

GEOSPATIAL APPROACH FOR ASSESSMENT OF VULNERABILITY TO FLOODS IN T/A JUMA MULANJE DISTRICT, SOUTHERN MALAWI

PRINCE ANDREW
Thyolo, Malawi

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DISSERTATION APPROVED BY:

SUPERVISOR:

Mr H. Yapuwa Signature: _____

ASSESSOR:

Title, Initials, Name Signature: _____

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ABSTRACT

Due to climate change and high population growth the occurrences of floods has significantly increase globally, with an impact on habitation and different sectors of the social life and economy. This, in turn, necessitates the use of different flood mitigation strategies, wherein flood vulnerability assessment plays a significant role. The proposed work presents a methodology that combines vulnerability under physical-environmental and socio-economic domains to assess the overall flood vulnerability. The methodology was applied to the case of traditional authority Juma, located on the banks of Thuchila river, in Mulanje district, Malawi. The spatial variation of hazard inducing factors and population statistics were analysed using Geographic Information System (GIS) tools. The geographical information system's (GIS) multi-criterial decision analysis (MCDA) approach was implemented to analyse both social economic vulnerability and physical environmental vulnerability of the area with criteria weights to incorporate the interests of different stakeholders. The critical combinations of the two domains of vulnerability in the assessment of the vulnerability to flood, to have efficient flood management in the study area was demonstrated in this study and can be made use of for any flood event. The flood vulnerability greatly depends on physical/environmental factors and combination with socio-economic indices gives more realistic results. The final vulnerability map shows the variation in term of vulnerability levels to floods.

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ACRONYMS/ABBREVIATIONS

DRM: Disaster Risk Management

MCDA: Multi-Criteria Decision Analysis

IPCC: Intergovernmental Panel on Climate Change

GIS: Geographical Information Systems

TA: Traditional Authority

NSO: National Statistical office

LULC: Land Use/Land Cover

AHP: Analytical Hierarchy Process

PV: Physical-environmental Vulnerability

SV: Socio-economic Vulnerability

CR: Consistency Ratio

DEM: Digital Elevation Model

NGO: Non-Governmental Organisation

TWI: Topographic Wetness Index

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1. BACKGROUND AND INTRODUCTION

1.1. Background

River floods are one of the most common natural hazards, causing devastating impacts worldwide. Previous studies have indicated that increased exposure of people and assets, as a result of population increase and economic growth, has caused more damage due to weather-related natural disasters including flooding(Tanoue et al., 2016). In addition, climate change and widespread poverty in hazard-prone areas may increase the frequency or magnitude of flooding (International Council for Science, 2017). To mitigate the adverse impacts of flood, the design and implementation of risk management strategies are necessary. Since floods are common and cannot be prevented, flood risk assessment plays an important role in flood disaster management and decision making(Deepak et al., 2020).

Global floods

Floods have the greatest damage potential of all natural disasters worldwide and affect the greatest number of people. Flooding has already caused more than 1 trillion US dollars globally since 1980, and the situation is poised to worsen (Mtembenuzeni & Kushe, 2019) and Since 2000, 400 large-scale flood events registered in the EM-DAT database have caused the deaths of more than 2000 people, affected 8.7 million others and generated at least €72 billion in losses (Guha-Sapir et al., 2015). According to Tanoue et al (2016) The impact of flooding is especially harmful in developing countries due to low levels of flood protection. For example, 6,648 flood fatalities were recorded in 2013 in India and Nepal, while the Philippines has suffered from recurring flooding that caused more than 100 fatalities every year between 2011 and 2013, and prolonged flooding in Thailand in 2011 caused serious economic losses. Developed countries have also suffered from flooding: in Europe, the Danube flooded in 2013, as did the Kinu River in Japan in 2015. However, flood loss and damage, especially in terms of numbers of fatalities, are generally less severe in developed versus developing countries due to historical efforts to mitigate

flood impacts. Differences in flood risk among regions reflect the balance between the magnitude of the flood (hazard), the number of people or the value of assets potentially affected by flooding (exposure), and the susceptibility to harm or lack of socioeconomic capacity to cope with flood risk depending on economic, social, demographic, cultural, institutional and governance factors (Nasiri et al., 2016).

Floods in Malawi

Malawi is one of African country mostly suffering frequent floods and between 1996 and 2013, floods accounted for 48% of major disasters (Robert, 2019). According Malawi 2019 post disaster needs assessment, (2019) (PDNA) shows that out of 28 districts in Malawi, 17 were affected by 2019 floods, and cause loss and damages amounted to US$220.2 million. In view of the country's high vulnerability profile, the recurrent phenomena in the form of flood hazards affects millions across the country leaving behind a trail of losses in the form of lives, property and livelihoods. Chikwawa, Nsanje, Phalombe, Mulanje, Kalonga, Lilongwe and Blantyre are the most flood prone district in Malawi. On average Malawi loses US$ 9 million or 0.7 percent of GDP each year due to floods in the southern region of the country(Program & No, 2009). The economic and social losses because of floods continue to mount year after year. Between 1996 and 2013, floods accounted for 48% of major disasters, and their frequency and severity is increasing (Robert, 2019). Over the past five decades, Malawi has experienced more than 19 major floods, with these events increasing in frequency, magnitude and scope over the years(*Malawi 2019 Floods Post Disaster Needs Assessment Report*, 2019).

Floods in mulanje district

Mulanje district is among one of the district in the southern region of Malawi severely affected by floods. These events negatively affect different sectors in the district including agriculture, education, health, and other sectors(Emergency & Appeal, 2019). According to Malawi 2019 Floods Post Disaster Needs Assessment, (2019) 0.27% of transport sector was affected by 2019 floods in the district, 1.01% of crop subsector, 0.15% of livestock subsector, 0.20% of irrigation subsector, 6.20% of housing subsector, and 7.06% of water sanitation and hygiene (WASH). The likelihood of be affected by floods are estimated to over 20,000

household(Plan, 2022) and among the following are most flood prone areas in mulanje district includes, TA Mabuka, Nkanda, Chikumbu, Jema, and Juma. Traditional authority Juma has been affected by floods due to over flow of Thuchila river. Due to deforestation and high population growth in TA Juma increases the risk of the river and flash floods in the district(*Republic of Malawi Mulanje District Council Socio-Economic Profile*, 2022).

The concept of vulnerability

Vulnerability determines how people will be affected and where are spatially located. The concept of vulnerability is approached from different disciplines and professional fields such as academia, disaster management agencies, climate change community and agencies. According to intergovernmental panel on climate change (IPCC), vulnerability is defined as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate change and extremes. Concerning climate change vulnerability, it refers to the state of susceptibility to harm from exposure to climate hazards, and the ability of a unit of analysis to cope with, and recover from, such exposure as well as manage incremental and long term changes in climate(Hemachandra et al., 2018). Though many definitions exist, the concept of vulnerability in this study considers the approach provided by Well and Collaborators. For them, it is the factors determined by physical, social, economic, and environmental factors or processes which increases the susceptibility of people to the impacts of disasters. Vulnerability to flooding, therefore, has many dimensions such as social, geographical, economic and political that influence how floods affects inhabitants in varying ways and with different intensities. Many approaches in assessing vulnerability to geo-environmental disaster exist. These approaches are reflecting in various analytical concept and models, which serves as guides for developing indicators for measuring that type of vulnerability. Many models have been used to approach the broader concept of vulnerability and have been well described elsewhere. For instance, the Conceptual Framework to identify Disaster Risk, defines risk as a function of hazard, exposure, vulnerability and capacities. Since vulnerability is also social, this framework appears incomplete as it excludes exposure and capacity from vulnerability. Bohle's Double structure of vulnerability,

however, recognise exposure and coping capacities as determinant of vulnerability but exclude sensitivity and resilience in the definition of vulnerability.

1.2. Problem statement

Flooding is one of common natural disaster that Malawi is experiencing which red to lose of life and property, social and economic disruption and environmental degradation. According to Journal, (2016) to counter and mitigate the floods and its negative impacts vulnerability assessment in the exposed areas is crucial. Despite a lot of flood vulnerability assessment studies being conducted a gap still exists where no comprehensive study on vulnerability assessment of floods using geospatial tools in Malawi has been conducted which is very critical as it vital for flood vulnerability assessment studies, especially in areas where data is scarce or outdated which is the case in Malawi(Analysis, 2020).

1.3. Objective of study

The main objective of this research is to assess vulnerability to floods using geospatial tools in Mkando area, Mulanje.

To achieve the main objective, the following sub-objectives were defined:

- To undertake geospatial socio-economic assessment in the study area.
- To carry out geospatial building and population exposure assessment

1.4. Research Questions

- How are the socio-economic characteristics of the area related to the population's vulnerability to floods?
- Does the structure type in the area reduce or increase exposure to the floods?

1.5. Significant of study

Research activities have been carried out about assessment of vulnerability for floods in T/A Juma, Mulanje district(*Benefits of Slower Population Growth in*

Mulanje District, 2018). But most of the vulnerability assessment studies less focus on using geographical information system(GIS) tools and remote sensing which is valuable tool for flood vulnerability assessment(Behanzin et al., 2016). Thus, this study fills the gap by using the GIS tools in the study which is according to Behanzin el al., (2016) is vital for flood vulnerability assessment studies, especially in areas where data is scarce or outdated. Most importantly, the study contributes important scientific data that supports the attainment of the Sendai frame work for disaster risk reduction (2015-2030) to achieve substantial reduction of disaster risk and losses in lives, livelihoods and health (UN, 2015).

2. LITERITURE REVIEW

2.1. Hazard

There are several definitions of hazard. Varnes(1984) defined natural hazard as the probability of occurrence of a potentially damaging phenomenon within a given area and specified period of time. This implies that hazards can be potentially dangerous especially if they occur in populated areas and may lead to great Impact in such areas depending on the hazard intensity and how vulnerable the elements at risk are. UN-ISDR(2004) mentioned that every hazard is characterised by its location, intensity, frequency, and probability. Their definition of hazard is a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption and environmental degradation. Crozier(1993) as cited by Hufschmidt(2011) define natural hazard as a condition that expresses the probability of damaging event occurring with a specified magnitude within a defined time period and area for instance the magnitude-frequency relation of process such as earthquake, landslides or floods. According to Hufschmidt (2011) such a conceptualisation of hazard is widely accepted and applied in present day risk researches.

2.2. Flood Hazard

Flooding is one of the most devastating natural hazards on the Earth's surface. It causes damage each year to cities, roads and agriculture with a very high cost in lives and to the economy as a whole. Jha et al., (2012) as cited by Uwakwe (2015) says floods may occur as a result of ground infiltration; failure of dams, pumping systems and reservoirs; from glacial melt, snowmelt or rainfall which can develop into flash or riverine floods; and can originate from the sea in the forms of coastal degradation and storm surge. Other causes of flooding include population growth; urbanization; land use such as deforestation, intensive agriculture, and unplanned flood control measures; cyclones; and climate change(Rahman, 2014).

There are several types of floods. Rahman (2012) categorized floods into the following classes, namely, urban flooding, flash flood, river or fluvial floods, semi-permanent flooding, coastal floods, groundwater floods, pluvial or overland floods. Additionally, the characteristics of floods are important in understanding the physical hazard posed by that flood type. These includes water depth and its spatial variability, spatial extent of inundation, particularly at areas that are not normally covered by water, water velocity and its spatial variability, duration of flooding, suddenness of onset of flooding, and the capacity for erosion and sedimentation(Iii, 2003).

In TA Juma the flood type is usually classified as river flood. Most of the floods originates due to overflow of Thuchila river and affect the surrounding areas. This flood type is characterized by high water velocity, short duration, and most times it leads to erosion and sedimentation in the environment.

2.3. Factor influences flooding susceptibility

There are different socio-economic factors that influences the susceptibility of the communities, households, and individuals to floods hazard these including demographic characteristic, and building characteristics

Demographic characteristics

Biological differences like age, gender, marital status, education and employment make different demographic groups more or less susceptible to extreme events and climatic shock. Other than influencing exposure, demographic and socioeconomic characteristics are principal drivers of population's ability to prepare for, respond to, cope with and recover from natural disasters and impacts (Muttarak, 2017). According to Cutter, (1995) as cited by Muttarak, (2017) literature commonly identifies the elderly, children, women, the disabled, members of minority ethnic groups and individuals with low income as being more vulnerable to shocks.

