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THE APPLICATION OF GIS AND REMOTE SENSING IN MAPPING SEISMIC MICRO ZONES RISK IN MALAWI (KARONGA)

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Abstract

Earthquakes have been a stumbling bar to development in Malawi's northern region, especially in Karonga. This is a district that is prone to natural disasters. Despite the government's and non-governmental organizations' efforts to mitigate the impact of earthquakes, none of them have been successful. Seismic waves have a variety of consequences, including injuries, human fatalities, property and infrastructure damage, economic losses, and communication disruptions, to name a few.

Earthquake hazard micro-zoning is a relatively new methodology for site selection and infrastructure development investment around the world. It's the way to go when it comes to assessing and integrating multiple interconnected aspects in a GIS context to define specific hazard zones. The number of people killed in an earthquake disaster is mostly determined by the magnitude, depth of the seismicity, and distance of infrastructure / land use from the epicenter, as well as the intensity of the shaking, which is influenced by geomorphology and geological factors. The goal of this research is to create a seismic map for Karonga town by combining historical seismicity datasets with liquefaction potential zones that incorporate land use, geological, and geomorphological elements into the demarcation of degrees of earthquake hazard zones within the study area in GIS and Remote Sensing technologies, with expertise of multicriteria evaluation and Analytical Hierarchy Process (AHP) appraisal. The accessible seismicity data layer, geomorphological, land use, and geological databases are the key data layers considered for the assessment. Several thematic layers were created, with weighting and ordering assigned before normalization. The final seismic hazard zones map was created with ArcGIS 10's raster computed tool. The output hazard zones were then categorized into five levels of hazard: "very high," "high," "moderate," "low," and "very low."

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ACRONYMS/ABBREVIATIONS

GIS	GEOGRAPHICAL INFORMATION SYSTEMS
MCA	MULT-CRITERIA EVALUATION/ANALYSIS
AHP	ANALYTICAL HIERARCHY PROCESS
MASDAP	MALAWI SPATIAL DATA PLATFORM
LPZ	LIQUEFACTION POTENTIAL ZONES
EHZ	EARTHQUKE HAZARD ZONES
DEM	DIGITAL ELEVATION MODEL
HSG	HYDROLOGICAL SOIL GROUND

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1. CHAPTER ONE

1.0 Introduction

Earthquake hazard micro-zonation is a relatively new methodology for determining the risk levels associated with earthquakes within a region. Assessment and monitoring of natural hazards in a region, such as earthquakes, are critical for governing authorities and the general public. Such studies give a set of instruments that aid in better infrastructure development planning, mitigation measures, and the construction of an early warning system. Within karonga, the study focuses on the threats posed by earthquakes, the contributing variables to earthquake hazard, and the source and causation of earthquake hazard. Earthquakes normally occur due to plate motions owing to specific geological and tectonic settings of the earth. According to a study by Statista (2016), the global total estimated death toll due to earthquakes from 2000 to 2012 was 493, 736.

The first major earthquake hazard (risk), according to UP Seis (2016), is the influence of ground shaking, which can cause damage to buildings. Liquefaction, landslides, floods, Tsunamis, and fire can all occur as a result of the shaking hazard caused by seismology during an earthquake. Seismology is a branch of study concerned with the formation and propagation of earthquake shock waves across and through the earth's surface (Alexander, 2001; Biggs et al., 2009a, b).

The East African Rift System (EARS) has been subjected to earthquake dangers as a result of these seismic events, with numerous reports over the years. The EARS has active seismicity as a result of movement along its fault boundaries. Despite their growing fatality, Skinner (2003) claims that "there is no evidence that seismic risks are occurring more lately than previously

. 'If the claim that the environment is not being exposed to new seismic risk is true, then follows those humans are investing in regions that are potentially harmful to tremors and seismic dangers (Skinner, 2003). This could be why the people of Karonga Town were predisposed to such a risk as a result of the town's development. According to Skinner (2003), "population expansion, urbanization, pressure to develop marginal areas, economic expansion creating more constructed environments prone to damage, and increasing inability of government to cope with even small-scale disasters that have previously happened" are among the variables that expose populations to seismic risk.

Pal et al. (2006) used Geographic Information System to combine numerous environmental and seismic data layers, including geology (GE) (rock type, liquefaction, and fault line), geomorphology (GP) (soil type classification), seismicity (SM) (depth and magnitude), and infrastructure/land use (LU) (roads, schools, and health facilities) (GIS) Using Satty's analytical hierarchy technique, the study was carried out by assigning ranking and weightage, and then normalizing the weightage and rankings. The ultimate product was a karonga seismic hazard zone. The condition of earthquake hazard levels in a region must be known in order to plan any infrastructure development. Earthquake danger is the primary cause of the collapse of many potential facilities due to shaking, especially when building rules are not followed properly.

1.1Background

Many natural disasters strike the Karonga district in Malawi's northern region, including floods, high winds, and earthquakes, to name a few. Due to their natural occurrence, several reasons have been offered for these natural disasters, particularly earthquakes. Earthquakes, in this scenario, are the ground motions caused by the abrupt release of strain energy in the rock that has built up through time.

The majority of seismic waves, on the other hand, are caused by abrupt ground movement along fault planes within the earth's inner crust (alexander 2001). Many residents in Karonga have vivid memories of earthquakes that occurred in 2009. People were injured or killed as a result of the earthquake waves, which also caused property and infrastructure damage, economic losses, and social disturbances.

Earthquake or seismic wave is one of the natural disasters that demands special attention in Karonga since it is one of the catastrophes that has been occurring frequently(active) in many locations and is one of the costliest in terms of human and economic damages (skinner,2003). Various stockholders were constantly seeking lasting solutions to the district due to karonga's extreme susceptibility to seismic waves. Therefore, GIS approaches in mapping seismic micro zone risk and understanding potential causes leading to earthquake are required for an effective and systematic approach of regulating periodic seismic waves. The majority of the data is geographical, and it was mapped with GIS, a sophisticated tool for gathering, storing, analyzing, and displaying massive amounts of data.

1.2 problem statement

Earthquakes have been a stumbling bar to development in Malawi's northern region, particularly in karonga area (skinner,2003). This is a district that is prone to natural calamities. Despite the government's and non-governmental organizations' efforts to mitigate the impact of earthquakes, none of them have been successful. Seismic waves have a variety of consequences, including injuries, human fatalities, property and infrastructure damage, economic losses, and communication disruptions, to name a few. This was demonstrated by the December 19, 2009 earthquakes, which were the most destructive in recent years, killing four people and 1153 houses were affected of which 755 collapsed and 389 clacked (GoM 2009 earthquake report)

The epicenter was located 20 kilometers south of Karonga Boma at longitude 33.811 and latitude -10.11. (Macheyeki et al, 2014). The problem that comes as a result of the earthquakes in karonga town is that most of houses develop clacks during rainy and partly dry season yearly. Since there has never been a study conducted in the district of this kind, therefore, this study with GIS and remote sensing technique would like to visualise and analyse seismic risks zones in karonga town

1.3 main and specific objective

1.4.1 main objective

The main objective of this study is to generate a seismic hazard map for karonga town

1.4.2 specific objective

- To identify risks zones within the town
- To analyze the collected data through Analytical Hierarchy Process (AHP) and Muit-Criteria Analysis (MCA)
- identify institutional arrangements in seismic risks interventions and their activities town

1.4 Research questions

- What are the potential areas of the earthquake hazards based on the lithology structure, seismicity layer such as faults lines, fracture zones and soil attributes?
- What is the economic impact of earthquake on the inhabitants of karonga?

- How might earthquake hazard micro-zonation assessment and mapping benefit the community as a whole and the Governing Body?
- Is there any benefit to the use of Multi-Criteria Evaluation (MCE) and Analytical Hierarchy Process (AHP) in a GIS and Remote Sensing Environment to manage earthquake hazard issues?

1.5 significance of study

The study is especially noteworthy because a number of active fault lines cross through the research area, making it even more vulnerable to earthquakes, as evidenced by an analysis of historical earthquake data in the area. Furthermore, the significance of the study region's seismic micro-zonation is that: Because of its location on a significant regional commerce route to the port of Dar es Salaam, the study region plays a vital role in preserving and strengthening the country's economy.

The district as a whole is a seismically active area with various tectonic plates and their boundaries (fault lines), making Karonga town a fascinating location for an earthquake hazard zonation exercise. It is all the more vital to do such research in order to analyze and quantify earthquake danger using GIS and Remote Sensing baseline information. As a result, the output can be utilized as a valuable tool for land use planning, particularly in terms of infrastructure development and mitigation measures. It generates charts and maps that are simple to read and access, making decision-making easier for governing bodies. The general people and governing entities in the study region can be made more aware of earthquake-prone locations.

1.6. Study Area

Karonga covers 4,386 hectares and is located about 220 kilometers north of Mzuzu in Malawi's northern region, on the low-lying North Rukuru river floodplain and along the coasts of Lake Malawi. Because of its placement on a main regional commerce route leading to Dar es Salaam's port (Tanzania). It is the one of the mostly rapidly urbanizing towns in a country that is still only 18 percent urban. It is Malawi's fifth-largest urban center, with a population of 64,756 people according to the 2018 census. The city's population has risen as a result of the city's expansion in 2013. Karonga has a sub-tropical climate with two different seasons: dry and wet, which last from June to October and November to May, respectively.

