

EARTHQUAKE HAZARD ASSESSMENT IN KARONGA DISTRICT USING GIS

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Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfilment of the requirements for the Bachelor of Science degree in Disaster Risk management

OCTOBER, 2022

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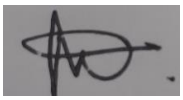
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ABSTRACT

Among the various types of natural disasters, earthquake is considered as one of the most destructive events which impose a great number of human fatalities and economic losses. Visualization of earthquake events and estimation of peak ground motions provide a strong tool for scientists and authorities to predict and mitigate the aftereffects of earthquakes. Karonga District is prone to seismic waves resulting from the tectonic activity associated with East Africa's great Rift Valley Fault, a constructive edge that forms Lake Malawi and in recent years there has been increase in construction of different infrastructures hence there is need of seismic hazard assessment in the area. This study was amained at assessing earthquake hazard in Karonga district using Geographical Information System platform by analyzing seismic data for the period of 1920 to 2021. The probabilistic seismic hazard assessment (PSHA) approach was implemented for the analysis. Finally, probabilistic seismic hazard maps for Karonga district for the return periods of 50 and 100years in order to aid in seismic zoning, seismic design, and seismic risk assessment of facilities, which can then aid in disaster management.

ACKNOWLEDGEMENT

I want to thank the Almighty GOD most of all for giving me life. Without the commitment and assistance of my supervisor, Mr. E. Chikalamo, the creation of this document would not have been feasible. He made time in his busy schedule to assist me and provide me invaluable advice as I wrote the dissertation all the way through the presenting stage.

Additionally, I would want to thank my parents for their support and Malawi University of Science and Technology for allowing me to conduct research for this program.

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1. CHAPTER ONE: INTRODUCTION

1.1. Background Information

Disaster resilience is a key global goal for sustainable development, as strongly advocated by the Sendai Framework (https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030). Integrating hazard, exposure, and vulnerability and quantifying the risk to people and the built environment are essential steps to achieve this goal. The outputs from such analyses are useful for informing disaster risk reduction policies and actions from socioeconomic and financial perspectives.

Earthquakes are one of the most powerful natural phenomena that can impose substantial human and economic losses on societies. Since 1980, earthquakes have accounted for 12.2% of all catastrophic natural hazards worldwide, contributing to 56.2% of all casualties and 25.2% of financial losses in total (Munich Reinsurance Company MunichRe, NatCatSERVICE Analysis Tool, & Natural Loss Events 1980–2018., n.d.). The top five countries that have been most frequently affected by damaging earthquakes are China, Indonesia, Iran, Turkey, and Japan, with 16%, 10%, 8%, 4.5%, and 4% of all damaging earthquakes, respectively (Centre for Research on the Epidemiology of Disasters (CRED). EM-DAT, 1).

Over the last decades, population growth along with unplanned rapid urbanization and poor land management have been underlying disaster risk drivers, so that leading to the accumulation of life and property assets in potentially earthquake-prone areas and thus resulting in an increase in earthquake risk (UNDRR, 2015) and (UN, 2015). According to the latest global seismic risk map (Silva, et al., 2020), there are currently 17 megacities around the world with a population of more than 10 million that are placed at the highest risk level, including Tokyo, Jakarta, Delhi, Beijing, Manila, Mexico City, Osaka, Los Angeles, Dhaka, Chengdu, Karachi, Tehran, Istanbul, Lahore, Nagoya, Bogota, and Lima.

One of the best efforts to address the impact of earthquakes on a region, especially in densely populated urban areas, is to conduct earthquake risk assessments. In this regard, a common practice to conceptually formulate earthquake risk is a simple convolution of three components (Preventionweb, 1) and (Sinadinovski, et al., 2005), as below:

Risk = Hazard × Exposure × Vulnerability. **(Equation 1)**

In recent years, there has been a growing amount of literature on earthquake risk assessment. On the global scale, one of the most relevant recent efforts has been performed in the framework of the Global Earthquake Model (GEM) project during 2009–2018 (Silva, et al., 2020), which aimed to provide a homogeneous global earthquake hazard and risk model by developing and combining several national and regional models and use of the state-of-the-art data and methodology. Some studies at national/regional scale include earthquake risk assessments for Europe, Italy. In terms of methodology, different studies apply different approaches to assess earthquake risk. In general, these approaches can be categorized into scenario-based, GIS-based, deterministic approach, probabilistic approach, real-time approach, seismicity–dependent, neural network and analytic hierarchy process, and holistic. In addition, several software platforms and codes have been developed to be used for modeling earthquake risk from local to global scales, such as Open Quake, HAZUS–MH, CAPRA.