Building characteristics

Building is one of the element at risk mostly affected by disasters including, floods. Building damage determine the intensity of floods. Condition of the building determine how the building will behave under a certain hazard. Behaviour of the

building also affected by building materials, height of the building, age of the building, and maintenance level(Schanze, 2014).

2.4. Vulnerability assessment approach

Various methods and approaches were developed to assess the susceptibility of communities to flood hazards these including, Disaster loss data method, Vulnerability curve method, Vulnerability indicators method and geospatial method.

Disaster loss data method; This method is constructed on data collection from real flood hazard and their usage such as a director to upcoming events. This method is a simple approach but will be a little inaccurate Because of unevenly recorded data so result of these methods should be treated caution(Nasiri et al., 2016).

Vulnerability curve method; This method the empirical damage or fragility curves are used to relate flood risks and elements at risks. According to Nasiri et al., (2016) the approach is essentially founded on data from well-documented case studies so typically restricted to dwellings in a specific area. This group of method picks out a sample of items in each selected class and a list of possible subjects is arranged. The data for all samples of each component class is averaged and step-damage curves created. The subsequent stage-damage curves are for potential damage, although similar methods can be used to measure damages that happen immediately after a flood. Method is based on actual damage survey so takes a lot of time and resource and the reliability of this method is less than others because it is not applicable for other regions(Rehman et al., 2019).

Vulnerability indicators method; The approach adapted to use available data for providing a logical Image of the place vulnerability. The method is widely used in flood vulnerability studies and preferred by policy makers for its clarified vulnerability image over space, a depiction which aims to priorities measures and plan for the risk response in specified region(Nasiri et al., 2016). However, this approach has number of shortfalls and weaknesses including, difficulties in quantification of a number of social indicators poses to the calculation it depends on complicated indices with and without weighting, also faced with considerable complexities related with standardization, weighting and aggregation methods and

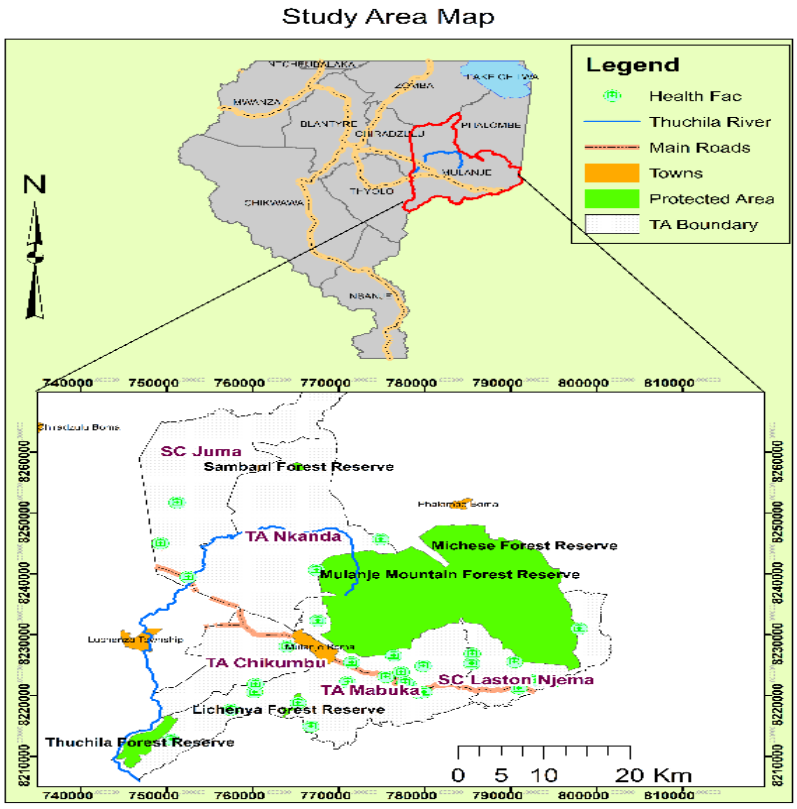
uncertainty is one more struggle with this method. Since each additive layer includes a diverse variable, struggle about variable Interdependencies must be fixed. **Geospatial approach;** Remote sensing and Geographic Information System (GIS) techniques have been successfully made use of in flood vulnerability assessment(Deepak et al., 2020). Also a variety of approaches such as GIS overlay analysis, Multi-criteria decision analysis, fuzzy approach, Random forest approach have been used in vulnerability related studies (Lee et al. 2015). Geographic Information System (GIS) based Multi-criteria decision analysis (MCDA) is a collection of methods for evaluating and combining geographic data and user preferences to aid in decision making(Deepak et al., 2020). Because of its flexible nature for analysing multiple and conflicting criteria, MCDA approach can be widely used to spatially represent flood vulnerability related studies. Moreover, interests from different stakeholders are incorporated in MCDA in the form of criteria weights, thereby providing a solution for a multi-dimensional problem such as flood vulnerability which could be viewed under economic, physical, social, environmental perspectives(Deepak et al., 2020). In general, remote sensing and geographical information method assess vulnerability in local scale more sensitive than other ones because considers specific local factor hence give accurate vulnerability of an area.

3. RESEARCH DESIGN AND METHODOLOGY

3.1. Study area

The Traditional Authority Juma was chosen as a study site because of the paradox expressed by the fact that it is a low social standing area with a relatively large number of flood affected people. Due to this low social standing the area has a lot of slums and some poor residential areas which increase the threat to the impacts of flooding. This area has recently been flood prone than it was twenty years ago. Climate change that leads to unprecedented amount of precipitation and also human activities pertaining to land use have exacerbate flood risk as cutting trees along Thuchila river for cultivation resulted into river flooding. Thuchila River extending from Mulanje Mountain runs through this area. During rainy season the river burst into its banks causing widespread damage to properties and even fatalities. TA Juma is located in Mulanje at 15.9166^{0}S and 35.3593^{0}E latitude and longitude respectively

The study area is shown in figure 1 below.



3.2. Methodology

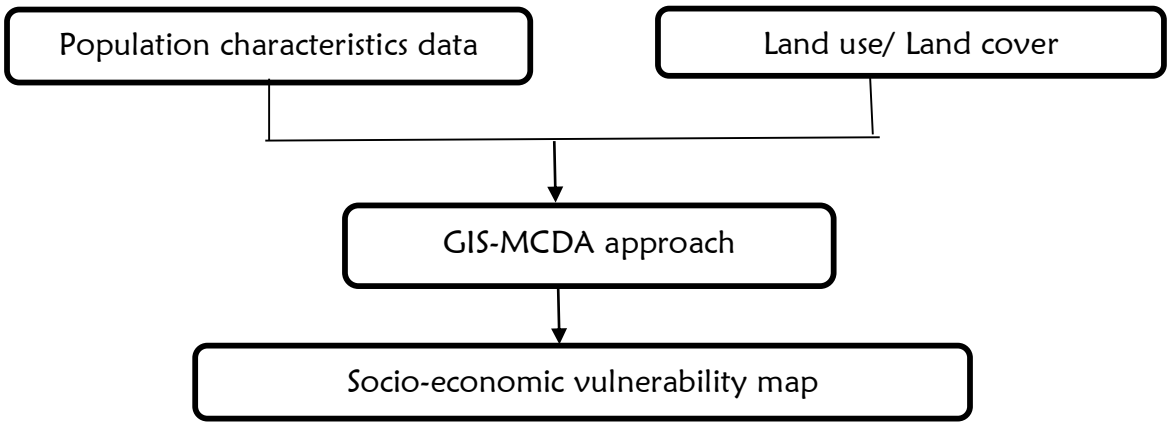
The methodology was designed to assess both socio-economic and physical vulnerability of the study area using GIS tools (T/A Juma, Mulanje district).

3.2.1. Socio-economic vulnerability

Indices including age group, gender, number of members in a family, the function of buildings, condition of buildings, unemployment and literacy rate of people, distribution of population density, and land use or land cover classification of the area were taken into account to estimate socio-economic vulnerability of the area. The following procedure was adopted for analysing the socio-economic vulnerability.

First, a hierarchical structure was created using population data and land use data by analysing various factors that influence the vulnerability of the area. The population data which was obtained from Malawi National Statistics office (NSO) includes age goups, gender, number of members in a family, function of the building, condition of buildings, unemployment, literacy rate, number of buildings and population density. This was used along with land use data obtained from land sat image derived by supervised classification to form the four objectives namely population, buildings, economics and exposed elements. These were considered as the three-level hierarchical classification model(Deepak et al., 2020). ArcGIS software was used to create the different map layers for the various parameters considered in the study.

Figure 2 below is the methodology for social economic vulnerability



3.2.2. Physical-environmental vulnerability

In the study, Proximity to the river, Slope, and Land use/land cover(LULC), patterns were factors identified to affect the physical-environmental vulnerability. Flooding in the study area is due to heavy rains and associated overflow from Thuchila river to nearby areas. As the nearness to the river increases the vulnerability to flooding event also increases. Moreover, a higher elevation and slope possess lesser chances of holding the excess water causing the flooding and consequently decreases the vulnerability. According to Deepak et al. Vulnerability in the physical-environmental aspect is further analysed by the land use land cover (LULC) pattern of the area. (LULC) was classified into four groups including built-up land, vegetation, water, and bare land

Table 1, Land use/Land cover classification

Land use/cover	Description
Built-up	Area that has been populated (for example residential, commercial, industrial, transportation and facilities)
Vegetation	Area covered with mature trees, shrubby plants and other plants growing close together.
Water	Area covered with water such as river and lakes
Barren land	Mountainous or hill areas, no covered vegetation Area, degraded land and all unused area.

Built-up area and roads cannot percolate water to subsurface and can make the area more vulnerable whereas forest/vegetation area can enhance the penetration of water to subsurface layers of earth and thus decreasing chance of flooding. A highly physical-environmental vulnerable area is those which are at higher flood risk due to its physical and environmental characteristics. For instance, area at a higher elevation/slope is less vulnerable, while the area at closer proximity to the river is more vulnerable. A combined assessment of such physical and environmental factors is made use of to classify the study area to different

vulnerable zones. A low vulnerable zone is less susceptible to flood and can be considered suitable for human settlements.

The following procedure was adopted to analyse physical environmental vulnerability.

Firstly, one level hierarchical structure was created from satellite data. The satellite data which was obtained from USGS earth explorer to identify the proximity to river, land use land cover, slope of the study area. ArcGIS software was used to create the different map layers for the various parameter of physical environmental vulnerability considered in the study including the elevation, slope, proximity to river and land use land cover.

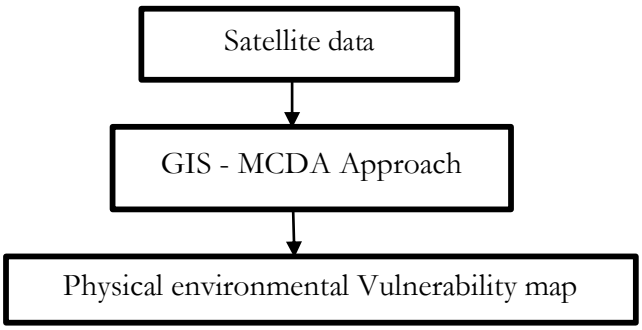


Figure 3. below is methodology for physical environmental vulnerability.