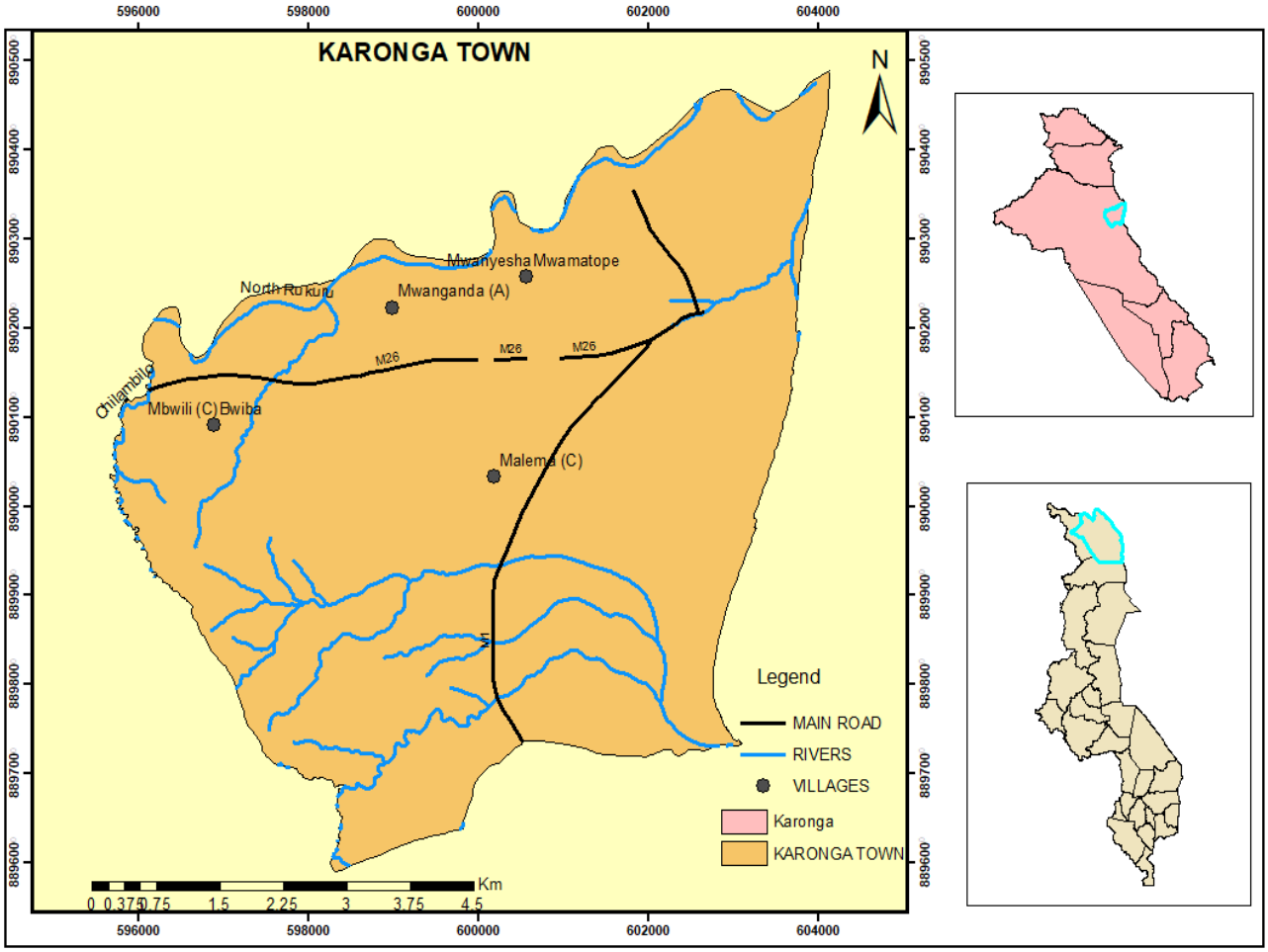


Figure 1.1. Map of karonga town

CHAPTER TWO

2. Literature review

2.1 Overview of the occurrence of earthquakes

When earthquakes happen, they produce seismic waves or energy bursts that can travel over the entire planet (de Blij and Muller, 1996). Earthquakes are more common in locations where tectonic activity is occurring, such as conservative, destructive, and constructive boundaries (Biggs et al., 2009). An earthquake produces a variety of waves, each with its own speed and direction (Ammon, 2010). An earthquake or an explosion can generate a seismic wave, which is an elastic wave. Seismic activity (Rayleigh and Love waves) moves along or near the earth's surface, while P and S waves move through the earth's interior (Alexander, 2001).

Body waves are waves that originate from the quake's epicenter inside the ground (Ammon, 2010). (Figure 2). P waves, or primary or pressure waves, are the first of them. They move quickly, pushing, pulling, and compressing the earth in the direction of their travel at speeds of over 225 miles per hour (360 km/h) through rock and about one-third that speed through water. S waves are secondary or shear waves that occur as a result of an earthquake (Biggs et al., 2010; Ammon, 2010). These waves travel at half the speed of P waves, but they are far more destructive. S waves travel perpendicular to the direction of travel. The direction in which the wave is moving Rayleigh waves, like rolling ocean waves, churn over and under.

An earthquake also causes secondary or shear waves called S waves (Biggs et al., 2010; Ammon, 2010). These travel at about half the speed of P waves, but can be much more destructive. S waves move perpendicularly to the direction the wave is traveling. Rayleigh waves churn over and under like rolling ocean waves; Love waves shake the earth from side to side. Love and Rayleigh waves, are the ones often responsible for making buildings collapse (Ammon, 2010). The point of fracture is known as the focus of the earthquake and the point vertically above the focus on the surface of the earth is known as the epicenter (De Blij and Mullar, 1996). Karonga Town is located on an irregular basin which lies on the fault line that forms part of the Livingstone fault (Biggs et al., 2010).

The tectonic activity linked with the great east African rift valley fault, a constructive margin that generates Lake Malawi, make Karonga Town vulnerable to seismic waves. In Karonga Town, a lot of earthquake threats are foreseen. The loading of sediments on the fault deepens to 6 km, according to Flannery and Rosendahl (1990), and Ebinger et al. (1999). This situation is a formula for liquefaction, especially with a rising water table, as most of the deposits constitute good aquifers. Parallel faults, according to Flannery and Rosendahl (1990), cause seismic waves to be reflected during tremors. The western shore, in contrast to the steep eastern limit, has a 5 to 10 km wide coastal plain covered in Quaternary deposits (Burke and Gunnell, 2008). Along the E-dipping Karonga Fault, hilly topography composed of Precambrian bedrock rises further west (Biggs et al.2010). In 2009, a calamity struck Karonga Town, which was sparked by an earthquake.

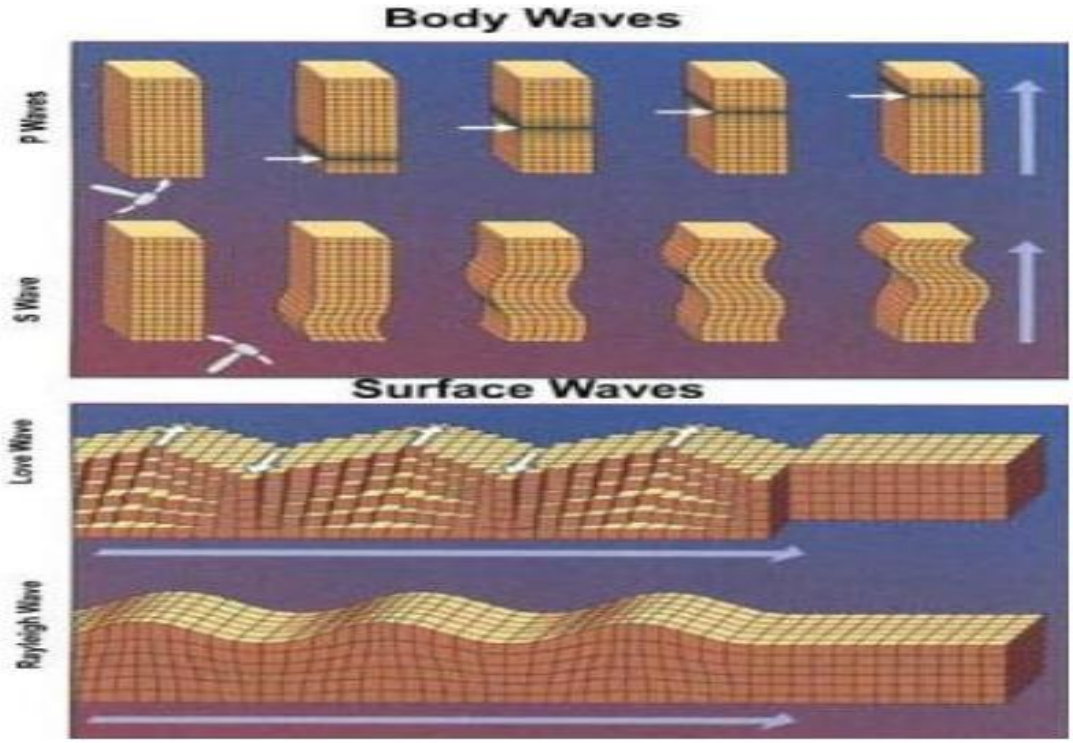


Figure 1.2. Types of waves generated by earthquakes (source: Ammon,2010)

2.2 Geology of Karonga district

Hard rock formations known as Basement complex Rock dominate the western part of Karonga, while superficial deposits, mostly alluvium, dominate the eastern side of the district (Carter and Bannet,1973). The area is primarily defined structurally by NW-SE major faults that dominate the basement complex rocks to the west of Karonga town. Lake Malawi is located in the eastern portion of the study region and is characterized by normal faulting patterns with a NW-SE orientation. Its major faults and thus also border faults that define the lake include the Livingstone border fault in the eastern half of the lake.

The karonga fault, which is similar in orientation to the Livingstone fault, is located on the town's far western outskirts. The karonga Basin, which is seismically active, is defined by these two faults, Livingstone to the east and Karonga to the west.

2.4 Causes of earthquakes and their impacts

Earthquakes can be caused by humans or natural disasters, with the latter being more often. These earthquakes are not random; rather, they are the result of various changes in the earth's crust that have been occurring for a long time. The four main causes of earthquakes are listed below.

