = [\text{P/A, Ed, Dp + Pd, Pg}] - [\text{Ws, Es, Evr, Pe}] \quad (7)$$

P/A: Preparedness/Awareness; Ed: Education Level; Pd: Population Density; Pg: Population Growth; Ws: Early warning system; Es: Emergency service; Evr: Evacuation Route; Pe: Past Experience.

Table 2 shows that economically, Ga-Kgapane Masakaneng has a ‘high vulnerability to floods’ with FVI = 0.52, whereas the physical dimension shows a ‘small vulnerability to floods’ with FVI = 0.20 and the social component has a ‘vulnerable to floods’ level, FVI = 0.27. The economic component scored higher vulnerability than physical and social components in Ga-Kgapane Masakaneng, suggesting that flood vulnerability in the area is exacerbated by their economic state or characteristics. The study found that most household members in the area are unemployed and those employed generally earned low incomes. The Ga-Kgapane Masakaneng area exhibits a 'vulnerability to floods' level and may need to pay more attention to economic factors to mitigate flood vulnerability.

Table 2. Flood vulnerability levels in Ga-Kgapane Masakaneng [source: Field survey, 2016].

Ga-Kgapane Masakaneng Flood Vulnerability		
FVI Components	**FVI Values**	**FVI Designation**
FVI Physical	0.20	Small vulnerability to floods
FVI Economic	0.52	High vulnerability to floods
FVI Social	0.27	Vulnerability to floods
FVI Total or General	0.34	Vulnerability to floods

Table 3 shows that, physically, Lenyenye has a 'small vulnerability to floods', FVI = 0.14, whereas economically and socially, it has a 'vulnerability to floods' level. It was found that the social and economic components are worsening vulnerability to floods in Lenyenye village. More efforts are needed to focus on the socio-economy of this village to reduce and prevent floods, and their impacts. The overall level of flood vulnerability of Lenyenye shown in Table 3 is also 'vulnerability to floods' at FVI = 0.34.

Table 3. Flood vulnerability levels in Lenyenye [source: Field survey, 2016].

Lenyenye Flood Vulnerability		
FVI Components	**FVI Values**	**FVI Designation**
FVI Physical	0.14	Small vulnerability to floods
FVI Economic	0.38	Vulnerability to floods
FVI Social	0.40	Vulnerability to floods
FVI Total or General	0.34	Vulnerability to floods

Table 4 shows flood vulnerability in Nkowankowa Section B and C and the index values indicate that economically and socially they are classified as 'vulnerability to floods'. Physically, the Nkowankowa settlements have higher vulnerability (FVI = 0.58) than both economic and social components, suggesting that topography has a more significant influence on the flood vulnerability in the area. The area is very flat and allows large amounts of flood waters to accumulate during heavy rain (Figure 3). Generally, the Nkowankowa area is 'vulnerable to floods' and more focus and attention are required on the physical component than on social and economic components of vulnerability. Flat or low-altitude locations exacerbate the vulnerability to floods because run-off from higher ground tends to accumulate in these low elevations [77].

Table 4. Flood vulnerability levels in Nkowankowa Section B and C [source: Field survey, 2016].

Nkowankowa Section B and C Flood Vulnerability		
FVI Components	**FVI Values**	**FVI Designation**
FVI Physical	0.58	High vulnerability to floods
FVI Economic	0.39	Vulnerability to floods
FVI Social	0.34	Vulnerability to floods
FVI Total or General	0.40	Vulnerability to floods

Figure 10 provides a comparative analysis of flood vulnerability assessments between the three study sites. Nkowankowa Section B and C villages are generally more vulnerable (FVI = 0.40) to floods than the other two study sites. Nkowankowa is dominated by physical component of vulnerability (due to its low altitude) which is higher than the other two locations. Ga-Kgapane Masakaneng exhibits higher vulnerability than the other two in the social component, whereas, economically, Lenyenye has the most vulnerability.