3.2.3. Combined vulnerability to floods.

A region can be considered vulnerable to flood if it is both socio-economic and physical-environmental vulnerable. This concept can prevent over estimation in many cases as a socio-economic vulnerable region may not be physically/environmental vulnerable. Thus, the socio-economic vulnerability (SV) obtained from MCDA approach and the physical/environmental vulnerability (PV) from MCDA approach was combined using AND operator to get the spatial distribution of vulnerable zones (V) within the study area. This can be expressed as:

$$V = SV \cap PV$$

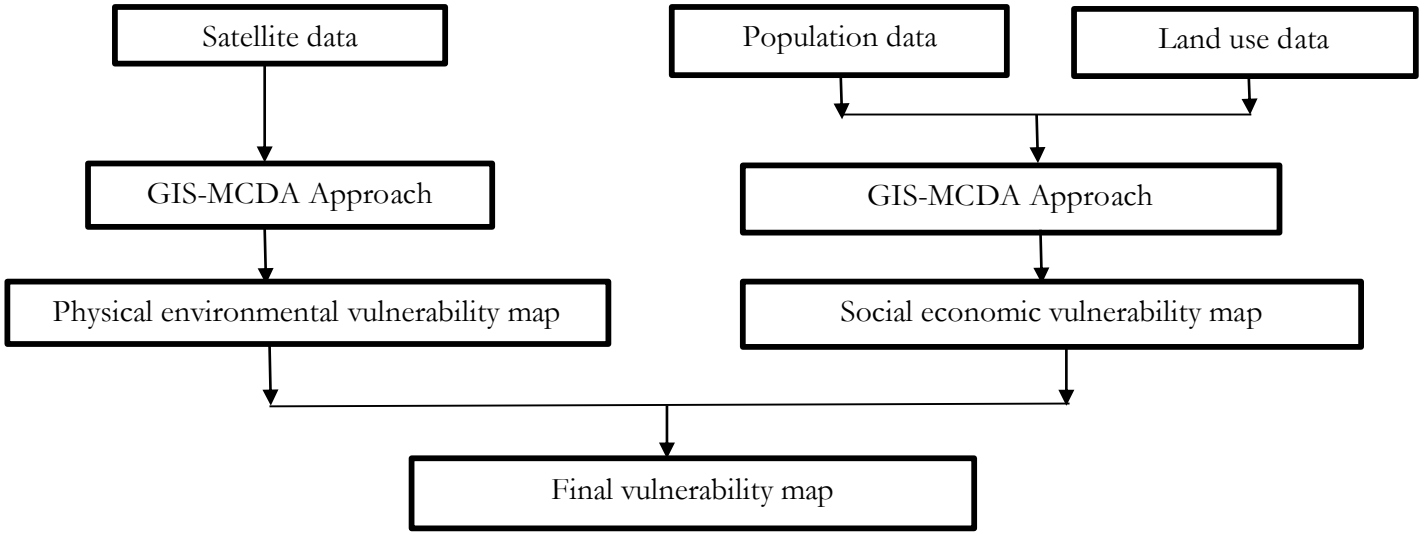


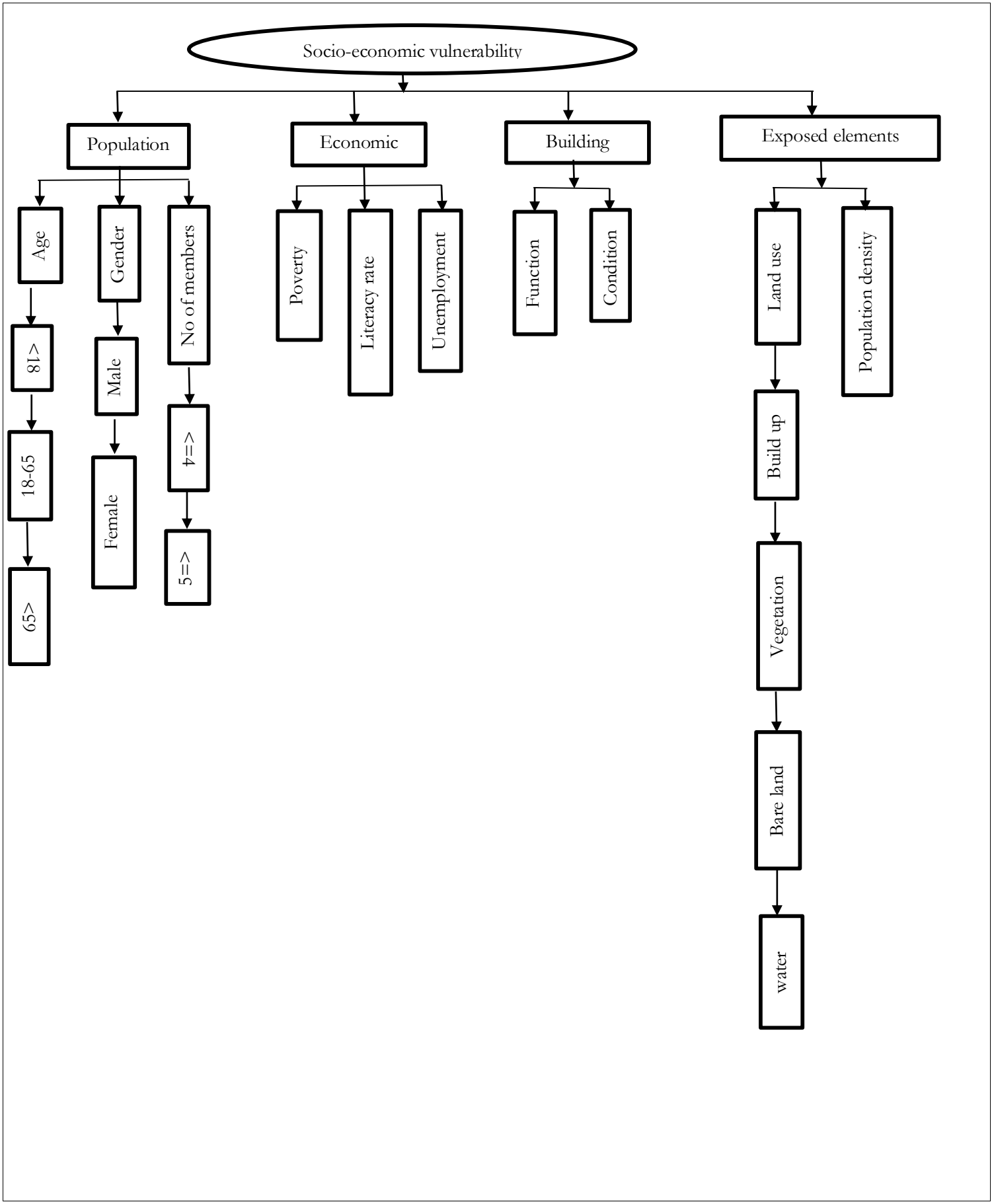
Figure 4 below shows the Methodology for Vulnerability Assessment

3.3. Multi-criteria decision analysis(MCDA) process

The details pertaining to the assessments of vulnerability for the study area are discussed subsequently.

3.3.1. Analysis of factors affecting socio-economic vulnerability

Figure 5 below is hierarchical structure of socio-economic vulnerability model


Socio-economic vulnerability
Population
Economic
Building
Exposed elements
Age
Gender
No of members
Poverty
Literacy rate
Unemployment
Function
Condition
Land use
Population density
<18
Male
<=4
Build up
18-65
Female
5=>
Vegetation
65>
Bare land
water

The **figure 5,** above is the hierarchical structure of socio-economic vulnerability model. The population indices considered were age group, gender, and the number of members per house as the second level factors. The third level classification for age was included as, age below 18 years, age between 18 and 65 years and age above 65years, as the extremes of the age spectrum are more vulnerable to the disaster. In the case of gender, third level classification include male or female and for the number in family representing houses with members less than 4 or greater than 5, considering the fact that larger families would have more dependent to evacuate and thus have to share the resources.

The second level factors for the objective buildings include function, and the condition of the buildings. Based on the type of use, buildings were classified into residential and commercial buildings. A similar classification was followed for the condition of buildings. The buildings were classified into three as, houses with good living condition, liveable condition and with the poor condition, with maximum weightage given to houses with unliveable condition and minimum weightage to those with good condition.

The next objective of economics, considered unemployment, poverty and illiteracy as the factors. The unemployed are dependent on other family members and are considered more vulnerable. While considering poverty, poor people are considered more vulnerable as they have very low capacity to anticipate, absorb, and recover after a floods due to limited resources thus economically more vulnerable. Illiterates were considered as more vulnerable as they generally lack the basic knowledge to adapt in a hazard situation. While considering the objective of exposed elements, the second level factors include land use, and population density. Under land use, built-up, agricultural area and barren land were considered as the third level factors. The urban area was considered as highly vulnerable to a flood event, whereas the vulnerability of agricultural land is dependent upon on the crop season and the barren land always possess relatively low vulnerability. The population density and density of buildings are also important factors that influence socio-economic vulnerability in risk areas.

According to the hierarchical classification, three-level of maps were prepared. The process of map preparation assumes negligible effect of the floating population within the study area. Various map layers were created in the ArcGIS platform. The weights were assigned to each factor using Analytical Hierarchy process (AHP). After creating the hierarchical structure of socio economic vulnerability model, the relative importance of each pair of criteria of the model is evaluated. Saaty's 9-point continuous scale (Song & Kang, 2016) was used for weighing each criterion for the creation of a pairwise comparison matrix. First the pair-wise comparison matrix was created using each of the attributes within the third level factors. The score of one indicates that both criteria were equally important whereas a score of 9 indicates extreme importance of one criterion over the other. All scores were assembled in a pairwise comparison matrix with the value of 1 on the diagonal and reciprocal scores on the lower left triangle. The pairwise comparison generated was based on expert opinion which was evaluated. For each level in hierarchy it is necessary to understand the consistency of judgement to accept the results of judgement. The Parameter consistency ratio (CR) is used to check the consistency and the value of CR greater than 0.1 has to be re-evaluated. By trial and error, the weights for each factor in the third level were obtained. Using each of these weights, weighted overlay was performed on the third level factors to create the second level factors. Similarly, weight estimation and overlay for each of the second level and third level factors were performed respectively to obtain the final vulnerability map.

The measurement of each of these factors was done on different scales. Thus, rescaling of these factors to a common scale was necessary. The factors were standardised to a linear scale of 1 to 10, where 1 represents very low vulnerability and 10 represents very high vulnerability. A simple additive weighting procedure such as weighted linear combination was used to combine each criterion. The 3rd level maps were combined using WLC to create 2nd level maps and further these 2nd level maps were clustered to generate 1st level maps based on the four above mentioned objectives. The final social vulnerability map was obtained by combining the four objectives by assigning equal weightage to them.

Analytical Hierarchy process (AHP)

AHP is a decision-making technique utilized for solving complex problems, with many parameters of interrelated objectives or concerned criteria(Rimba et al., 2017). The level of each parameter is not equal, some parameters are dominant over others(Rimba et al., 2017). Different weights can generate the difference in the level of susceptibility. It is based on ranking from the experts, literature reviews and previous study. The AHP pairwise have to be consistent with all pairwise comparisons. The social economic AHP parameter for flooding include population (age, gender, and number of members in a family), building characteristics (function, and condition), economic (poverty, illiteracy, and unemployment) and exposed elements (land use and population density)

No	Function	Weight
1	Age	0.55
	Age less than 18	0.65
	Age between 18-65	0.16
	Age greater than 65	0.23
2	Gender	0.33
	Male	0.33
	Female	0.66
3	Number of family members	0.12
	Members <= 4	0.16
	Members 4 >	0.83
4	Unemployment	0.12
5	illiteracy	0.33
6	Poverty	0.55
7	Land use	0.25
	Build up	0.68
	vegetation	0.25
	water	
	Bare land	0.07
8	Population density	0.75

9	Condition of building	0.68
	Good	0.07
	Liveable	0.25
	Poor	0.68
10	Function of Building	0.23
	Residential	0.13
	Commercial	0.88