2.4.0 natural cause

volcanic eruptions

Volcanic eruptions are the primary source of the earthquake. This type of earthquake happens in places where volcanic activity is common. Certain movements in the earth's crust are created when boiling lava seeks to break through the surface of the earth with an increasing pressure of gases. Lava movement underneath the earth's surface can potentially cause some disruptions. This causes harm by sending shockwaves into the earth. These tremors are minor. They have a limited range as well. There have, however, been some exceptions, with volcanic earthquakes wreaking havoc and killing thousands of people.

tectonic movements

The upper mantle is made up of plates that make up the earth's surface. The plates are constantly shifting, causing the earth's crust to shift. There are three types of movements: constructive, destructive, and conservative. Constructive earthquakes occur when two plates move away from each other, and they are modest. Destructive plate boundaries occur when plates move towards each other and crash. This is quite harmful. Conservative is the same as crust passing past. This type of earthquake has a range of magnitudes

Geological faults

The displacement of plates from their original plane is referred to as a geological fault. It doesn't matter if the plane is horizontal or vertical. These planes do not emerge out of nowhere, but rather grow over time. Tectonic earthquakes are caused by the movement of locks along these planes. These faults form as a result of geological causes. The fracturing of rocks is caused by plate movement, which releases a lot of energy. This type of earthquake has the potential to be devastating.

2.4.1. Man made

Man's interference with nature can also be a contributing factor in earthquakes. Earthquakes can be caused by a disruption in the crustal balance caused by heavy water clubbing in dams. Nuclear weapons can cause specific types of seismic waves to travel across the earth's surface, disrupting alignment of plates. The large removal of rocks from various regions through mining activities can also cause disruption.

CHAPTER THREE

3. Methodology

3.1 Data collection and pre-processing

Seismicity, geological, geomorphological data layers, and infrastructure/land use data layers were the key data layers employed in this investigation. The soil attributes and geology according to rock types were retrieved from the Mzuzu geological survey department and Geobook Meta data in the case of geomorphological and geological data, which were incorporated into a GIS environment, and the geohazards component was demarcated in the form of liquefaction potential. The liquefaction potential zones of the same research region currently under research for delineation of earthquake hazard were produced based on the prior study. As a result, this was employed as one of the contributing variables or a theme layer for the current study's final delineation of earthquake danger zones, which was combined with seismicity data layers. For the seismicity data layer, the magnitude, depth, and intensity of each earthquake occurrence from 1950 to 2020 were taken into account.

The seismicity data layers were obtained in an excel spreadsheet format from the Mzuzu geological survey department, then edited, converted, and exported to ArcGIS format. The whole seismicity database from 1950 to 2020 is represented in the graphs below, including magnitude, and date. It shows the magnitude of earthquakes reported against each year. The thematic layer or factor was created after the seismicity datasets were edited, converted, and exported to ArcGIS format. The seismicity datasets are all in ArcGIS format once they've been exported in form of points feature.

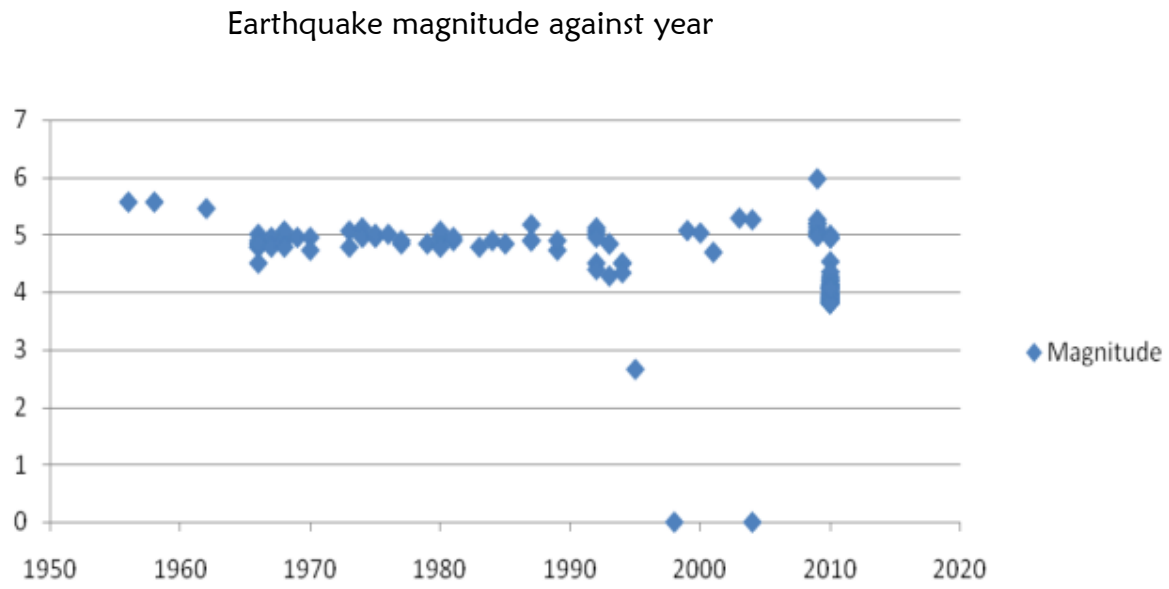


Figure 1.3. Recorded magnitudes of seismic waves from various places in Karonga from 1956 - 2010 (source, Geological Survey department - Mzuzu)

To prepare the factors, an ArcGIS 10.5 spatial analytical tool was used to use an interpolation technique called inverse distance weighting (IDW). Because all seismicity data is in point format once opened in ArcGIS 10.5, this is straightforward to interpolate a raster surface from points. Earthquake depth distribution, magnitude distribution and shanking intensity are the three components created using interpolation techniques. The earthquake depth distribution was calculated using the depth or shallowness of the earthquake. It was subsequently classed based on the premise that the larger the hazard, the shallower the earthquake depth, and the lesser the hazard, the deeper the earthquake depth. The magnitude distribution of earthquakes was the other raster surface created using the interpolation methodology. It was classed based on the magnitude of the earthquake, with smaller magnitudes being a lower risk and larger magnitudes posing a higher risk.

Finally, within a research region, a raster surface representing levels of shaking intensity was created. Only the shaking intensity level for large earthquake events above 5 magnitudes was evaluated specifically for the creation of the raster surface. It was classed based on the size of the shaking danger, with smaller shaking being a lower risk and larger shaking posing a higher risk in the aftermath.

The Soil Data including sand, sandy loamy and sa20ndy clay soil were the three soil qualities used in this study that were downloaded from the European Soil Data Centre (EUDASC). Expert opinion, literature, experiences, discussion, and accessible research on karonga soil properties were used to assign weighting and ranking. All of these soil attributes were converted to raster (.img) format so that they could be analyzed further in ArcGIS using the raster calculator.

The geology shape file was digitized in ArcGIS 10.5, and it was divided into three (3) classes: consolidated rocks, unconsolidated rocks, and fault line. Expert opinion, literature, experiences, conversation, and available research on Karonga's geology were used to create these three (3) classes. Following the digitization of these three classes, the shapefile (.shp) was converted to raster (.img) format in preparation for GIS raster calculator analysis. For the research region exclusively, Faultline data and DEM were downloaded from MASIDAP. The fault line data was saved as a vector shape file (.shp) and then transformed to raster in the form of a buffer for further analysis. Using ArcGIS 10.5 and a DEM, a slope was created.

3.2 Analysis of data layers

The approaches used here were designed to produce earthquake hazard zones. Different geomorphological data according to soil qualities, geology data of rock type according to geological formation, and fault lines were combined in the ArcGIS environment to develop Liquefaction potential zones.

Before starting into this study, a few similar articles and research from around the world were looked into to see what MCA and AHP techniques were all about. The Analytical Hierarchical Process (AHP), commonly known as Saaty's model, was used to analyze six layers outside of the ArcGIS context (1977, 1980, 1992, 2008). According to Sekac et al. (2016), the Multi Criteria Analysis (MCA) approach has been demonstrated to be a useful decision-making tool for dealing with complicated decision constellations involving technological, economic, ecological, and social factors.

In terms of lithology, rock formations were divided into two categories: unconsolidated and consolidated. According to Rodda (1974–1966) and Hirst (1965), karonga are made up of just two major consolidation states: unconsolidated bedrock and consolidated bedrock. Based on this information, weighting and ranking were assigned on a scale of 1 to 4, with 1 denoting low potential and 4 denoting strong potential to liquefy during earthquake shaking.

The three soil components were reclassified based on saturation status, with the understanding that unsaturated and soft soils are more prone to liquefaction and can magnify seismic waves, resulting in liquefaction. The assumption for fault zones is that areas closer to fault lines have a higher potential to liquefy after an earthquake, whereas those further away from fault lines have a lower potential. Meters(m) intervals were used to establish fault buffers.

Fault zones that likely to surrender the central tendency of epicenter of earthquake occurrences in a tectonically active region, according to Pal et al. (2007) and Sekac et al. (2016). Slope is also seen as an important factor that contributes to liquefaction following an earthquake. In ArcGIS 10.5, the DEM was extracted and the surface tool was used to generate slope. Using the Saaty's model in an excel spreadsheet, each of the six elements was given a weighting and ranking.

Different specialists' perspectives, literature, conversation, and publications were used to allocate weight and rank. The pair wise comparison matrix, devised by Saaty, was used to normalize the weights and determine the consistency ratio in order to be consistent with the weightage and ranking. The raster calculator was used to incorporate all of the normalized weights and ranks into ArcGIS 10.5 The methodical step-by-step technique used and the formula for estimating the liquefaction potential zone are shown in Figure 4. Pal et al. (2007) and Sekac et al. (2016) used the MCA approach in ArcGIS to calculate the results. One of the four layers examined to determine final earthquake hazard zones is the liquefaction potential zone.