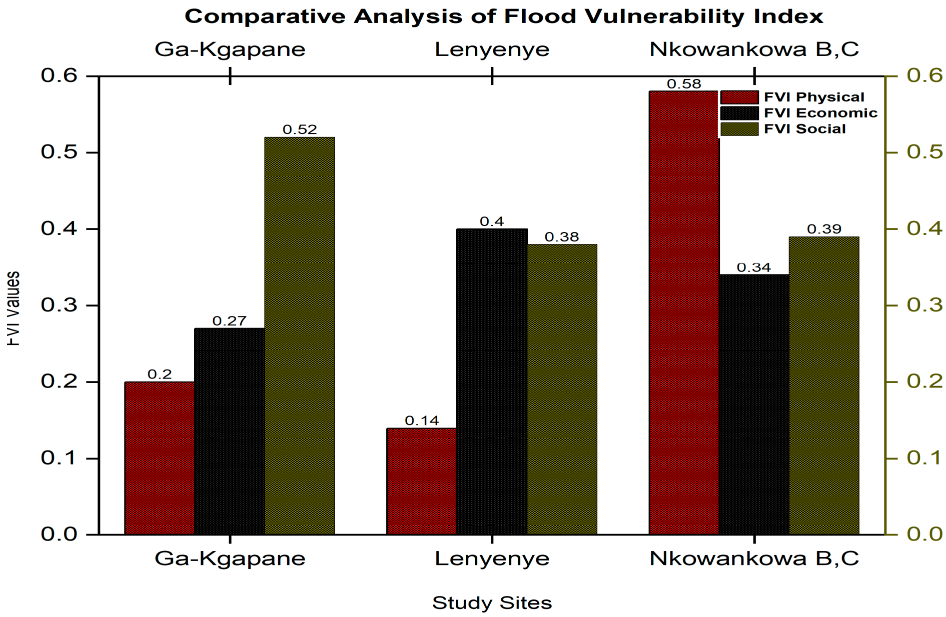


Figure 10. Comparative analysis of the FVI between the three study sites.

3.4. Flood Adaptation Strategies and Actions

The study found that floods have caused severe damages in all three study sites at Ga-Kgapane, Nkowankowa and Lenyenye in Mopani District. Households were seriously affected; as some of the houses were flooded, some individuals drowned, rivers spilled and overflowed, and certain roads were cut off or made impassable. The social survey, key informant interviews and field observations were the main instruments employed to identify flood adaptation strategies/actions in these areas. Households and key informants (government officials) were also asked to rank all identified coping strategies according to their preference and effectiveness.

We found that community adaptation strategies/actions were common across the sites at Ga-Kgapane Masakaneng, Lenyenye and Nkowankowa Section B and C (Figure 11). Most of the respondents preferred to make a 'Le-guba' (a raised porch surrounding a house), with shares of 30.5% at Ga-Kgapane, 27.8% at Lenyenye and 23% at Nkowankowa. Figure 12 shows the 'Le-guba' surrounding many houses across the study sites, suggesting that this long-term adaptation mechanism is popular with respondents. We also found that constructing a furrow around houses and culverts on roads was also popular, having a share of $\geq$22% at all three sites. Another common action involved use of sandbags made of burlap, polypropylene or sturdy materials containing sand and/or soil. Temporary relocation was also an option for severe cases of flooding, particularly in Lenyenye and Nkowankowa. Fewer respondents opted for the more permanent strategies/actions such as building protective walls around homes and terraces in the fields (<10%). The least preferred options were building houses with stone and mortar and constructing a personal drainage system.