Table 2. Weight for Socio-economic vulnerability factors

Analysis of factors affecting physical environmental vulnerability

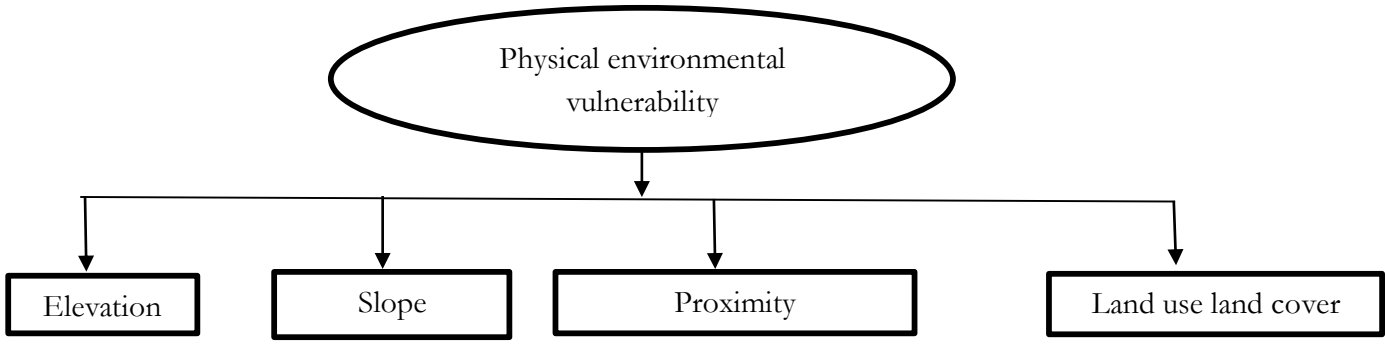


Figure 6, hierarchical structure of physical environmental vulnerability

The figure above is the hierarchical structure of physical-environmental vulnerability model. The physical environmental factors considered were elevation, proximity to the thuchila river, slope, and land use land cover. Raster layers were created using ArcGIS software from remote sensing data for the analysis. Elevation of the area from the mean sea level was one of the factors affecting the physical-environmental vulnerability. A Digital Elevation Model (DEM) was used to get the spatial variation of elevation in the study area. The Cartosat DEM of one arc second spatial resolution (approximately 30 m) was used in this study. Those pixels which lie in higher elevation are considered to be less prone to flood as compared to those in low-lying areas. The slope was another aspect considered in the study, derived from DEM using GIS tools, with the index reflecting the degree of topographic change. Regions with high slopes drain the water faster compared to the flat regions that are more susceptible to flooding. Proximity to the river was another most important factor affecting the vulnerability. It is considered that an

area having closer proximity to the river channel is more likely to be affected by the flooding. Since both proximity to river and elevation are incorporated in the study, a combination of situations like an area nearer to the river but having higher elevation was considered as less vulnerable. Land Use Land Cover of the area is also a key factor which determines the intensity of flood. Five land classes over the study area were identified by field studies and using the supervised classification of Landsat image, the study area was classified into Built-up area, Water cover, Tree-cover, Barren land and Paddy fields. Built-up area includes regions where buildings and roads exist, with least percolation of water to the sub-surface; whereas paddy fields are recharge zones where water easily reaches the subsurface layers. Thereby built-up area contributes to flood hazard vulnerability, whereas paddy fields and barren lands can decrease the chances of the area being flooded. Different raster maps created for all the indices considered to be inducing factors for flooding were analysed.

The weights were assigned to each factor using Analytical Hierarchy process (AHP). After creating the hierarchical structure of physical environmental vulnerability model, the relative importance of each pair of criteria of the model is evaluated. Saaty's 9- point continuous scale (Song & Kang, 2016) was used for weighing each criterion for the creation of a pairwise comparison matrix. First the pair-wise comparison matrix was created using each of the attributes or factor. The score of one indicates that both criteria were equally important whereas a score of 9 indicates extreme importance of one criterion over the other. All scores were assembled in a pairwise comparison matrix with the value of 1 on the diagonal and reciprocal scores on the lower left square. The pairwise comparison generated was based on expert opinion which was evaluated. For each level in hierarchy it is necessary to understand the consistency of judgement to accept the results of judgement. The Parameter consistency ratio (CR) is used to check the consistency and the value of CR greater than 0.1 has to be re-evaluated. By trial and error, the weights for each factor were obtained.

Table 3. Weight for physical environmental vulnerability factors

No	Function	weight
1	proximity	0.527
2	slope	0.332
3	land use land cover	0.141

4. RESULTS AND DISCUSSIONS

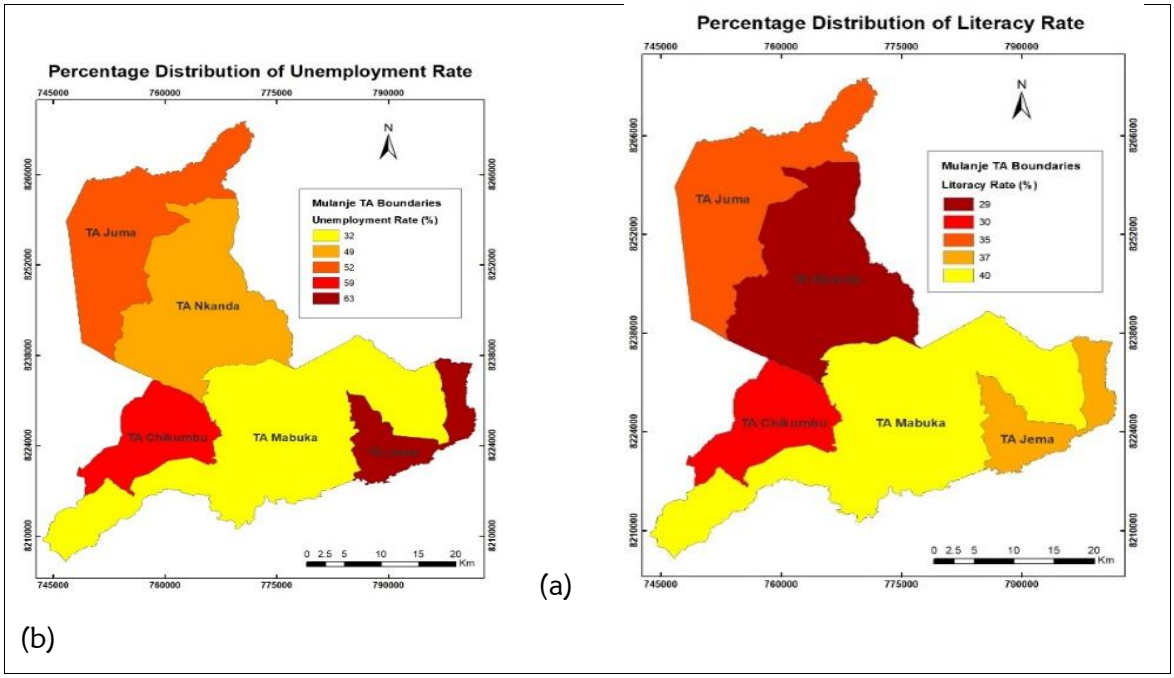
In this section, we present and describe the results obtained through the spatial analysis for all single and composite indicators for vulnerability used for final vulnerability map of TA Juma in Mulanje district.

4.1. Socio-economic vulnerability

The study illustrates the assessment of the vulnerability in generating the vulnerability to floods in mulanje district, TA Juma. The summary of the outcomes of the study is as follows;

The standardised criteria weights for different parameters obtained using AHP for the study are presented in **table 1** above. The second and third level maps were produced for different functions from the third level maps and the vulnerability map for each collection of function were prepared as explained below.

4.1.1. Economic indicators



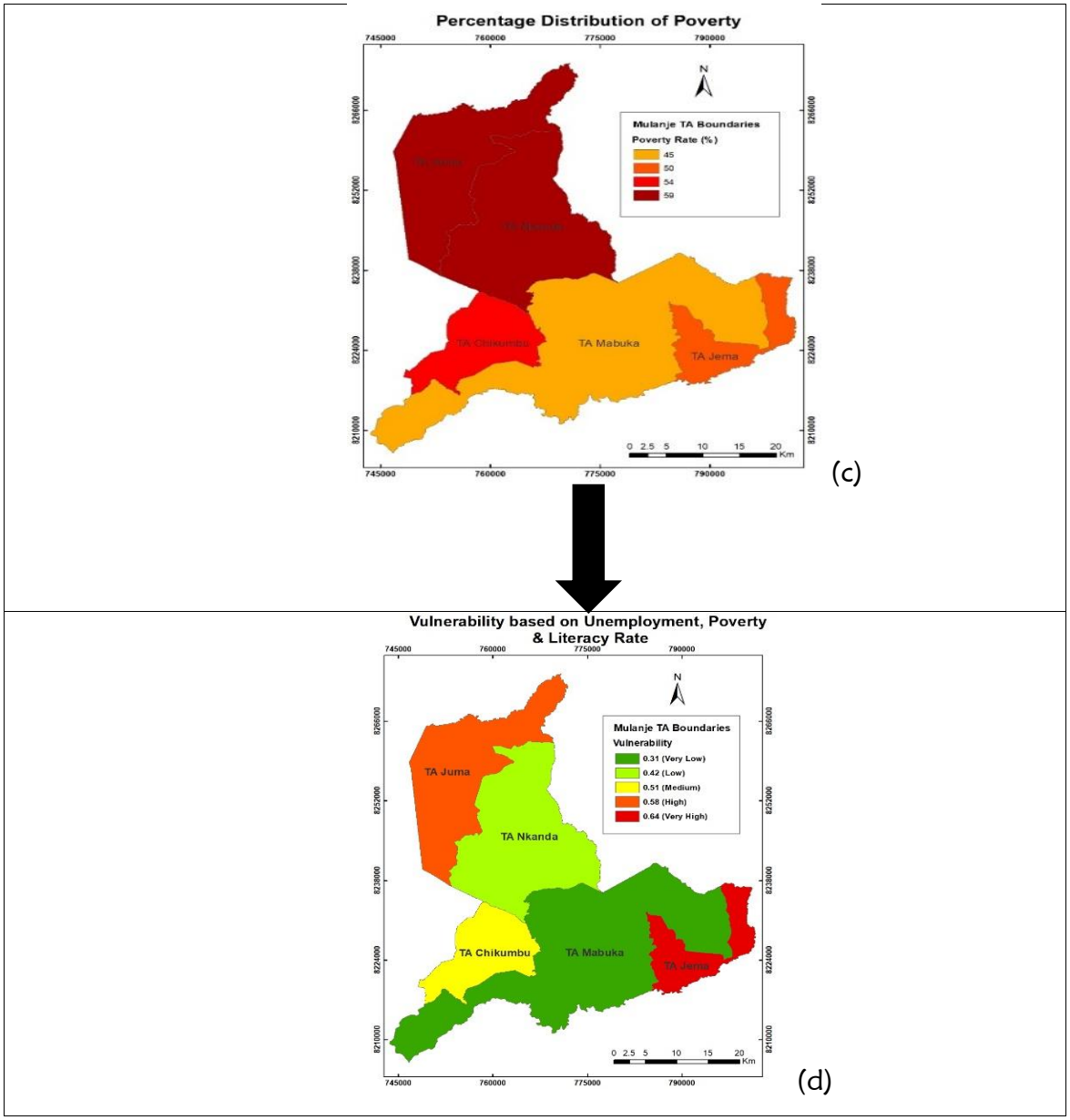


Figure 7 below are map for unemployment rate(a), literacy rate(b), poverty rate(c), and vulnerability map(d) after combine the three variables

The maps above were for second level of hierarchy structure which shows the percentage of unemployment (a), literacy (b), and poverty (c) respectively. These parameters represent economic factors for our area of study. Economic factors determine the capacity and susceptibility to hazard, hence contribute to the resilience of individual and community, to floods disaster.