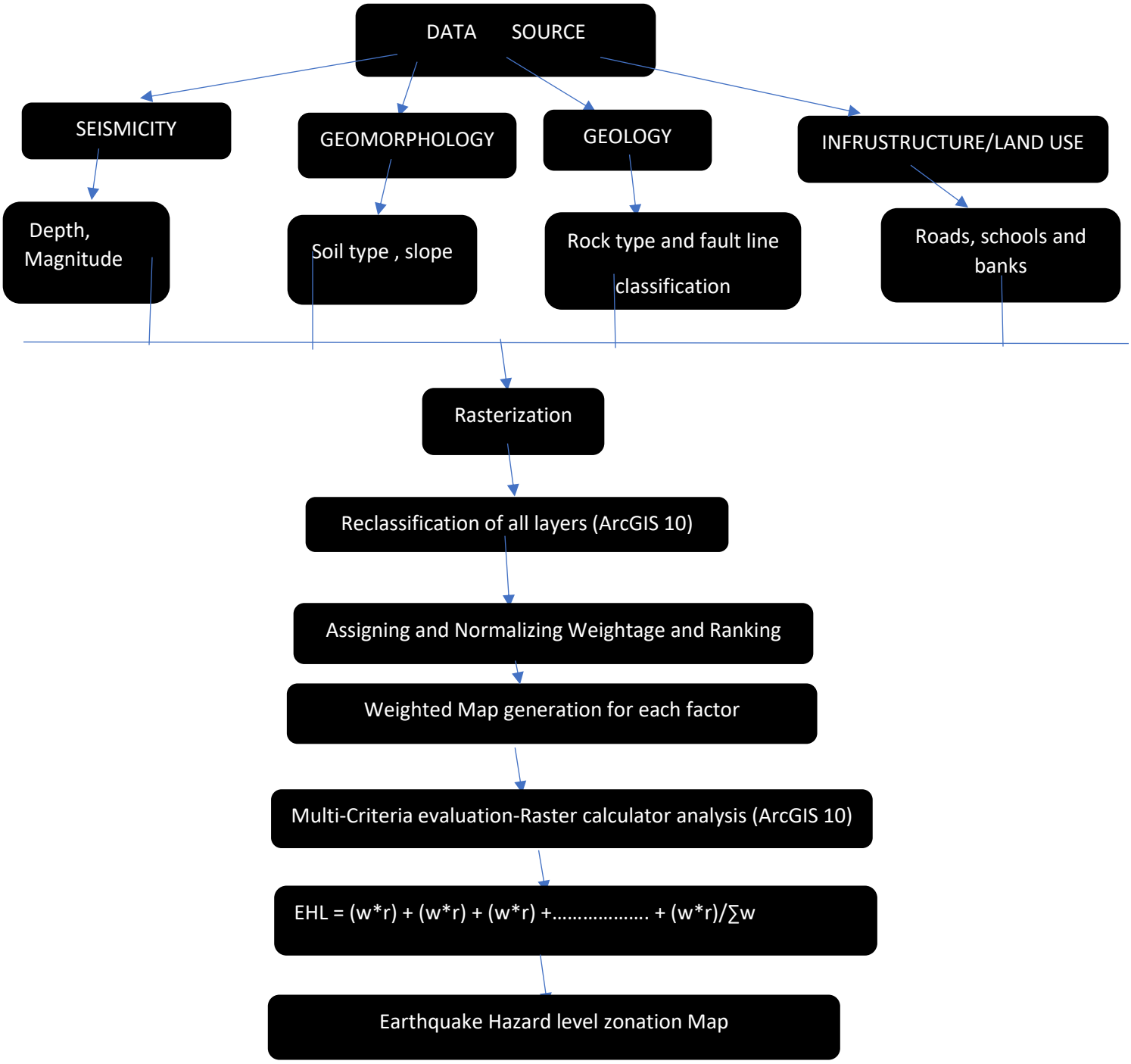
Seismicity data, such as earthquake depths and magnitudes, were extracted, altered in MapInfo Professional 10.0, transformed, and exported as suitable layers into the ArcGIS environment for further analysis. The depths and magnitudes of the earthquakes were both in point characteristics. As a result, the natural neighbor interpolation tool in ArcGIS was mostly employed for this investigation because it generates a raster surface by averaging the values of the points. The natural neighbor interpolation methodology was used to produce surface layers for earthquake magnitudes and depths. The earthquake layer was classed based on the principle that the shallower the depths, the greater the risk of shaking and vice versa. Similarly, the earthquake magnitude layer was reclassified based on the principle that the smaller the magnitude, the lower the likelihood of shaking, and vice versa. The LPZ layer was brought into communion with the two seismic thematic layers and merged using AHP procedures in an excel sheet, and the MCA methodology in ArcGIS 10.5 was used to construct the earthquake hazard zones of the research area. Following the techniques described earlier, weights and rankings were assigned to each of the four variables, which were then normalized to determine the consistency ratio.

Figure 4. shows a flowchart that summarizes all of the steps and methods used in this investigation.

Table 1: Data sources

Data	Description	Sources
Seismicity (Depth and magnitude)	Extracted from ASTER DEM	Mzuzu Geological survey
Geomorphology (soil type, slope)	Derived from ASTER metadata	MASDAP
Geology (rock type and fault line)	Derived from Geological metadata	Mzuzu geological survey
Infrastructure (roads, school, banks)	Extracted from karonga metadata	Karonga District council

Figure 4. METHODOLOGICAL FLOW CHART



3.3 Assigning of weighted and analytical hierarchy process

Furthermore, all layers were weighted and graded using AHP processes or Saaty's model, which were based on expert opinion, excellent judgment, literature, and best practices. It is a standard strategy for assessing, synthesizing, analyzing, and prioritizing man criteria in order to attain a common set of goals. It facilitates effective group decision-making by allowing members to draw on their collective experience, values, and knowledge to deconstruct a problem into a hierarchy and solve it using AHP processes. AHP mostly contributed in allocating weightage and ranking within a range of values '1–4' in this investigation. Each individual of the 6 criteria was given a scale value ranging from 1 to 4 for liquefaction potential zones.

Lithology, for example, was divided into two categories: un-consolidation and consolidation. Consolidation was given the rating '1' in this scenario because, due to its consolidated properties, it does not liquefy during earthquake shaking. Value '4', on the other hand, was given an un-consolidation status due to its significant potential to liquefy after an earthquake. This means that when an earthquake occurs, the seismic wave is amplified when it comes into touch with unconsolidated geology, which might result in surface subsidence. When a seismic wave collides with consolidated bedrock, its strength is reduced. As a result, the earthquake hazard was given a value range of '1-4.' This signifies that the number '1' is low and the number '4' is high. For example, earthquakes with a magnitude of 3–4.2 were given a value of '1', while those with a magnitude of 5.3–7.5 were given a value of '4', owing to the fact that the bigger the magnitude, the greater the potential for shaking, and vice versa. One of the characteristics of AHP, according to Sekac et al. (2016), is that it allows for inconsistency while also providing the consistency ratio (CR) to highlight the congruity of consistency not exceeding the permissible (CR) of >0.10. If the consistency ratio reaches 0.10, the weightage must be re-evaluated. The CR also represents the likelihood that the matrix ratings were created at random. Table shows the normalized and assigned weights for six factors used in LPZ,

while Table 3 shows the normalized and assigned weights for four factors used in EHZ. In terms of liquefaction factors, lithology came out on top with a normalized weight of 0.383, while slope came in last with a normalized weight of 0.041. With a normalize weight of 0.383, LPZ scored highest in terms of earthquake danger, whereas magnitude ranked lowest with 0.091 normalize weights. Table 2 shows the pair-wise comparison for LPZ, whereas Table 4 shows the pair-wise comparison for EHZ. Finally, the ArcGIS raster calculator was used to build the final LPZ and EHZ map for the research area after normalizing and satisfying the consistency ratio of 0.01 for LPZ and EHZ

3. RESULTS AND DISCUSSION

Liquefaction potential zones were created using three thematic layers derived from geological and geomorphological data, as well as six elements that were fully analyzed and incorporated into the ArcGIS environment. Similarly, seismic hazard potential zones were created using past earthquake data. The earthquake depths, magnitude, and were the two seismic layers. Before entering the normalized weights into the ArcGIS 10.5 program and using the raster calculator tool to construct the Final seismic hazard zones for the research area, the LPZ and EHZ data were subjected to a rigorous and dynamic AHP process. Multi Criteria Analysis is extensively used in disaster risk reduction to analyze phenomena such as flooding, soil erosion, and ground water evaluation, to mention a few, and it was used in this work as well.

Evaluations of possible liquefaction zones (LPZ) Green et al. (2013), Koulali et al. (2015), and Pal et al. (2007) found that soils with a loose consistency or quick sand easily became fluid and disaggregated during earthquakes, a process known as liquefaction. Unconsolidated particles have a strong propensity to liquefy or separate from one another during earthquake shaking, according to these experts. Lithology, soil texture, soil AWC, fault zone, and slope were the LPZ parameters. Table 2 shows the pairwise comparisons performed on each factor.