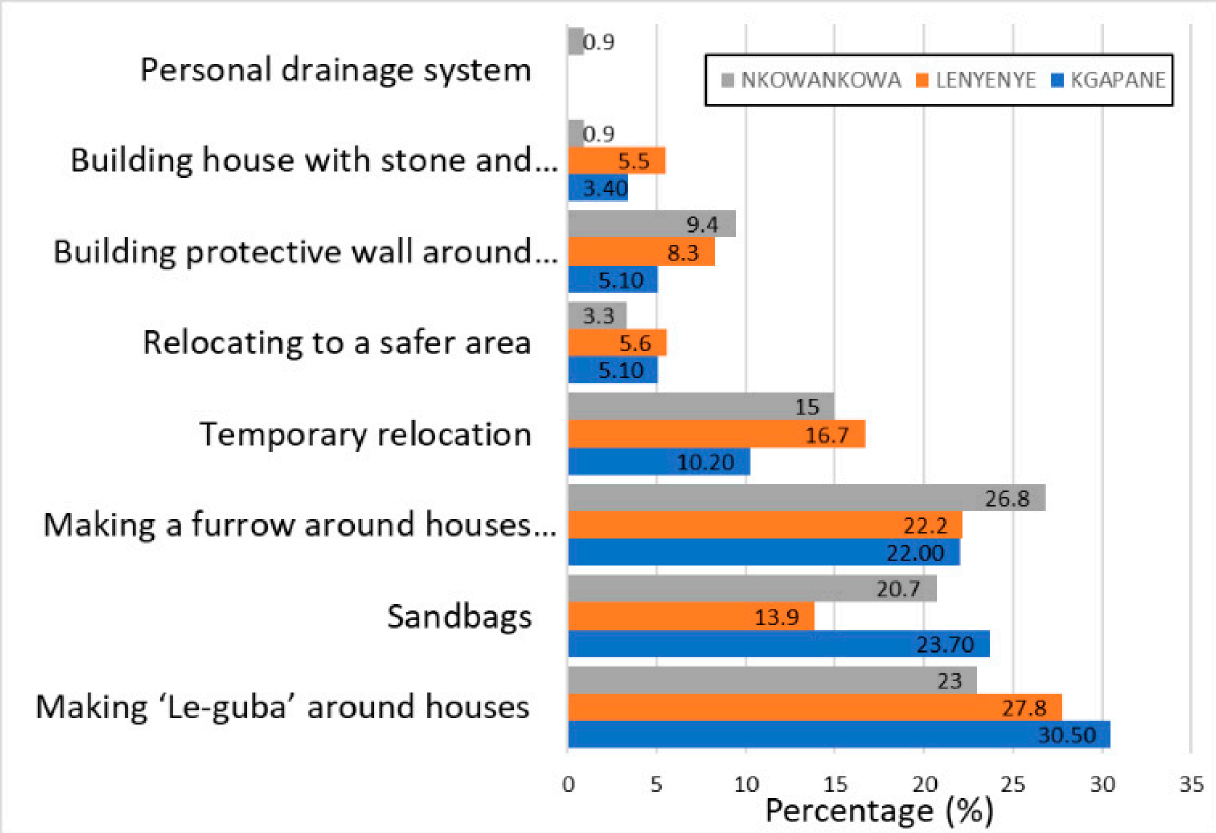


Figure 11. Household floods adaptation strategies in Nkowankowa, Lenyenye and Ga-Kgapane Masakaneng [source: Field survey, 2016].

Figure 12. Several examples of a "Le-guba" on the stoep of houses in the study area [source: Field survey, 2016].

The road and storm water management authorities in Ga-Kgapane Masakaneng suggested that the best way to deal with floods in the area was to relocate people because the area was not meant for residential purposes and had previously been used as a dumping site. However, due to historical inequalities and high population growth, this would not be a simple task and, therefore, most respondents were not willing to relocate. The Acting Director of MDDMC, also a key informant, indicated that as the population was increasing, it was advisable to construct better drainage systems and houses to prevent further damage.

In support of low-income families, the South African government built low-cost houses across the country under the Reconstruction and Development Programme (RDP) of 1994 [78], and some were built in the study sites. In some cases, there were problems with the housing quality and also the location of the project. Many RDP houses had been damaged by flood waters (at the time of fieldwork) and households occupying them were at risk and 'vulnerable to floods'.

4. Discussion

This study focused on understanding the risk and vulnerability and adaptation to flood hazards among rural communities in Greater-Tzaneen and Greater Letaba municipalities in South Africa's northern Mopani District. We combined an analysis of vulnerability of the study sites to extreme rainfall and flooding, with physical, social and economic factors via a flood vulnerability index. In addition, resilience of a community is a key determinant of how vulnerable they may be, and this is particularly so in rural areas of South Africa; hence the focus of this study. We found that although extreme daily rainfall is rare, it occasionally occurs in this region, mainly during times of La Niña events when tropical storms and severe thunderstorms are more likely. Although there is a very small chance of tropical cyclones entering the Limpopo Province from the Mozambique Channel [49], when they do, they cause widespread extreme rainfall and floods in the study region. In addition, poor drainage, lack of culverts or blockages in drainage channels were the other factors that compounded flood vulnerability. A geo-spatial analysis using remote sensing data revealed two types of flooding caused either by extreme rainfall or by poor drainage or blocked drainage channels. Thus, analyzing all these factors plays a significant role in flood management and adaptation to prevent excessive damage and loss of lives and livelihoods in future.

From the field survey, we calculated the FVI [42] and found that the overall (social, economic and physical dimensions) level of flood vulnerability in the three rural settlements is 'vulnerability to floods'. This level is considered a medium-level vulnerability such that the area/community can recover from flood damage in months [47]. However, the individual components of the FVI reflected different contributors to vulnerability levels across the three sites. Nkowankowa Section B and C had a higher vulnerability than the other two locations in the physical component because of its flat terrain and poor drainage. It is also nearer to the escarpment where rainy days are more regular. Lenyenye had the higher vulnerability to floods in the economic dimension mainly due to its high unemployment or poor wages, whereas Ga-Kgapane Masakaneng was more vulnerable in the social dimension due to low education levels and lack of awareness/preparedness. By rank, Nkowankowa Section and C was more vulnerable to floods (FVI = 0.40) than both Lenyenye (FVI = 0.34) and Ga-Kgapane Masakaneng (FVI = 0.34). Topography should be considered in Nkowankowa Section B and C during planning for the construction of future infrastructure, buildings and other development activities, as plain or flat slope areas are very prone to floods, whereas high elevations areas are free from floods but not flooding [79]. Well-drained gravel roads can also mitigate ponding or flooding on roads, often disrupting movements of people for social and economic activities.