Unemployed people, who represent the group with least capacity to recover from flood damages without external help, are, in general, sparsely distributed across the

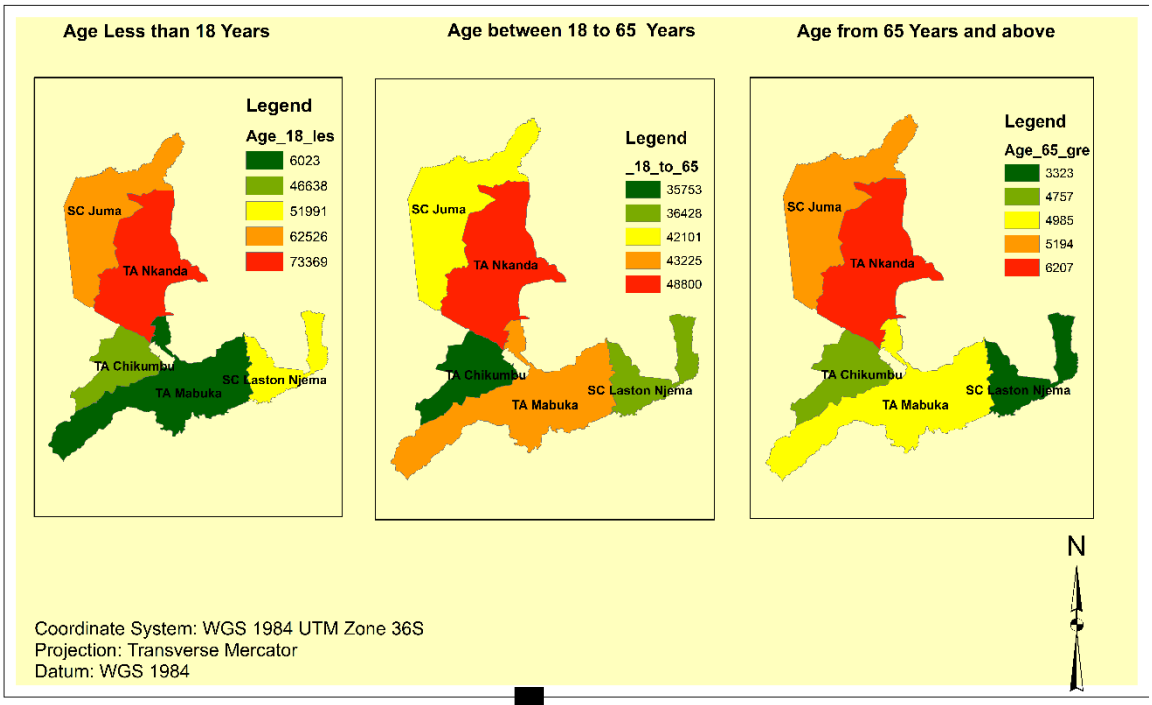
district. The percentage of unemployed people as shown in **figure 1(a)** appears to be high in TA Jema with 63 % followed by T/A Chikumbu with 59%, then Juma with 52%, TA Nkanda had 49% and TA Mabuka has least number of unemployed people which is 32%. Based on the indicator of unemployment it shows that TA Jema, Chikumbu and Juma are much vulnerable to floods since large number of people are jobless as such they cannot build strong houses, since they cannot afford standard building materials hence less resilient. At the same time unemployed people cannot afford safe land for settlement as such they mostly based in high flood risk areas. And also after a disaster they may much depend on assistance from government and other civil societies and non-governmental organisation. But the argument comes in with the weight assigned to unemployment which is 0.12. This shows that unemployment cannot much contribute to the vulnerability of people to flooding. This maybe because people in the area can have other means of earning income apart from get employed like farming and running businesses that can increase their resilience to flood disaster since they can able to build standard houses that can with stand during floods, buy a safe land for settlement and also bounce back after a flood disaster since they have strong financial muscle which increase their resilience.

The lower literacy rate was mostly located in TA Nkanda and Chikumbu with 29% and 30% respectively. Higher literacy rate was mostly located in TA Mabuka and Jema with 40% and 37% respectively whereas TA Juma had medium percentage of literacy rate among all TAs with 35%. The lower the rate of literacy the lower the capacity of people to take effective measures to prevent, mitigate, prepare for the flood hazard. Also the higher the higher the rate of understanding the warning systems hence taking effective action to respond to a flood event. Based on this indicator TA Mabuka is more resilient to flooding since has higher percentage of literacy whereas TA Jema has less resilient due to higher percentage of illiteracy. map reviewed that TA Mabuka has high literacy rate of 40%, and the next is TA Jema with 37, which is followed by TA Juma with 35%, then TA Chikumbu had literacy rate of 30%, and at the bottom was TA Nkanda with 29%. Based on weight assigned to illiteracy rate which 0.33, it shows that it has higher

contribution to increase the vulnerability of people to flood disasters than unemployment.

Poverty is another resilient component. The rate of poverty appears to be higher in TA Juma and Nkanda with 59% in both TAs. TA Mabuka has the lowest rate of poverty of 45%. Poor people has less capacity to recover during post disaster phase without external assistance like governmental and NGOs, and other companies and civil societies. They also lack capacity to build standard house that can with stand during flooding and also, they tend to build in more risk flood prone areas due to lack of financial resources to buy a safe land for settlement. All these increases the susceptibility of poor to flooding. Due to high percentage poverty in TA Juma and Nkanda the area is more susceptible to flood compared to TA Mabuka which has least percentage of poverty of all TAs. The vulnerability map presented in **figure 1(d)** is a result of combination of three resilient indicators: poverty, unemployment, and literacy rate. Based on combination of these resilient indicators TA Mabuka has very low level of vulnerability, followed by TA Nkanda. TA Jema has very high level of vulnerability and TA Juma has high vulnerability level. This means in these areas the rate of poverty, illiteracy, and unemployment is very high hence they lack resilient. This results are similar with what Toteng & Mulalu (2019) found when assessing flood vulnerability in Ramotswa and Taung villages in the south east district of Botswana. They found that due high population in these district there was high unemployment and school attendance was very low which contributed to poverty. This thus contributed in increasing the vulnerability to floods.

4.1.2. Age distribution



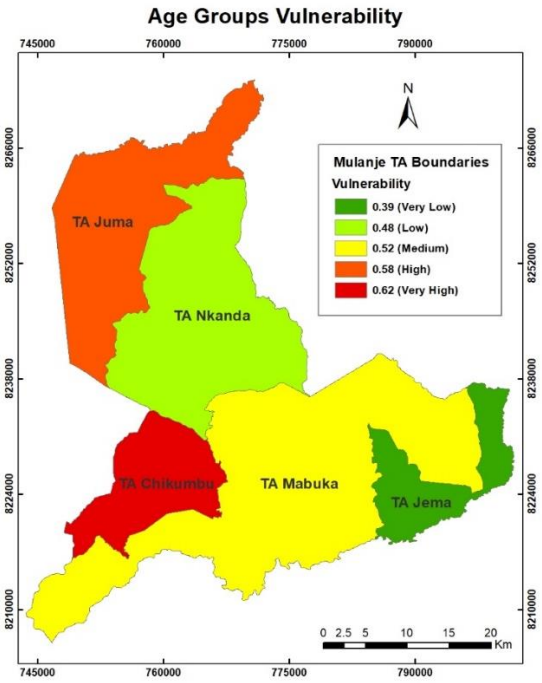


Figure 8. Age distribution maps (a) under age of 18 map; (b) age between 18-65 map; (c) age above 65 map; (d) vulnerability map from combination of three variables

The map above shows the population of age distribution in floods prone traditional authorities in mulanje district.

Concerning the spatial distribution of the age throughout the district, **map (a)** shows the percentage of population under the age of 18 in all TAs. The map reviewed that there is high concentration of younger people below the age of 18 in TA Nkanda with 73,369 (57.2%), followed by TA Juma with 62,526 (56.9%) young people, and TA Jema has concentration of under 18 with 51,991 (56.7%) young people then TA Mabuka has 46,638 (55.5%) and lastly TA Mabuka has least number of under 18 with 36,023 (53.5%). Young people or children are much dependent on their guardians or parents for their daily basic needs therefore increases the number of people depend on external relief item after a disaster hence less resilient. Also children are not physically fit and cannot take effective measure in responding to floods hence more susceptible to flood impacts therefore increases then number of injuries and fatalities during flood disasters in areas where have higher number of children of which in this case is TA Nkanda and Juma. Since these two TAs are much close (high proximity) to thuchila river which much overflow during rainy season hence are more vulnerable to floods.

Map (b) in figure 8. Shows the age distribution of 18 to 65. People within this age range represent group of people with high capacity to recover from flood damage without much support from external assistance, and less susceptible to the impacts of floods. From this age range TA Chikumbu, Juma and Jema has higher population hence are less vulnerable to flood event since majority of its population are economically productive and can be able to recover in post disaster phase. People of this age range can be able to take effective and action to prevent, mitigate, prepare and respond during the flooding therefore lessen their vulnerability to floods. On the other hand, TA Nkanda and Mabuka are more susceptible to flood event as its population has less adults, 48,800 (38.3%), and 43,225 (38%) respectively.

From the **figure 8. Map(c),** showing the age distribution of population above 65. The map reviewed that there is higher concentration of elderly people in TA Nkanda 6,207 representing 5.5% of the population and is seconded by TA Nkanda with 5,194 (4.8%) elderly people, and is followed by TA Mabuka by 4.6%, and lastly is TA Jema with lowest population of elder people which is 3.6. Elderly people are physically weak and also most of them are poor as the statistics shows(*The Fifth Integrated Household Survey (Ihs5) 2020 Report* `, 2020),and more dependent on relatives for their basic needs and this expose them more vulnerable since they lack resilience and incapacitated since they cannot insure their houses, themselves on medical scheme, and also their property, they cannot invest neither savings hence they cannot bounce back after a disaster without external assistance. Being less physically fit they increases the cases of injuries and fatalities during flooding. Despite being old, elderly people have more experience on how to respond during flooding therefore they are not much susceptible as children that it has assigned with less weight 0.23.

The vulnerability map presented in **figure 8. Map (d)** is the result of combination of these three susceptibility indicators; age below 18, age between 18 to 65, and age above 65. Based on combination of these susceptibility gives that TA Chikumbu is very high vulnerable followed by TA Juma which is high vulnerable to floods due to high population of age below 18 and above 65. Since TA Jema and Nkanda has high population of people of age between 18 to 65 thus its less susceptible to the floods and its impacts. These finding are in agreement with what Ketcha et al.,(2017) found which found that children and elderly were more susceptible to floods in the southeast of the district of Cocody in Nigeria since they are difficultly in terms of mobility, economic activities and physical capacity, in turns this reduced their capacity to access to information or to appreciate the urgency of certain situation, even to access suitable land for settlement.

4.1.3. Gender

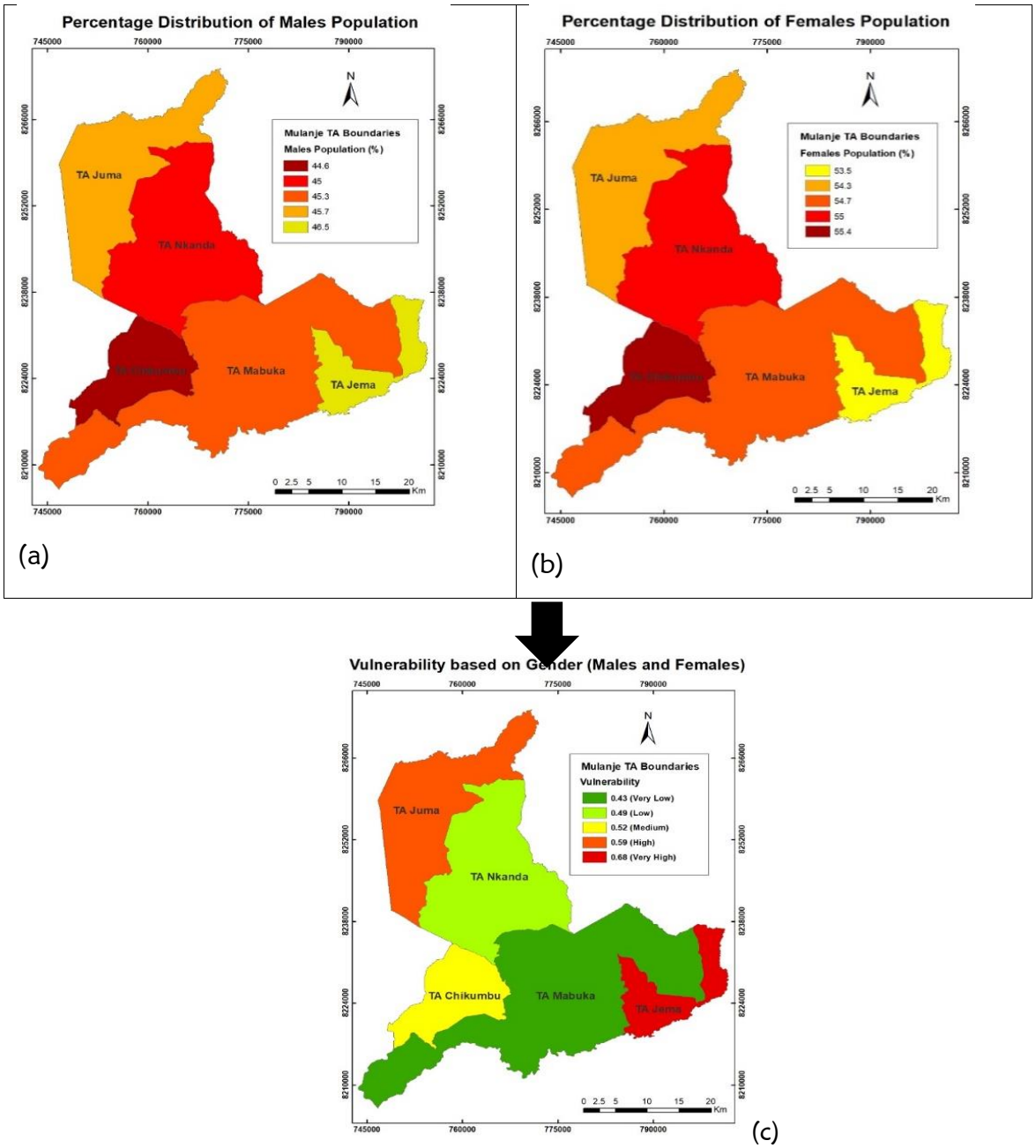


Figure 9. Gender distribution maps (a) male map; (b) female map; (c) vulnerability map

The spatial distribution of gender in the study areas is displayed in the **figure 9** above.