Table 2: AHP KEY

1	equal importance
3	moderate importance
5	strong importance
7	very strong importance
2,4,6,8	intermediate values
1/3, 1/, 1/7, 1/9	values for inverse comparison

Table 2. Pair wise comparison matrix

	Seismicity	Geology	geomorphology	Infrastructure
Seismicity	1	5/1	4/1	7/1
Geology	1/5	1	½	3/1
geomorphology	¼	2/1	1	3/1
Infrastructure	1/7	1/3	1/3	1
Sum	**1.59**	**8.33**	**5.83**	**14**

Table 2:0. Pair wise comparison matrix

Dividing each cell by sum of values of corresponding column

	Seismicity	Geology	geomorphology	Infrastructure
Seismicity	1/1.59	5/8.33	4/5.83	7/14
Geology	0.2/1.59	1/8.33	0.5/5.83	3/14
geomorphology	0.25/1.59	2/8.33	1/5.83	3/14
Infrastructure	0.14/1.59	0.33/8.33	0.33/5.83	1/14
Sum	**1.59**	**8.33**	**5.83**	**14**

Davis (1954) and Andrew (2005) discovered that unconsolidated sediments increase seismic waves and are prone to liquefaction, whereas consolidated sediments or rock types do not amplify seismic waves and instead reduce the intensity of seismic wave propagation. The weighting and ranking of each component were assigned in accordance with the preceding principle. According to karonga Soil Bureau (1960), geology is divided into two (2) consolidation states: consolidated and unconsolidated bedrocks. As a result, Geobook (2009) confirmed karonga bedrock by identifying geological classes and their corresponding consolidation status. Existing publications and research by Seeley et al (1970) and Rodda (1974 – 1966) re-confirm the veracity of the initial study by Malawi Soil (1960) on karonga geology types. As a result of this precept, the weighting and ranking were applied, and the theme layer was created, as illustrated in Figure 6. With a consistency ratio of 0.01 in Table 3, the normalized weights and raking for all 6components are shown.

Table 3. Normalized pair-wise comparison matrix for EHZ

	Seismicity	Geology	Geomorphology	Infrastructure
Seismicity	0.6289	0.6002	0.6861	0.5000
Geology	0.1258	0.1200	0.0858	0.2143
Geomorphology	0.1572	0.2401	0.1715	0.2143
Infrastructure	0.0898	0.0400	0.0572	0.0714

Table 4. Normalized and assigned weights for 4 factors used for EHZ

	Seismicity	Geology	Geomorphology	Infrastructure	Criteria weights
Seismicity	0.6289	0.6002	0.6861	0.5000	0.0646
Geology	0.1258	0.1200	0.0858	0.2143	0.1365
geomorphology	0.1572	0.2401	0.1715	0.2143	0.1958
Infrastructure	0.0898	0.0400	0.0572	0.0714	0.60380

$$\frac{0.628+0.6002+0.6861+0.500}{4} = 0.6038$$

Table 5. calculating the consistency

	Seismicity	Geology	Geomorphology	Infrastructure
Seismicity	1	5	4	7
Geology	0.2	1	0.5	3
Geomorphology	0.25	2	1	3
Infrastructure	0.14	0.33	0.33	1
Criteria weights	**0.6038**	**0.1365**	**0.1958**	**0.0646**

Table 5:0

Multiplying each cell by criteria weight values of corresponding column

	Seismicity	Geology	Geomorphology	Infrastructure
Seismicity	1 * 0.6038	5*0.1365	4*0.1958	7*0.0646
Geology	0.2*0.6038	1* 0.1365	0.5*0.1958	3*0.0646
Geomorphology	0.25 * 0.6038	2* 0.1365	1*0.1958	3*0.0646
Infrastructure	0.14 * 0.6038	0.33*0.1365	0.33*0.1958	1*0.0646
Criteria weights	0.6038	0.1365	0.1958	0.0646

Table 6: Ranking/rating and normalised weightage for LPZ

	Seismicity	Geology	Geomor phology	Infra Structure	Weighted sum values	Criteria weights	Ratio
Seismicity	0.6038	0.6825	0.7832	0.4522	2.5217	0.0646	2.5217/0.6038 =4.1762
Geology	0.1208	0.1365	0.0979	0.1938	0.5490	0.1365	0.5490/0.1365 =4.0225
Geomor phology	0.1570	0.2730	0.1958	0.1938	0.8136	0.1958	0.8136/0.1958 =4.1553
Infra structure	0.0863	0.0445	0.653	0.0646	0.2616	0.6038	0.2616/0.0646 =4.0488

Max=4.1762+4.0225+4.15534.0488= 4.1007

$$\text{Consistency index (C.I)} = \frac{\text{max-n}}{\text{4-n}} = \frac{\text{4.1007-4}}{\text{4-1}} = 0.03358,$$

where n is the number of compared elements

$$\text{Consistency Ratio (CR)} = \frac{\text{Consistency index}}{\text{Random consistency index}} = (\text{C.I/R.I})$$

Table 7. Random consistency index

N	1	2	3	4	5	6	7
R.I	0	0	0.52	0.89	1.11	1.25	1.35

Therefore, CR=0.03358/0.89 = 0.037311< 0.10

According to the EHZ pairwise comparison provided, Seismicity was assigned the lowest rank, whereas infrastructure was allocated the greatest. As indicated in Table 5, the EHZ allocated and normalized weights exhibited a consistency ratio of 0.01. The normalized weight of LPZ is 0.383, whereas the normalized weight of infrastructure is 0.638. Soil classification based on infiltration rate was obtained from USDA soil taxonomy (1975) and compared to Malawi soil classification based on the Malawi's Ministry of Agriculture Soil Land Use Capability Classification System Guideline. According to its texture, soil is classified into three (3) groups, which are A, B, and C, as shown in Table 8 below.

The highest infiltration rate is found in Group A soil, while the lowest is found in Group C soil. To put it another way, Group 'C' soil has a higher run-off rate than Group 'A' soil. As a result of the significant water infiltration in the soil, it is easy for it to liquefy during an earthquake. In comparison to category 'C,' sand, loamy sand, soils have a strong propensity to liquefy during earthquake shaking.

Table 8. Classes for HSG

A	B	C
Sand	Sandy loam	Sandy clay

The available water holding capacity (AWC) of soil indicates its ability to store water for a certain amount of time. In comparison to soil group 'A,' which has a poor water holding capacity, soil group 'C' has a high-water holding capacity. According to Sekac et al. (2016), there is no risk of liquefaction if the available water holding capacity in the soil is very low, but liquefaction during an earthquake is feasible if the available water holding capacity is higher. Soil drainage is critical for determining a soil's drainage potential. Because of the amount of water stored in the soil, it has been determined that water logged soil has a very high potential to liquefy during earthquake shaking. The assigned weightage and thematic map depicted in were provided. Other geological structures such as faults, lineaments, and other geological structures were also taken into account. These zones were defined, and a buffering methodology was used to identify liquefaction-prone areas. Fault lines, of course, are where earthquakes happen. The multi ring buffer was used to calculate the proximity to fault lines, resulting in four severity zones. As a result, the greater the distance from the fault line, the lower the potential for liquefaction, and the smaller the distance, the greater the possibility for liquefaction.

The assigned weightage and thematic map depicted in Figure were provided in Table. Thematic maps shown in Figure below