It is worth mentioning that any earthquake risk assessment may inevitably be associated with modeling complexities and a number of limitations and challenges in developing accurate evaluations. The challenges mostly include data inaccessibility, how to integrate several spatial parameters having different resolutions, how to combine types of data layers with different concepts (e.g., the combination of social and physical vulnerabilities), as well as considering the domino effects of secondary indirect hazards (e.g., tsunamis, fire following earthquakes, earthquake-induced landslides, soil liquefaction, land subsidence, etc.).

Malawi experiences earthquakes as it lies along the East African rift system. Notable earthquakes in Malawi occurred in 1989 in Salima district with magnitude of 6.2 MW and in 2009 in the Karonga district with magnitude 6.0 MW. The Karonga earthquake received more attention than the Salima event because the Karonga events affected a large population (Kushe, Manda, Mdala, & Wanda, 2016). When earthquakes hit Karonga districts in 2009, some of the notable effects were surface fault formation, land subsidence, property damage, and death (Kushe, Manda, Mdala, & Wanda, 2016). In this paper, we attempt to address the quantification of the present-day earthquake risk in Karonga. In this context, we evaluate earthquake hazard using GIS platforms by probabilistic approach in R-CRISIS to map out the seismic hazard in Karonga at 50years, 100years and 475years return period.

1.2. Problem statement

Considering the rapid construction of high-rise buildings and various infrastructures during recent years in Karonga town, make it necessary to study seismic hazard in this area. Although there have been many attempts to estimate earthquake hazards and risk in Malawi but hence there is need to conduct the earthquake hazard and risk assessment in Karonga district and to deal with it from different viewpoints and implementing various methods.

1.3. Objectives

1.3.1.1. Main objective

The main objective of this study to assess earthquake hazard in Karonga district using GIS

1.3.1.2. Specific objective

In order to achieve the main objective of this study, the research will be conducted based on the following specific objectives;

- To map earthquake epicenters in Karonga district

- To quantify the level of seismicity in Karonga district

1.4. Research questions

1. What are possible sources of seismic activities in Karonga district?
2. Where does earthquake happen?
3. What magnitude do they have and how frequently do they occur?
4. What is the distribution of seismic hazard in the district?

1.5. Significant of the study

The first milestone towards achieving improved seismic resilience in Malawi is to assess earthquake hazard and risk accurately, hence the finding of this research will help in land use planning, seismic zoning, earthquake predictions, seismic monitoring, vulnerability assessment and also to update for recent seismic events records.

2. CHAPTER TWO: LITERATUREB REVIEW

2.1. Introduction

Natural hazard management is one of the most important applications of remote sensing and geographical information systems (GIS) technologies (Tehrany, Pradhan, & Jebur, 2014) and (Umar, Pradhan, Ahmad, Jebur, & Tehrany, 2014) . GIS as a technology of gathering, combining, analysis and manifesting spatial data (Abdullah, Pradhan, Mansor, & Shariff, 2015b) has a very significant role in improving the quality of studies related to natural hazards and possibility of prediction, management and mitigation of their disastrous consequences. Collection and classification of historical data about a disaster makes it possible to have a relatively realistic estimation of its behavior and rhythm of occurrence (Youssef, Pradhan, & Hassan, 2011).

The widespread use of Information technologies has become a vital element to many disciplines in recent years; for example, city planning, social sciences, engineering etc. Particularly GIS-based studies for urban planning have started to gain more importance as a powerful tool to evaluate alternative planning scenarios. Planning is directly related to both physical space and social space. Earthquake hazard map can be produced by the use of this information. A clear understanding of the spatial distribution of earthquake events facilitates the prediction of seismicity and vulnerability

Among natural disasters, earthquake is considered as one of the most destructive and devastating phenomena which seriously threatens the life of people, properties and infrastructures. This fact makes it a necessity to investigate various regions of the world to gain a scientific understanding about the mechanism of occurrence and recurrence of it. There are nearly daily reports about earthquakes in different parts of the world, but until now there is no way to predict the exact location and intensity of the next event. As earthquakes imposes a great deal of damages to societies, seismologists and engineers concentrate on studies to find out the rhythm of occurrence of seismic events and seismic hazard analysis to apply the results in construction standards and codes in order to mitigate the rate of losses related to earthquakes. (Nouri, Prahan, & Abdullahi, 2016)