Based on the spatial distribution of gender throughout the district **figure 9(a) and (b),** it shows in TA Chikumbu 55.4% of its population are women where men take the least 44.6%, and is seconded by TA Nkanda with 55% women and 45% men. TA Juma and Jema has the low women population 54.3% and 53.5% than men

population 45.3% and 46.5% respectively. Generally, floods like any other disaster affect men and women differently. This is due to deep cited inequalities; women are at greater risk to suffer the impact of floods than men(Analysis, 2020). Mostly in rural areas men enjoy legal, social, and economic opportunities much more than women. This gender gap of access and control of resources, economic opportunity, political voice and in power put women at disadvantage when it comes to withstand of cope up the impacts of floods. Women given less attention on socio-economic indicators hence they bare much socio-economic effects and impacts. Women are more likely to be poor than men. All these factors make women more vulnerable to floods.

As a result of combination of these two indicators, it determines the susceptibility of the area to the floods hazard which intend to determine the level of vulnerability each TA has. **Map (b) on figure 9** shows that TA Jema is very high vulnerable with 0.68 whereas TA Juma is high vulnerable to flood with 0.59 due high population of women than men. Based on gender distribution TA Mabuka has very low vulnerability level since it has high population of men. The final findings are in line with what (Deepak et al., 2020) found when assessing vulnerability to floods in Ernakulam district, Kerala state in India, where due to deep cited inqualities, including in economic opportunity, education access, access and control of resources womes suffer greater burden to floods, and its impacts.

4.1.4. Number of family members

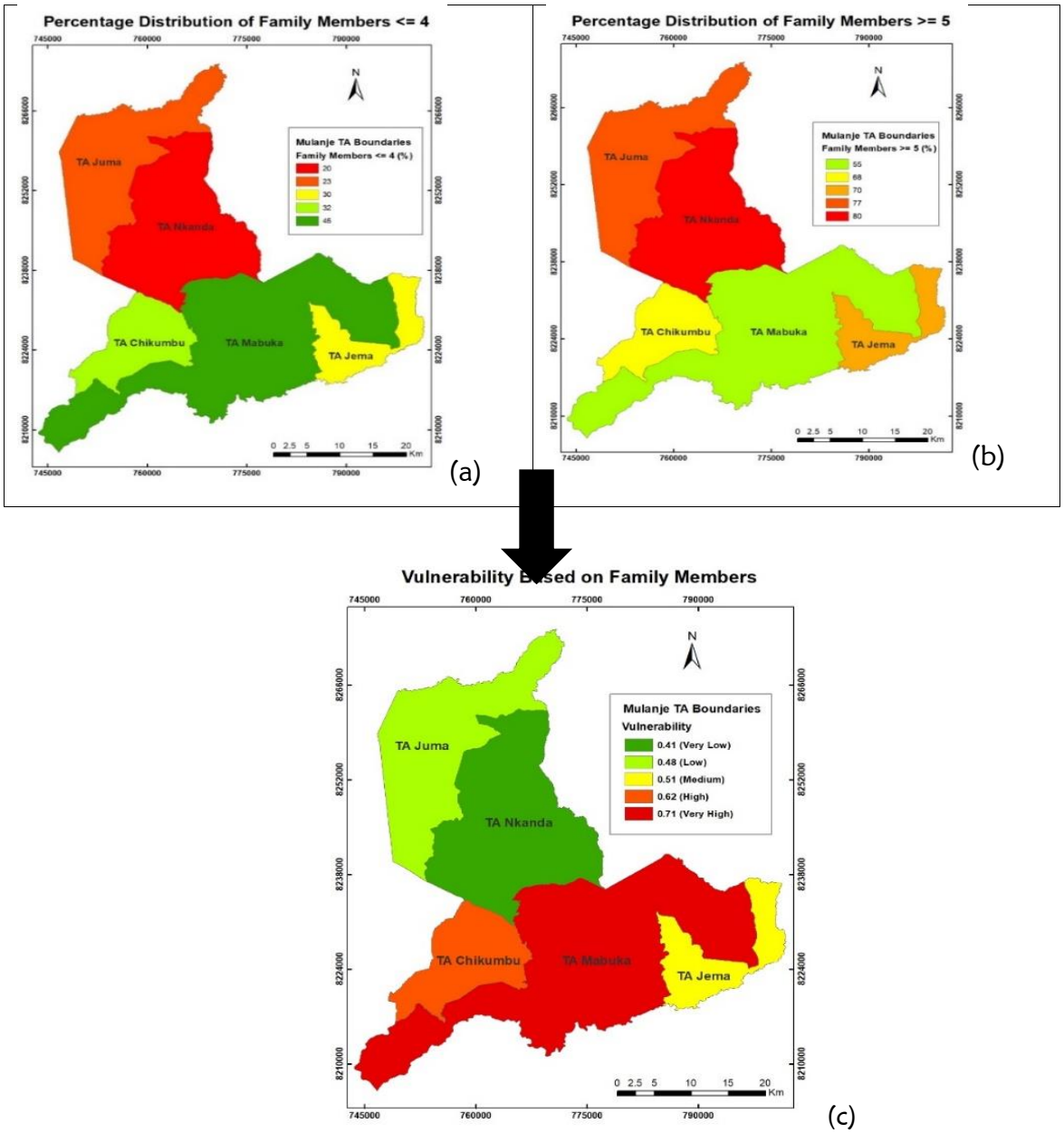


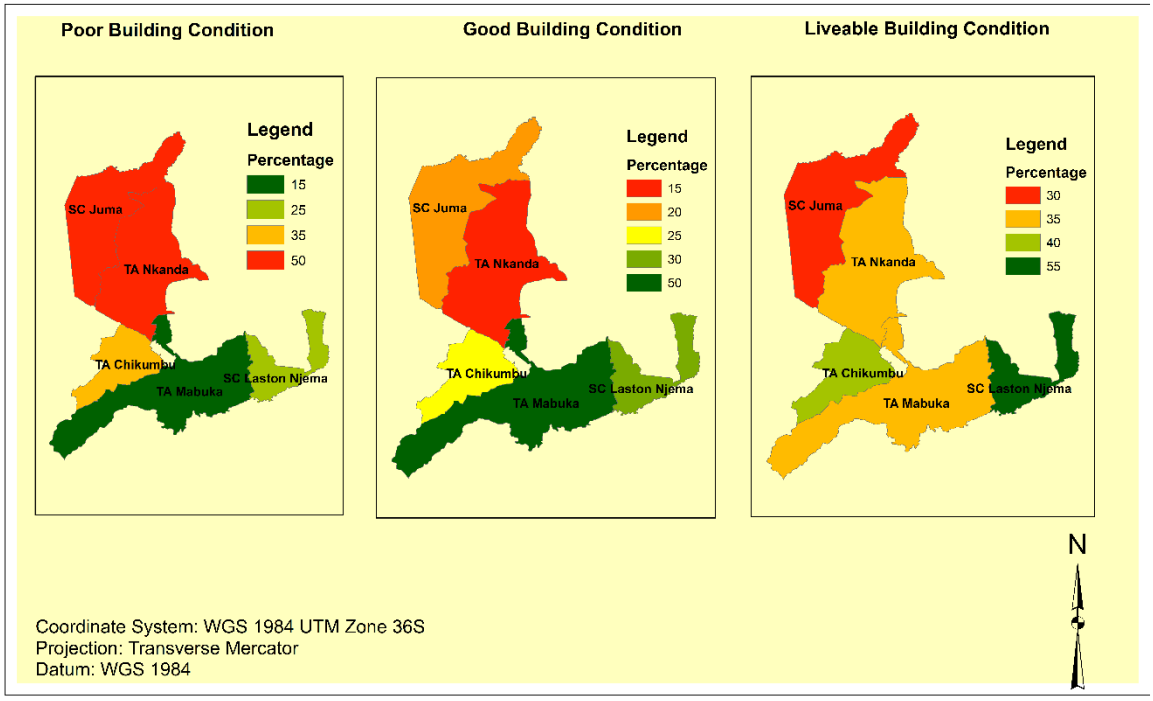
Figure 10. Number of family distribution; members less than or equal to 4 map(a), members greater than 4(b), level of vulnerability map (c)

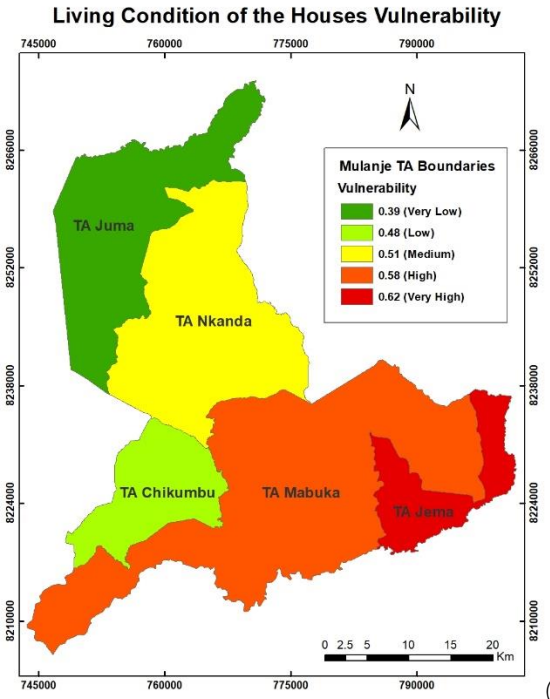
The number of family members per household determine the extent of resilience of the household. From **figure 10(a) and (b)** shows the percentage of family members in each TA. The percentage of family members greater than 5 appears to be high in TA Nkanda, and Juma with 80% and 77% respectively, compared to family members less than or equal to 4 which are 10% and 13% respectively. TA Mabuka and Chikumbu on the other hand has high percentage of household with number of family members less than or equal to 4. Large families face a lot of challenges to recover from a disaster since a lot of resources is required to meet the need of

every family member compared to small families. It often very difficult to rescue people when population is high hence increase the injuries and fatalities due to flooding. From this perspective TA Nkanda and Juma lack resilient hence more vulnerable to the impact of floods due to high population of household with members more than five.

Map(c) in figure 10 is the result of combination of the two indicator; family members less than four, and family member greater than or equal to five. The map expresses the vulnerability level based on the combination of the two variables. Due to high number of household with family members greater than 5 in TA Mabuka and Chikumbu, the level of vulnerability is very high and high, 0.7 and 0.6 respectively. From there variable TA Juma and Chikumbu are very low and low vulnerable to flood since has less households with family members greater than five. The results of Deepak et al., (2020), are similar with these findings where due to high number of households with members greater than 5 increase the vulnerability southern region of Ernakulam district, in india, where due to high number of households with members less than 4 decrease the vulnerability to floods of the northen region of the district.