Maps of all factors

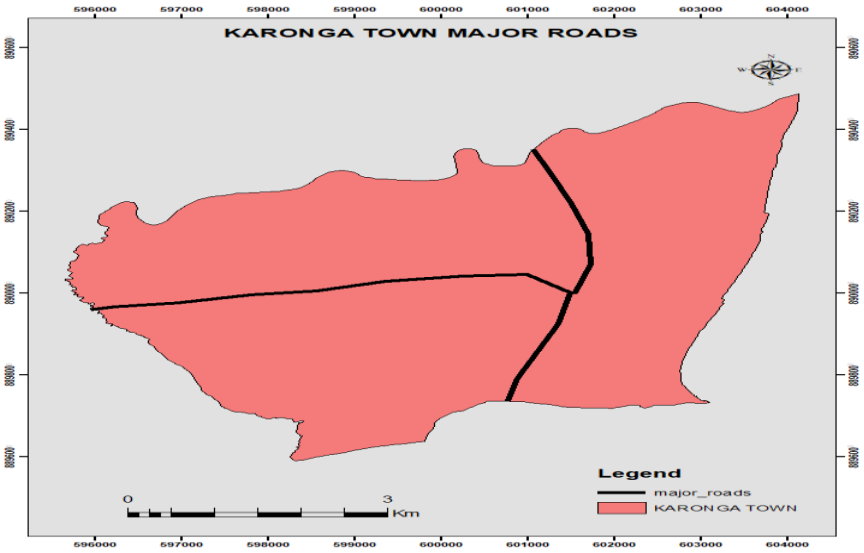


figure 5

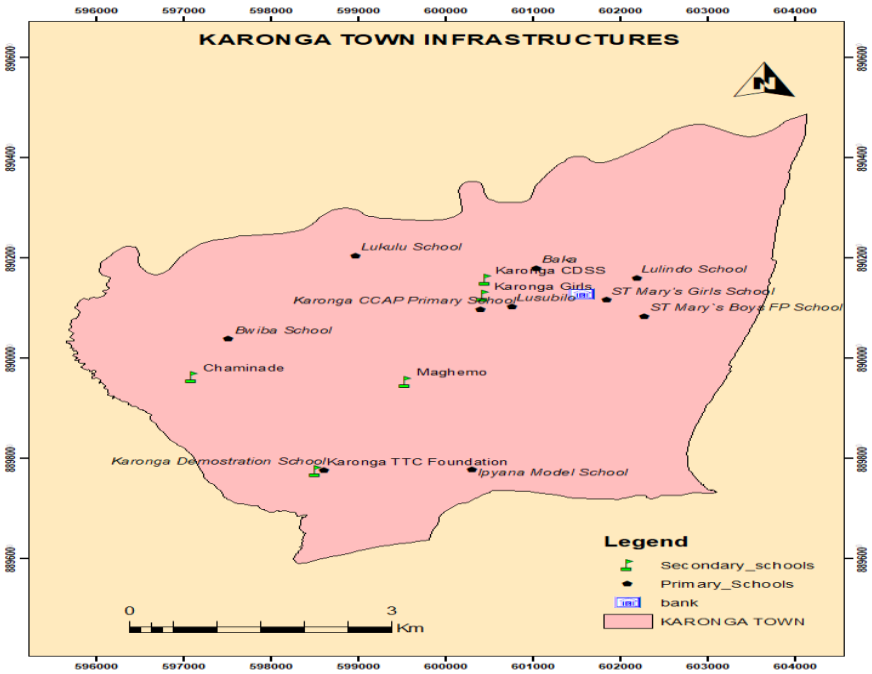


Figure 6

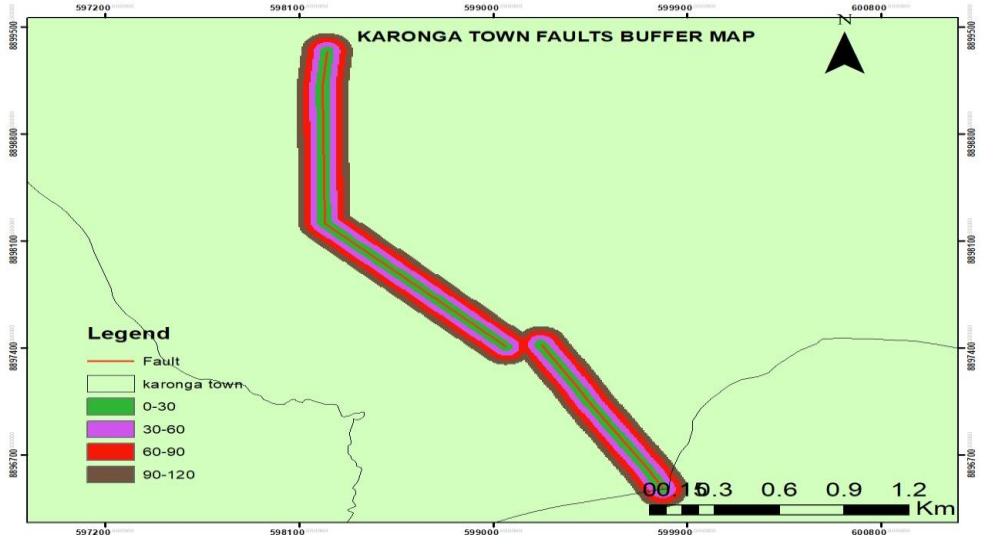


Figure 7

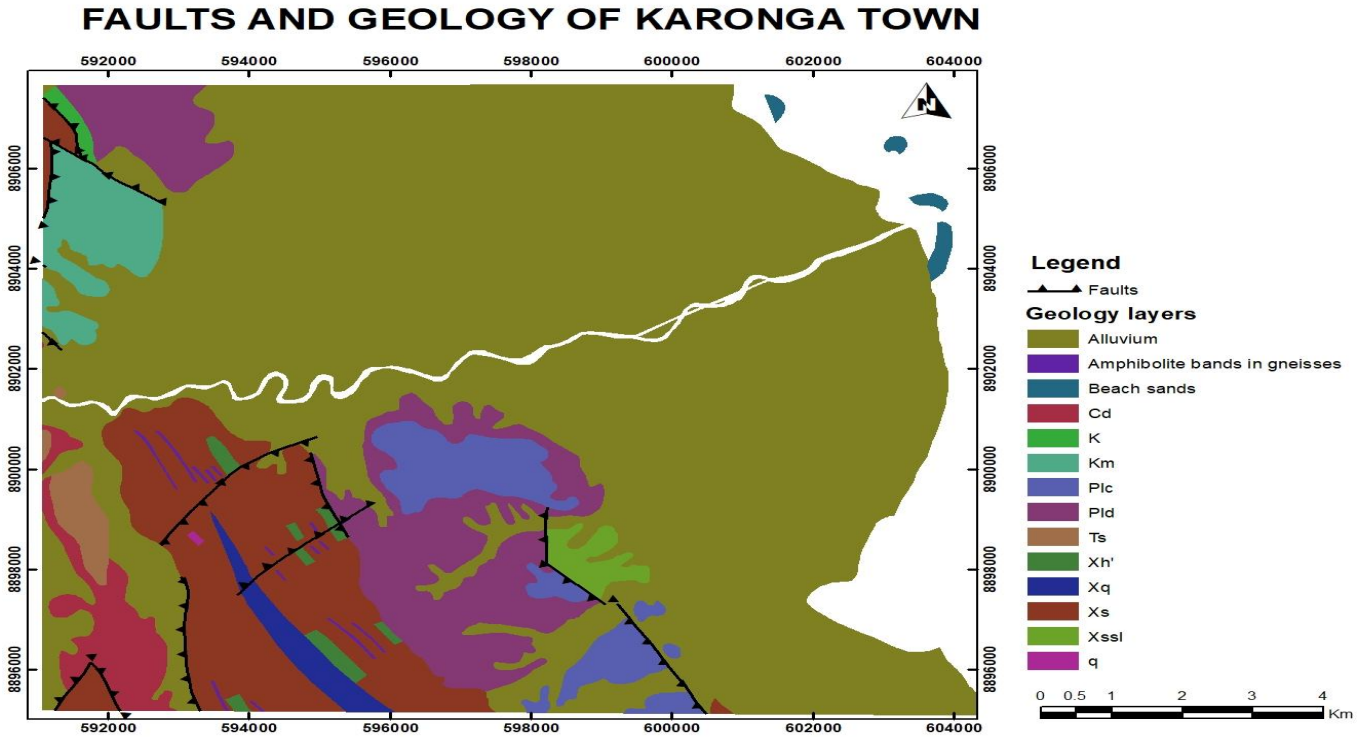


Figure 8

figure 9

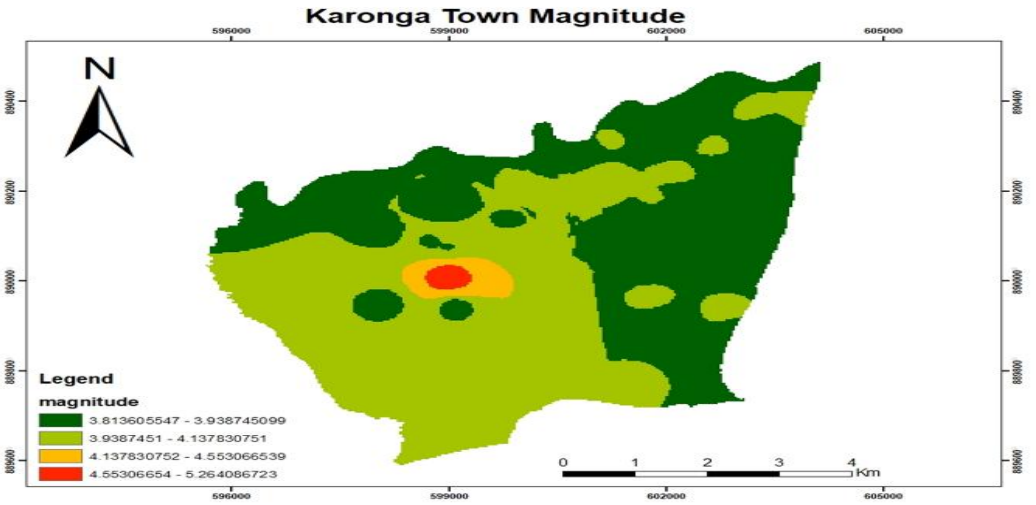
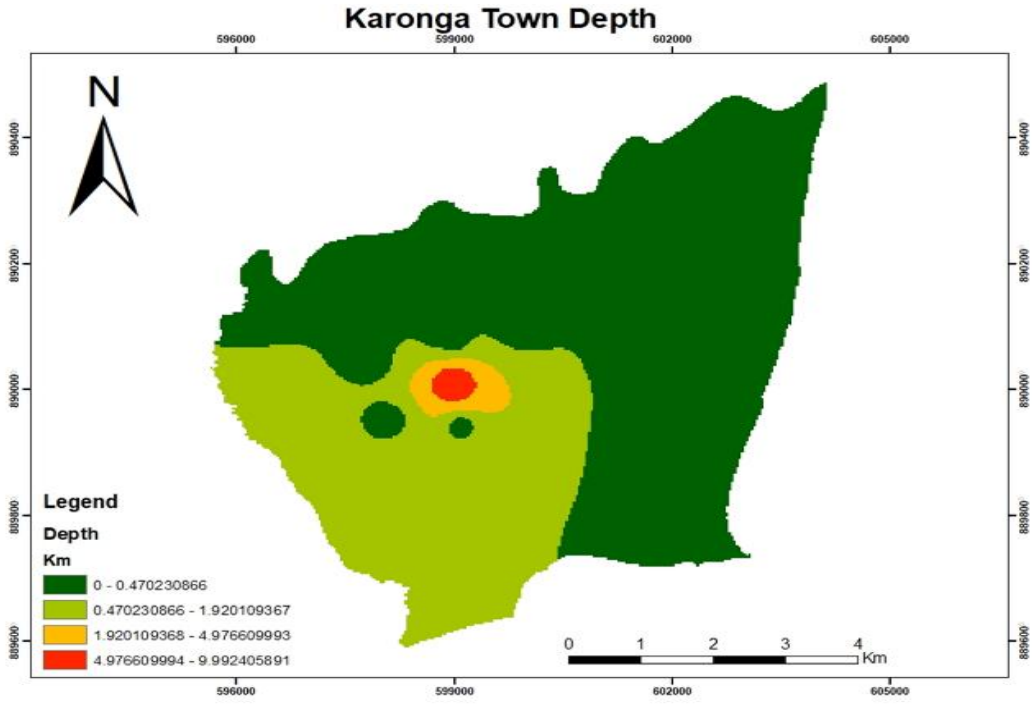