Vulnerability studies can be complicated. Vulnerability is a concept that is incomplete without assessing the capacity of individuals to resist the impacts of floods [42]. There is a strong link between the components of vulnerability, as they do not operate or function independently of each other. The best means of conducting a comprehensive vulnerability study is by including all these components. Individuals can have a similar socio-economic status and physical exposure but employ different coping/adaptation strategies. Although this study dealt with historical and present-day flood vulnerabilities in Mopani District, projections of future vulnerabilities under climate change are even more important. Moreover, focusing on regional sensitivity, adaptive capacity and local exposure is critical in understanding local vulnerabilities and flood-related impacts [80]. This helps the policy and decision makers, and civil protection and disaster managers, to know exactly where to concentrate and invest to deal with risk and hazards.

Relevant and affordable adaptation strategies/actions are required to match the vulnerability levels of each area and its components. In addition, impacts of floods experienced over a region may influence local adaptation choices [81] with rural communities having high exposure, risk and minimal ability to recover. We found that the three study sites employed a variety of common adaptation strategies/actions to deal with the flood problem. Some strategies were more long-term, such as constructing a 'Le-guba', whereas others were short-term, such as temporary relocation, perhaps to higher ground. Issues of poor siting and quality of RDP houses, historical inequalities and population growth compound flood management in the region.

As the risk from floods increases, there is an urgent need to improve methods in decision support systems towards an effective early warning system, e.g., [48]. Accurate weather forecasts of extreme precipitation are crucial, while ensuring that weather warnings reach rural communities in a timely manner in order to protect lives, livelihoods and property. Another way to reduce risk is through implementation of a raft of improved and sustainable infrastructure maintenance regimes, with future developments focused on areas less prone to flooding [15].

There is a paucity of vulnerability assessments of rural settlements, such as those in Mopani District, where community livelihoods depend on natural resources and rain-fed subsistence agriculture, compounding their vulnerability compared to urban settlements. Despite being focused on the local scale, the findings of this study contribute to understanding the various factors that may affect vulnerability of similar rural communities to flood hazards. This is in addition to historical challenges such as lack of water supply infrastructure and good roads.

5. Conclusions

Our study detailed indicators and levels of vulnerability to floods in selected villages in Mopani District and determined a medium-level vulnerability calculated via the FVI. Analysis of extreme rainfall, geospatial maps derived from satellite remote sensing and other factors via the FVI determined that the study communities are indeed vulnerable to floods. The social survey revealed that the sampled households employed various adaptation strategies/actions to deal with floods in rural Mopani District. Although floods affected all three study sites, households employed several temporary and long-term adaptation strategies/actions. It was also found that the adaptation strategies employed by the three communities were markedly similar with only minor differences.

Although flood events may not be prevented, their impact and damage may be mitigated by proactive strategies employed by both vulnerable communities and disaster management authorities A participatory approach to flood risk management has also been recommended in a nearby town (Thohoyandou) where communities lead the response instead of a using 'top-down' approach [3]. Future research can also investigate the role of indigenous knowledge and local knowledge in water adaptation, as suggested by Zvobgo et al. [82]. Although our study focused on only the three vulnerable communities of Ga-Kgapane, Lenyenye and Nkowankowa in Mopani District, a bigger study that investigates flood vulnerabilities across the entire district is necessary. Local and traditional authorities in the district can also play an active role to discourage communities from settling on poorly drained lowlands.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Household survey questions and items.

Components	Indicators	
Social	• Sex • Education • Age • Marital status • Number people in households • Number of disabled people • Cultural heritage • Health status after flood events • Places of shelter.	**Awareness questions** • Flood risk awareness • Preparedness through early warning systems • Attendance of disaster related workshops • Financial support after flood events **Adaptation strategies and actions questions** • open questions
Economical	• Employment status • Main source of household income • Range of monthly income • Number of household members employed • Average expenditure per month • Dwelling quality and Infrastructure quality • Sanitation • Flood insurance • Recovery from floods	
Physical	• Rainfall • Topography • Flood frequency	

Table A2. Key informants survey questions and items.

Target	Type of Items
Authorities	• Drainage system capacity • Recent flood events • Socio-economic and environmental impacts • Community vulnerabilities • Factors determining flood vulnerability • Infrastructure damaged by floods • Diseases affecting communities after floods • Dam and storage capacity • Nature and availability of evacuation routes • Extent of flood vulnerability • Assistance from government and key stakeholders • Recommendations to reduce flood vulnerability • Recommendations to promote resilience to floods

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