4.1.5. Building condition



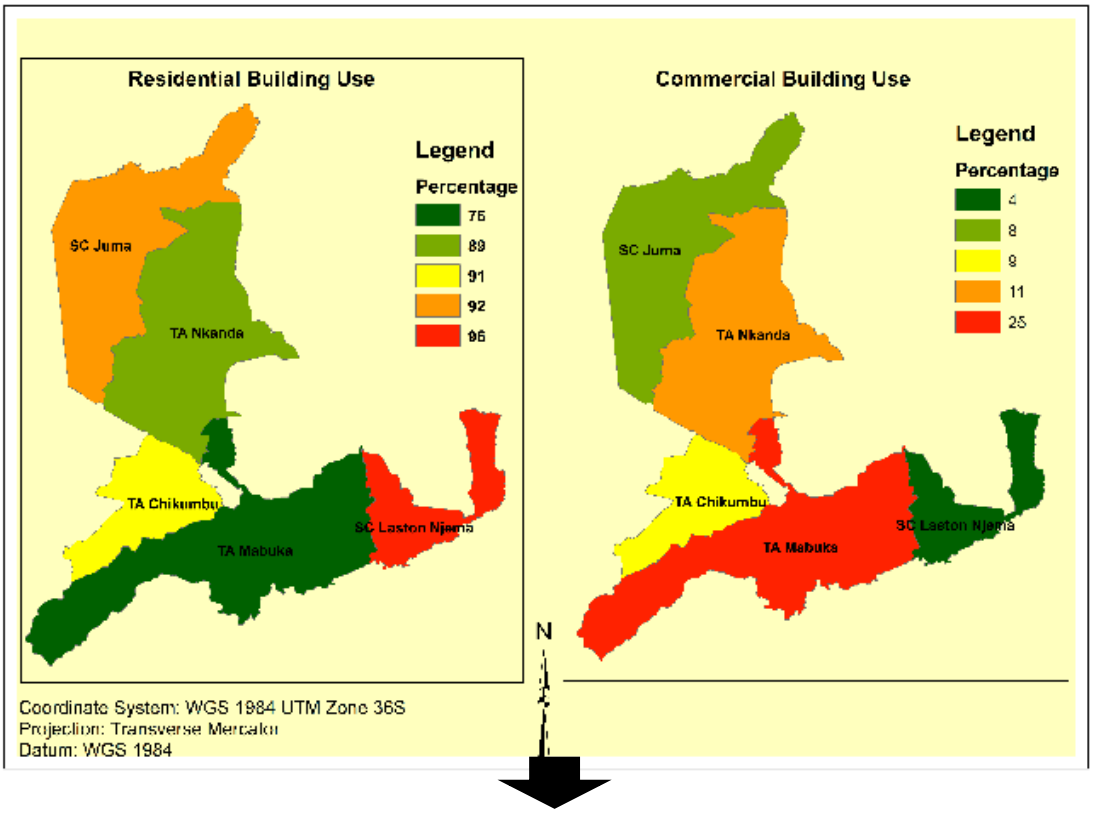


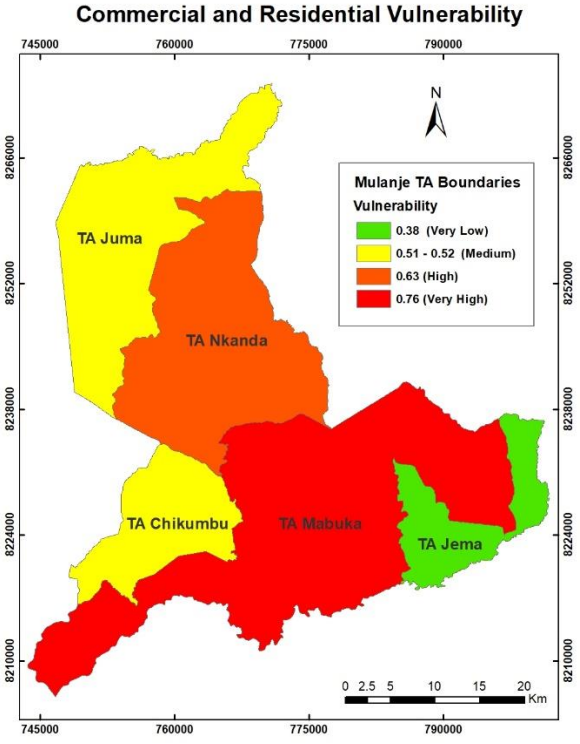
(d)

The data derived from the NSO on condition of the building **figure 12 map(a)** shows that TA Jema, Mabuka, and Chikumbu has higher percentage of good condition houses or buildings. Also data shows that TA Juma and Nkanda has higher number of poor buildings. In terms of liveable buildings TA Jema has higher percentage. Condition of the building determine how it will respond during flooding of different magnitude which determine the level of damage it can be caused to building, further losses and fatalities due to flooding(Rimba et al., 2017). Building are categorised into permanent, semi-permanent, and tradition buildings. Permanent(good)building are well build with standard building materials and these building can withstand the flood hence reduce the losses and damages. Traditional building are muddy houses which can easily damage.

The combination of these factors; good, liveable, and poor building determine the level of susceptibility to flood and its impacts. The combination map, **figure 12 map(b)** shows that TA Jema is very highly vulnerable seconded by TA Chikumbu. The map also shows that TA Juma is lowest vulnerable based of building condition. Based on research conducted by Schanze, (2014) shows that a lot of building in Castries old central business district and denney village were of good condition which reduce the vulnerability to flood, this is contrary the findings of this research.

4.1.6. function of the building





(c)

The results from commercial function building shows **figure 11 map(a)** that TA Mabuka has high percentage of commercial building about 25%, is seconded by TA

Nkanda which has 11%, TA Chikumbu has 9%, TA Juma has 8% and TA Jema has the least percent of commercial building. From residential function building results **figure 11 map(b)** shows that about 96% building in TA Jema are for residential function, in TA Juma 92% of buildings are residential. Date from the building function shows that TA has the lowest percentage of residential function building of about 75%, whereas in TA Chikumbu is 91% and TA Nkanda is 89%. The function of the building determines the susceptibility of the building, assets and population to flood event. Presents of commercial function building indicates of commercial activities happening in the area which also determines the resilient of the population to flood hazard. The higher the number of commercial function building the more commercial activities, which in turns reduce poverty level of large population. When the commercial affected lead to damage of assets on which people depends for survival. Despite being increasing the resilient of population commercial building when affected by flood a lot of assets lost and live people helpless mostly when they are not insured. Residential function building presents in settlement areas. Building type and material determine the level of damage it can be caused when affected by floods.

4.2. Socio-economic Vulnerability map

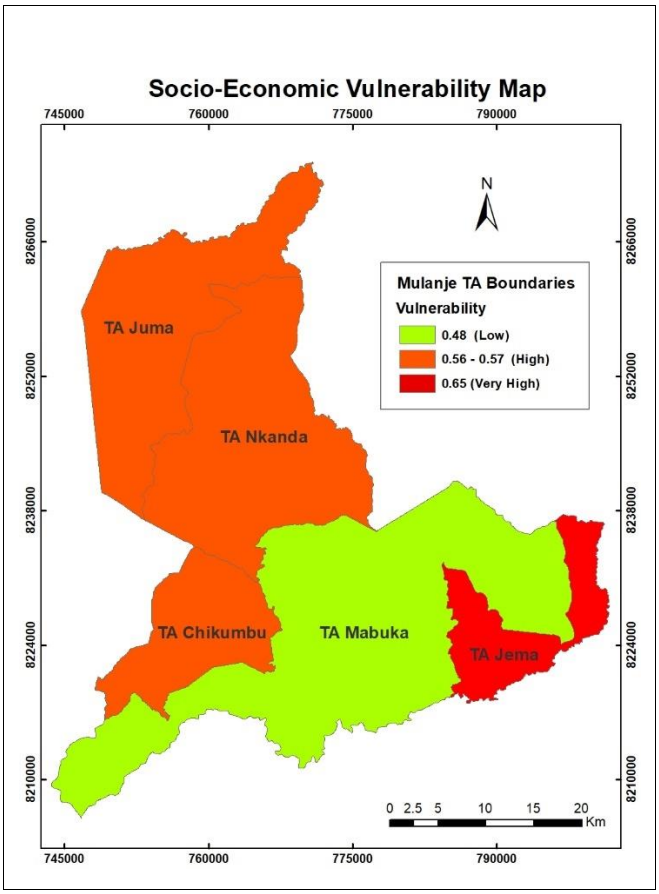


Figure 13, socio-economic vulnerability map

The overall socio-economic vulnerability map of the study area was obtained by combining all the socio-economic indicators and determine their share in terms of contributing to the vulnerability to floods. Based on socio-economic map TA Jema register to be very high vulnerable to floods. From the socio-economic perspective TA Juma, Nkanda and Chikumbu are higher vulnerable to floods and Mabuka is at low vulnerability to flooding. This is Similar to what Deepak et al., (2020), found where different wards of Aluva, in Ernakulam district, kerala state, india shows difference in socio-economic vulnerability.

4.3. Physical environmental (PV) vulnerability

The vulnerability to flood greatly depends on physical-environmental factors, so as to get the realistic picture of spatial variation of vulnerability they combined with socio-economic factors.

4.3.1. Slope

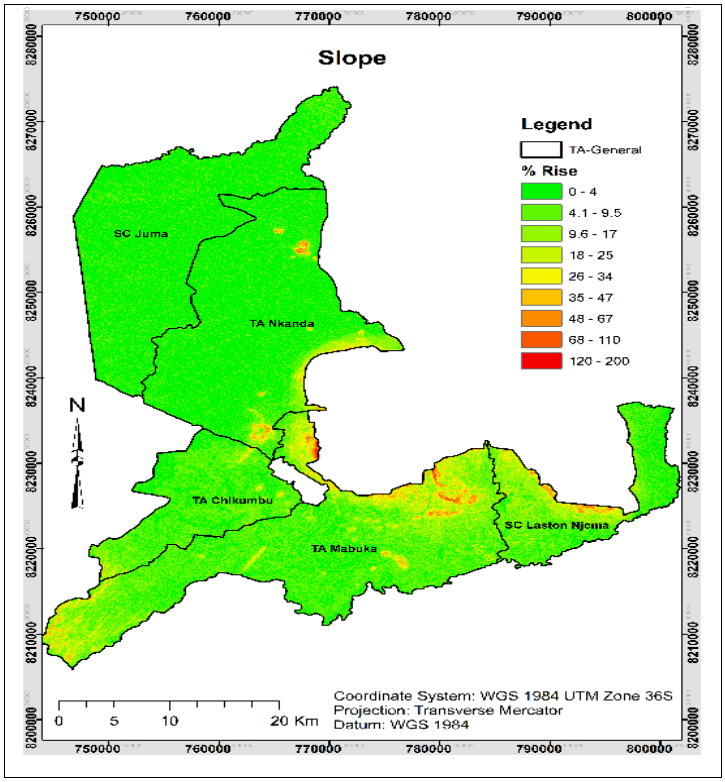


Figure 14, slope map

Figure 14, is raster layer showing the slope of the area created using ArcGIS software from remote sensing data. The slope was one of the physical aspect considered in the study, driven from DEM using GIS tools, with the index reflecting the degree of topographic change. Regions with high slope drains the water faster compared to flat regions. This makes flat regions more susceptible to flooding. From the slope map above, it shows that the northern region where TA Nkanda and Juma located is almost flat compared to southern region where TA Chikumbu, Mabuka, and Jema located which is higher because of mulanje mountain. Therefore, based on slope TA Nkanda, and Juma is more susceptible to flooding since it cannot drain rain water easily.