Karonga Town Magnitude
N
Legend
magnitude
3.813605547 - 3.938745099
3.9387451 - 4.137830751
4.137830752 - 4.553066539
4.55306654 - 5.264086723
0 1 2 3 4
Km

figure 9


Karonga Town Depth
N
Legend
Depth
Km
0 - 0.470230866
0.470230866 - 1.920109367
1.920109368 - 4.976609993
4.976609994 - 9.992405891
0 1 2 3 4
Km

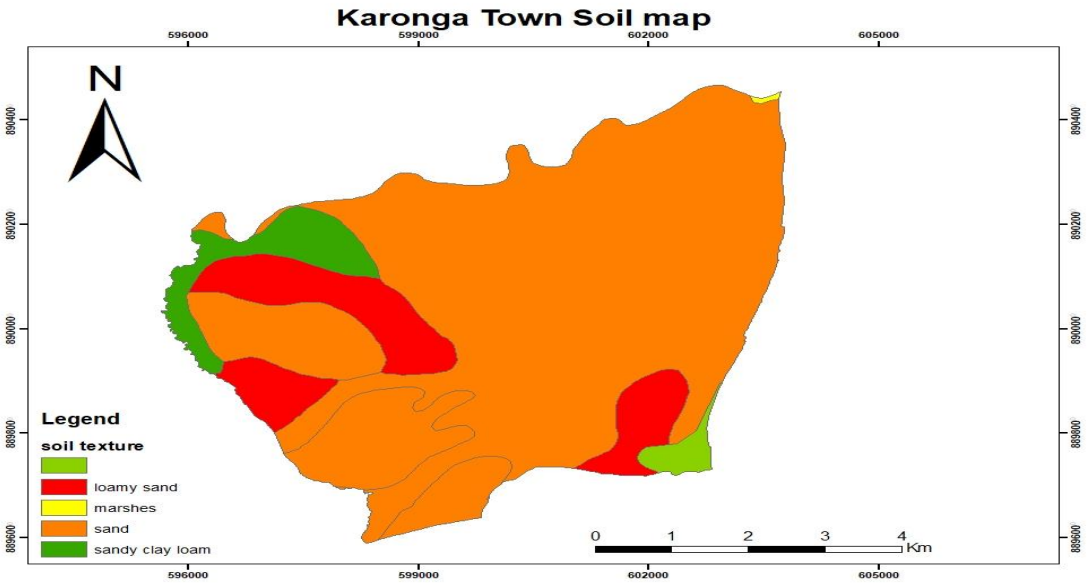


figure 10

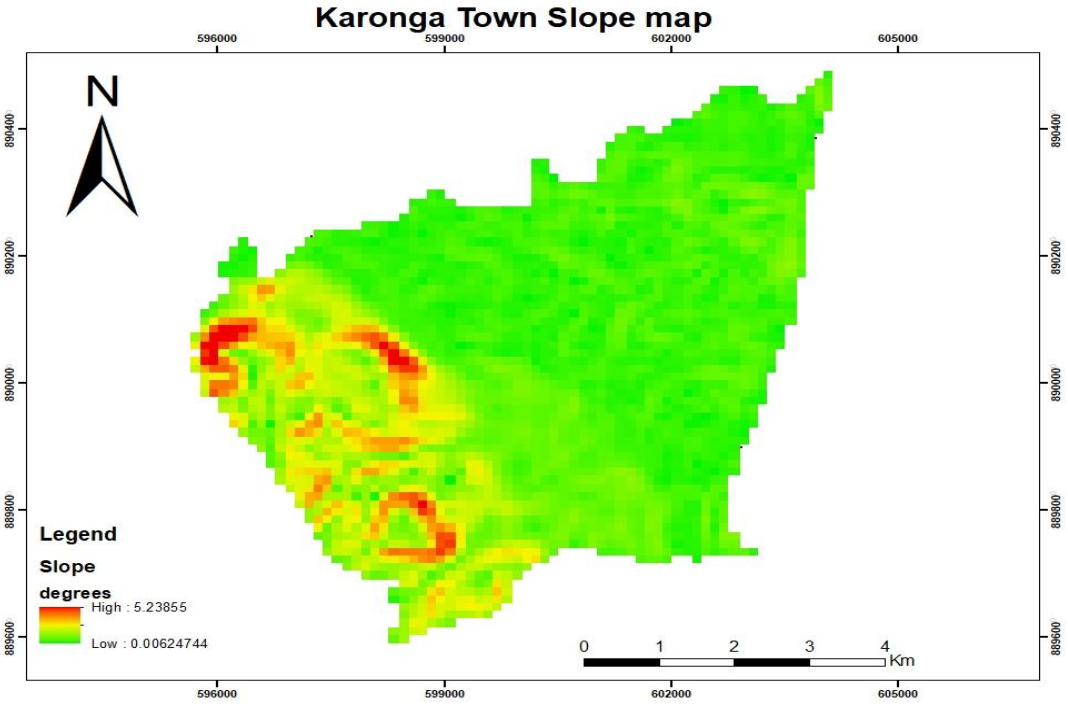


Figure 11

3.1 EARTHQUAKE DEPTH

Earthquake depth distribution is one of the common features that were considered for delineation of earthquake hazard zones. Keeping in mind that the sites have experienced shallower depth earthquake in the past, the same sites are more vulnerable for shallower depth earthquake in the future too. The raster surface of earthquake depth distribution was prepared from interpolation techniques using ArcGIS 10. It is obvious that the I shallower the earthquake event, there's higher possibility for earthquake damage to life and properties. However, the extent of damage will be determined by site and sub surface features. Deeper the earthquake events, lesser will be the possibility of damage, due to the fact that the waves from the earthquake focus have to travel long distance and face attenuation posed by different layers. However, on the other hand the strength of the waves can be amplified if it comes to areas of soft, saturated and unconsolidated sediments or rocks but can again be reduced when it comes to consolidated sediments or rocks. These all depends on how deep or shallow is the earthquake focus. According to these ideas, the raster surface was reclassified into five (5) classes. Higher weightage was assigned to shallower earthquake depth and low weightage was assigned to classes of deeper earthquake.

3.4 EARTHQUAKE MAGNITUDE

Magnitude raster surface was prepared through interpolation techniques and was used as one of the 4 factors into delineation of earthquake hazard zones. As was discussed earlier, all the historical earthquake magnitudes from year 2000 up till 2016 were acquired in the point format and the interpolation technique in ArcGIS 10,5 was used to generate the raster surface of magnitude distribution with the precept that if the particular sites have experienced greater earthquake events in the past, then the same sites will also be vulnerable for experiencing greater earthquake magnitude in the future. The raster surface prepared was then reclassified to four (4) classes based on its levels or magnitude. It was found out that the highest magnitude recorded within the study region was 5.26512 while the lowest magnitude was found to be 3.8136 in the study region. Evidently higher earthquake magnitudes pose greater damage to the surrounding environment and lower magnitude pose minimal or no damage. With this precept the weightage and rankings were assigned to each class.

3.5 ASSIGNING OF WEIGHTAGE AND RANKINGS

Through the integration of four (4) factors as discussed above, the earthquake hazard levels were calculated and delineated. Table below tabulates the weightage and ratings assigned for each theme with their classes form the delineation of earthquake hazard zones. The normalized weights were calculated using AHP techniques and finally were assigned for each theme. For the theme that contributes more to earthquake hazard were assigned high weightage and low weightage was assigned to theme that contributes less. As regards each class, ratings were assigned and again were normalized using AHP techniques.

Table 9. Weightage and ranking for each factor assessed for earthquake hazard Zonation

Theme	Weight	Class	Rating	Area (%)
Earthquake Magnitude (EM)	0.09	3-4.2 4.2-4.6 4.6-5.3 5.3-7.3	1 2 3 4	12 8 35 45
Depth (km)	0.99	1-3 3- 5- 7-	4 3 2 1	50 32 10 8
Soil texture	0.51	Sand Sandy loam Sandy clay	4 3 1	62 28 10
Fault's buffer (km)	0.18	10-20 20- 30- 40-	4 3 2 1	48 25 18 7
Slope(degrees)	0.40	0-6 6- 12- 18	4 3 2 1	47 26 19 6
Geology	0.76	Consolidated unconsolidated	1 4	21 79

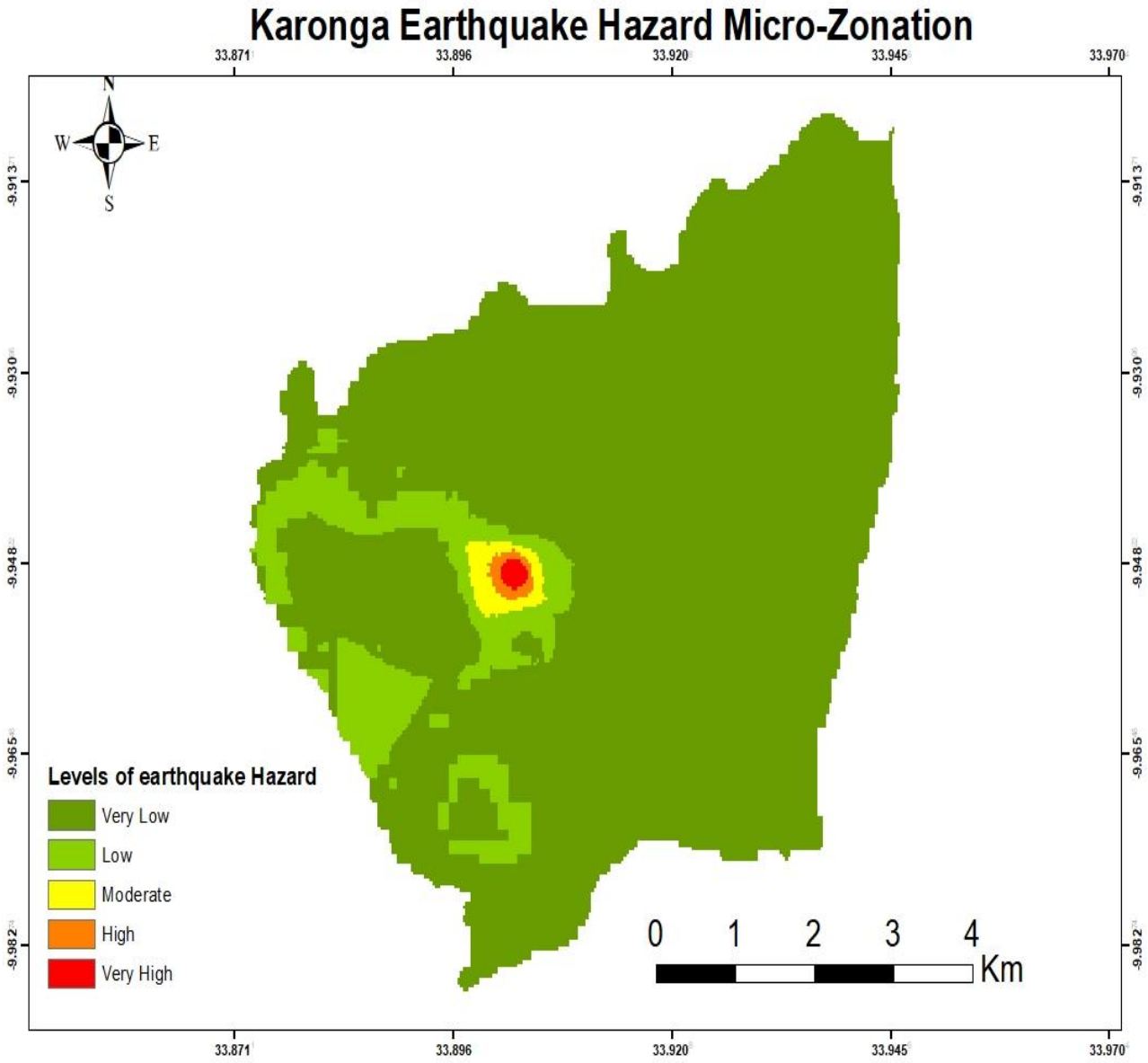
3 .6 DELINEATION OF FINAL RESULTS

Identifying earthquake hazard zones is essential to engineering fields for infrastructural design, policy makers and the general public. People need to be informed regarding the vulnerability of their residential and work areas, infrastructural assets along with the ambience in regards to earthquake shaking. After assigning all the weightage and ratings, the spatial analyses tool; Raster Calculator in ArcGIS 10.5 was employed in calculating and producing the final earthquake hazard zonation map. The final map derived was based on weightage and ratings assigned.

3.7 WEIGHTED SUM OVERLAYING ANALYSIS

The formula employed in a GIS environment to calculate and derive earthquake hazard zones levels was: EHL= magnitude*0.2692 +depth*0.08450 + faults*0.0415 +soil*0.2140 +rocks*0.0492 +slope*0.0240+ infrastructure*0.3169. The EHL value was then assessed and reclassified in order to delineate earthquake Hazard zones

Figure 12


Karonga Earthquake Hazard Micro-Zonation
33.871
33.896
33.920
33.945
33.970
N
W
E
S
-9.913
-9.930
-9.948
-9.965
-9.982
Levels of earthquake Hazard
Very Low
Low
Moderate
High
Very High
0 1 2 3 4
Km

3.7 EVALUATION OF INFRASTRUCTURES WITH HAZARD ZONES

Several known and available built-up infrastructures, such as roads, schools, banks, and other important built-up urban infrastructures, were taken into consideration in the study region to evaluate and consider their possible location on each Earthquake hazard potential zone.

These infrastructures are crucial in terms of maintaining and improving the country's civic amenities as well as socioeconomic prosperity. These analyses are to let governing bodies and general public as a whole know or figure out the possible threats to each built infrastructure, where this can assist in proper development planning and awareness. Also, it can assist in proper and better future development planning. highlights the total number and length of each built infrastructure on each zone of earthquake hazard levels. The table 'columns' indicates the hazard levels from very high to very low and the 'rows' indicates each built infrastructure assessed under each hazard levels or zones in terms of counts (number) and lengths (distance). Total length of roads with respect to each potential zone was measured in kilometers through spatial analysis techniques in GIS environment and the value was noted. Also, total number of count features like; schools, roads, and banks were counted with respect to each potential zones

. Table: 10 Built-up infrastructures assessed under each earthquake hazard zones

infrastructure	Very high	High	Moderate	Low
Schools	4	9	2	
Banks	2	4		
Roads	8	12	1	

Institutional arrangements

There are some organizations within the town which deal with hazards. These organizations use a cluster approach in dealing with these hazards. Some of these institutions include: Red Cross, Self Help Africa, World Vision, CADECOM among others (Table below). The stakeholders working in Karonga note that vulnerability to earthquake hazard has been aggravated overtime by the poor building standards and material which result in lack of or no enforcement of the building codes by the government in small town such as Karonga. According to the District Council Officials there are a number of institutions and non-governmental organizations working in Karonga helping people to rebuild affected houses however none of them is working in Karonga town which has forced households in the town to build their dwelling houses poorly. According to District Council Officials there are institution government structures which respond to disasters from grassroots at village level which report to area and then district level which report to the national level. The village civil protection committee notes the hazardous events in the communities assess the situation as quickly as possible and report to the areal civil protection committee.

The areal civil protection committee receives reports from village civil protection committee assess the needs of the area reported to been affected by hazards and report to the district civil protection committee. The district civil protection committee receives reports from the areal civil protection committee and determines the extent of the problem in the district. They determine the numbers of people affected by the hazard and determine the type and amount of support required to alleviate the problem. Such information with recommendations is presented to department of disaster risk management for consideration and support. If the situation is deemed a disaster the declaration is made and resources are pulled to the area.

Such institutional arrangements provide channels of communication and allows for delegation of power for interventions in times of disasters. However, according to Official from Cardecom these committees mostly function with bigger and perceivably large-scale hazards and disaster. The district council official said: „"Small scale events go unnoticed and are considered not notifiable to authorities and yet they are the most prevalent and cumulatively build to constitute the vulnerability which the communities have. " This obvious have a bearing on the way people are impacted by these hazards as their resilience is weakened by such smaller events.

TABLE.11 Institution involved in earthquake interventions and their activities.

Names of institution	Activities taken in disaster management
Office of the DC	Assessing the impacts of hazards and coordinating relief operation
Discover Malawi	Identify affected families, offer training on small scale businesses, and distribute drought resistant seed for irrigation farming during dry season.
Geological survey	Assessing the nature, scale, determining the epicentre and impacts of seismic hazards,
Meteorological services	Noting dates when shockwaves are experienced
CARDECOM	Identifying victims and coordinating relief operations
World vision	Identifying affected communities and coordinating relief operations, distribution of seeds replanting
Red Cross	Identifying affected areas, supporting victims, displaced and coordinating relief, construction of toilets, distribution of blankets

Source: karonga DC office, (Disaster department)

CONCLUSION

Earthquake hazards are common throughout the world and they are often accompanied with great loss of lives and infrastructural assets. The wide spread damage and death depends on the magnitude, depth of focus and distance of major human built-up infrastructure from the epicenter, the shaking intensity and the ambient geology and geomorphology. Thus, assessing the historical earthquake seismicity data layers coupled with geology and geomorphology can assist in identifying possible levels of hazard in each site. There is always a possibility that if the particular sites that have experienced big earthquake events in the past, then the sites remain vulnerable for greater earthquake magnitude in the future. If the sites have experienced great shaking intensity, then the sites are always vulnerable for greater shaking in the future earthquake event. If the sites have experienced shallow depth earthquake in the past, then the sites can expect shallow depth earthquake focus in the future too with more devastating consequences.

In the event of a high magnitude earthquake triggered at shallow depth at a site where the sediments, rock or soil are unconsolidated and saturated, then there is higher possibility of experiencing greater damage due to intense shaking. These are the ideas that could be integrated in a GIS platform to produce a meaningful delineation of various earthquake hazard zones. These maps can prove very useful to the administrators. Earthquake hazard micro-zonation mapping is an important tool for land use planning in terms of infrastructure development and mitigation measures. It creates easily - read, rapidly accessible charts and maps that facilitate decision making processes by Governing
bodies. Armed with the scientific knowledge of each earthquake hazard levels, future development planning can be done effectively towards site selection for investment decision of major infrastructure.

6. REFERENCE

Alexander D (2001). Natural Disasters, CRC Press, Tylor and Francis Group, USA.

Ammon CJ (2010), Seismic Waves, Department of Geosciences, SLU, (Class notes).

Karonga Earthquake Report, 2009, Karonga District Council.
Kambani C, Boyer C (2010). Malawi Disaster Risk Reduction and Climate Adaptation Research for CORDAID

Vivekananda J (2015). Disaster risk and its reduction; An agenda for Africa
Malawi government (2013). Karonga Urban Structure Plan, Ministry of Lands and Housing Physical Planning Department, Lilongwe

Saaty, T. L., (2008), Decision making with the analytic hierarchy process, Int. J. Services Sciences, Sitharam T.G and Anbazhagan. P (2016) Seismic Hazard Analysis and Preliminary Micro-zonation of Bangalore City, Civil engineering department, Indian Institute of Science, Bangalore-560 012 1 (1) 83-98.

UPSeis (2016), what are earthquake hazard? An educational site for budding seismology United States Department of Agriculture (USDA). (1975).

Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Washington, DC:

US Govt. Printer. USGS. (2018). Earthquake Hazard Mapping. https://www.usgs.gov/.

Abdalla JA, Al-Homoud AS (2004) Earthquake Hazard Zonation of Eastern Arabia. In: The 13th World Congress on Earthquake Engineering, Vancouver, B.C., Canada, 1-6August 2004.