4.3.2. Proximity

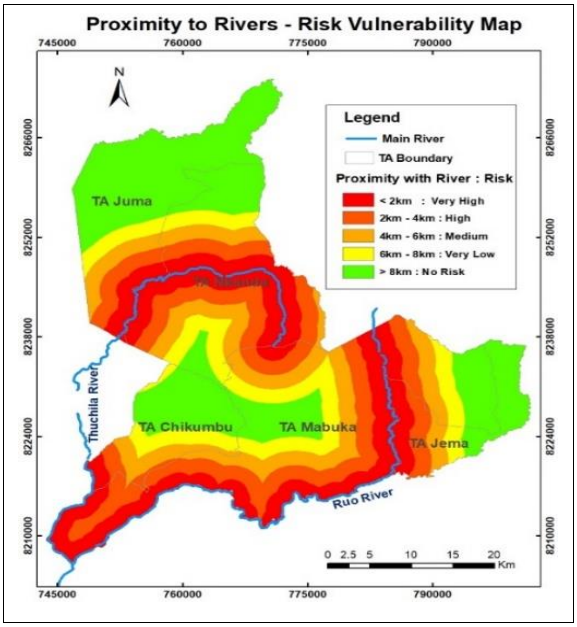


Figure 15, proximity map.

Raster layer above shows the proximity of area to river created using ArcGIS software from remote sensing data. Proximity to the river is another most important physical factor affecting the vulnerability. It is considered that an area having closer proximity to the river is more likely to be affected by the flooding. Since both proximity to river and slope are incorporated in the study, a combination of situations like an area near to the river but having higher slope or elevation was considered as less vulnerable. From proximity map shows that all TAs are near to rivers. TA Nkanda and Juma are very close to thuchila river whereas TA Chikumbu, Mabuka, and Jema are near to Ruo river. Considering the combination of proximity and slope, therefore, TA Juma and Nkanda being at flat area and near to thuchila river is more susceptible when river overflows. TA Jema, Chikumbu, and Mabuka though being near to Ruo river, but they are at higher slope hence less susceptible to flooding

4.3.3. Land use land cover

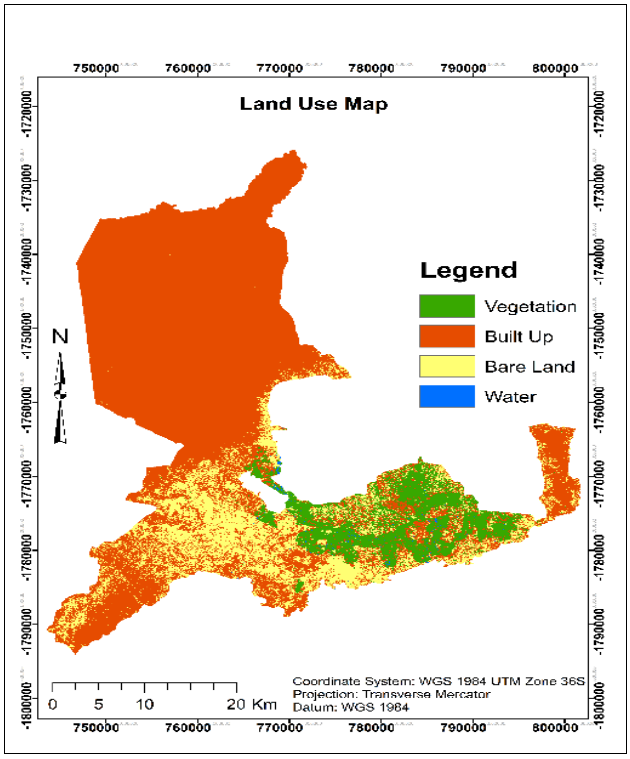


Figure 16, land use land cover map

Figure 9 above is a raster layer created by ArcGIS software from remote sensing data. Land use land cover of the area is also a key factor which determine the intensity of flood. Four land classes over the study area were identified by field studies and using the supervised classification of LISS 3 image, the study area was classified into build up area, water cover, bare land and vegetation covered area. Build up area includes regions where buildings and roads exist, with least percolation of water to the sub surface; whereas vegetation area covered with mature trees, shrubby plants and other plants growing close together are zones where water easily reaches the subsurface layers. Bare land like build up area increase the speed of runoff with least percolation. Thereby build up areas and bare land contribute to flood hazard vulnerability, whereas vegetation land decreases the chance of the area being flooded. From the raster map in **figure 10**, it shows that the northern part of the map where TA Juma and Nkanda exist is most encompassed with building whereas the southern region (TA Chikumbu, Mabuka, and Jema) is composed with vegetation and bare land. This tells that TA Juma and Nkanda are more susceptible to floods due to lack of vegetation which can increase

percolation. According to Samanta et al.,(2018) LULC directly and indirectly influence infiltration, evapotranspiration and surface runoff generation.

4.4. Physical-environmental vulnerability map

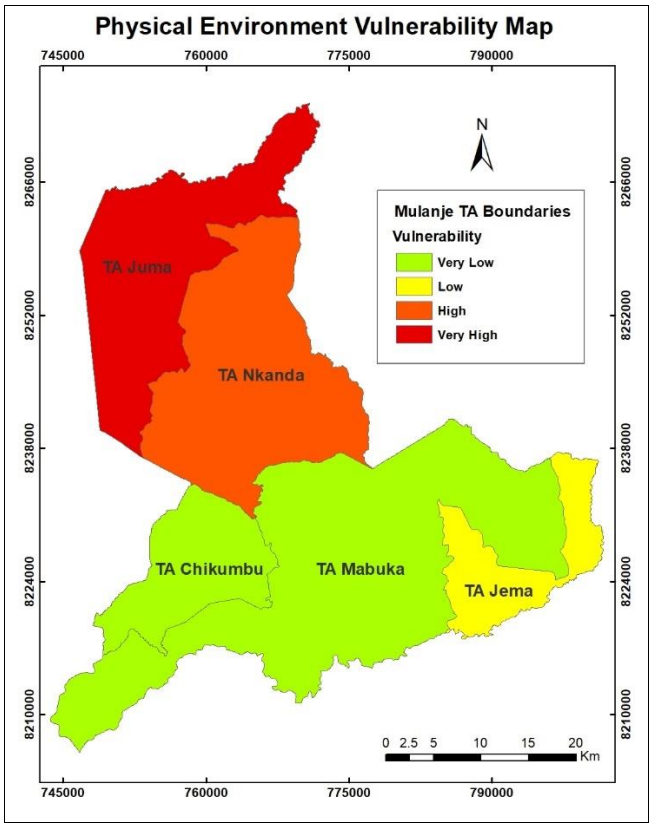
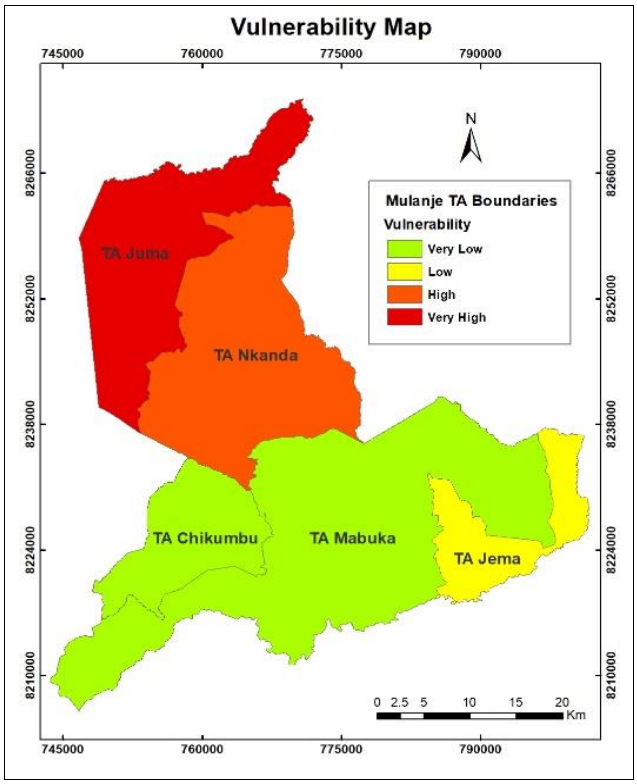


Figure 17 is physical vulnerability map

The overall physical environmental vulnerability map of the area of study was obtained by combining all physical-environmental factors considered in the study; slope, land use land cover, and proximity. Physical-environmental factors greatly determine the level of vulnerability to floods. Physical factors determine the susceptibility of the area to flooding in contrary to socio-economic vulnerability which determine the resilience and capacity of population to a flood(Deepak, n.d.). Based on combination of all the physical factors TA Juma is highly vulnerable seconded by TA Nkanda. PV map also shows that TA Jema has low vulnerability register to be more vulnerable to flood whereas TA Jema and Mabuka is very low vulnerability.

4.5. Vulnerability map of the study area



The overall vulnerability map of mulanje district was obtained by combining the socio-economic vulnerability and physical-environment vulnerability using weighted averaging. Different combinations were done for physical and socio-economic vulnerability. During events of large floods for instance with high return period of the order of 1000 years or more, the whole area will be submerged. In such a case, the physical-environmental vulnerability does not have relevance for decision makers, in such a case socio-economic vulnerability can play a key role to assess the resilience of the community and for taking further measures. Whereas in case of seasonal floods with low value of return period, the physical/environmental vulnerability has more importance since the area of impact will be based on the physical and environmental factors considered than the social and economic conditions of the area. A combination of socio-economic and physical/environmental vulnerability can give a realistic picture of the vulnerability to flood in the study area, to help in the computation of flood risk. Based on the combination of physical-environmental and socio-economical vulnerabilities TA Juma is very high vulnerable to floods followed by TA Nkanda. TA Chikumbu,

Mabuka, and Jema are lower vulnerable. The overall outcome of this research paper is contrary with results of the study conducted by Deepak et al,.(2020) on geospatial approach for assessment of vulnerability to floods in Ernakulam district, Kerala state India that found that the vulnerability to floods in the area was greatly influenced by socio-economic indices.

5. CONCLUTION AND RECOMMENDATIONS

5.1. Introduction

The overall aim of the study was to assess the vulnerability to floods of TA Juma in mulanje district. A geospatial approach (MCDA) and GIS tools (ArcGIS software) were used to analyse flood susceptibility in mulanje district. To achieve the objectives of the study three independent physical/environmental factors like LULC, slope, and proximity to the river were driven from geospatial data sets and used as input in ArcGIS software towards flood prone area mapping. These were used with socio-economic indicators which includes age group, gender, number of members in a family, the function of buildings, condition of buildings, unemployment and literacy rate of people, and poverty rate. As the result suggests, the combination of these variables are likely to give realistic vulnerability results for the study area. Five traditional authority in mulanje district (Jema, Nkanda, Chikumbu, Juma, and Mabuka) were assessed. Based on socio-economic grounds TA Nkanda, Chikumbu, Jema, and Juma determined to be high vulnerable to floods whereas TA Mabuka register low vulnerability to floods. From the physical/environmental findings TA Juma register high vulnerability followed by TA Nkanda and Juma. The overall vulnerability of area was obtained by combining the socio-economic vulnerability and physical-environment vulnerability using weighted averaging. From the outcome it shows that TA Juma is very high vulnerable to floods followed by TA Nkanda. TA Chikumbu, Mabuka, and Jema are lower vulnerable.

5.2. Limitations

1. Lack of data was the main challenge. Some of required was no found in statistics data like population at a village level.
2. Lack of funds. Some of the statistics data are not for free and you need pay to access them. Unfortunately, no funds available to access such data.

5.3. Recommendation

According to the finding of the study the following recommendations are made;

- The study recommend that government should initiate activities and measures to improve the living standards of people like provide loans, to enhance the resilience of majority.
- Measure to prevent, mitigate, and prepare for a flood event should be initiated as soon as possible to reduce losses as a result of a flood hazard. This may include planting trees along thuchila river, relocating from flood prone zones
- Further studies should be carried out to incorporate other physical factors that play role in flood susceptibility that were not included in this study to improve the results of vulnerability of TA Juma to flood hazard. The other physical factors include elevation, topographic wetness index(TWI), surface runoff, landform, lithology, soil drainage and soil texture.
- If geospatial (MCDA) approach is adopted as method of assessing the vulnerability not only to flood hazard but other types of hazard since it is less costly compared to other methods and also it saves time.

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