Generally, hazard mapping analysis is implemented in macro and micro levels. Macro level, which is the subject of this research, reports some general seismic characteristics of zones and sites, such as PGA, without considering the detailed specifications of the site under study. For this level, the application of GIS is compiling the seismic data containing earthquake catalogues and maps of seismic sources that are compiled with site map and analysis. Seismic micro-zonation is subdividing a region into smaller areas having different potential for hazardous earthquake effects. The earthquake effects depend on ground geomorphological attributes consisting of geological, geomorphology and geotechnical information. The parameters of geology and geomorphology, soil coverage/thickness, and rock outcrop/depth are some of the important geomorphological attributes. Other attributes are the earthquake parameters, which are estimated by hazard analysis and effects of local soil for a hazard (local site response for an earthquake). PGA, amplification/site response, predominant frequency, liquefaction and landslide due to earthquakes are some of the important seismological attributes. These datasets are compiled and analyzed to generate thematic maps based on assigning proper weightages to attributes (Nouri, Prahan, & Abdullahi, 2016)

When earthquakes occur, they create seismic waves or pulses of energy that can penetrate the whole earth (De Blij & Muller , 1996). Earthquakes are more common in areas with tectonic activity such as conservative, destructive, and constructive margins (Biggs, Nissen , Craig, Jackson, & Robinson, 2010). Different types of waves are generated by an earthquake with its speed and direction (Ammon, 2010) .A seismic wave is an elastic wave that is created by an impulse such as an earthquake or an explosion. Seismic waves can be divided into: body waves that emanate from the site of the quake inside the earth (Ammon, 2010) and surface waves that travel either along or near the earth's surface (Rayleigh and Love waves) (Alexender, 2001). The general concept of how the earthquake sources interrelate with each other is demonstrated in Figure 1

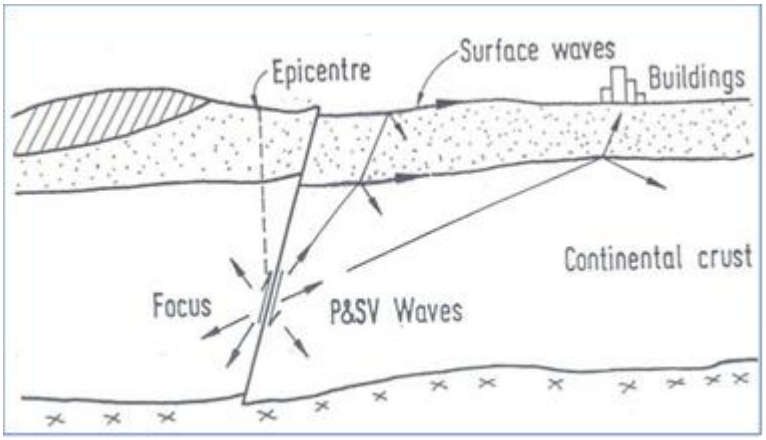


Figure 1 The general concept of how the earthquake sources interrelate with each

2.2. Seismic hazard evaluation

Seismic hazard quantifies ground motions generated due to an earthquake in terms of peak ground acceleration (PGA) or other similar parameters associated with a scenario earthquake (Kramer, 1996).

Earthquake hazard can be defined as the probability of occurrence of a damaging earthquake which may produce advance effects on humanin activities. In present there are two methods of seismic hazard assessment: probabilistic seismic hazard assessment (PSHA) and deterministic seismic hazard assessment (DSHA). DSHA is a method for estimating location-specific seismic hazard that is affected by the maximum earthquake from the controlling sources that can influence the specific location. PSHA for a site is developed considering all ground motions that can occur in the specified seismic zones of any possible magnitude and/or any possible distance between source and site. The main advantage of PSHA is that it combines all of accidental uncertainties that comes from the analysis of seismic zone parameters from a future earthquake at particular site (McGuire, 2004). PSHA provides a probabilistic approach of a characteristic unit such as ground acceleration.

The risk assessment involves evaluation of seismic hazard, vulnerability of structures, exposure, and finally loss estimation. Thus, the total risk can be expressed simply in the following pseudo-mathematical form: (Sinadinovski, et al., 2005)

Risk = Hazard × Vulnerability × Exposure

in which '*Hazard*' is defined as the potential of a natural phenomenon to cause damaging impacts and is characterized by its intensity or magnitude, location, frequency, and probability of occurrence. The term '*Exposure*', also known as '*Elements at risk*', indicates the number of people or amount of assets which are exposed to hazards, and '*Vulnerability*' is the susceptibility of a community, assets, or systems to damaging effects of a hazard

2.3. Geological structure of Karonga

Karonga District is prone to seismic waves resulting from the tectonic activity associated with East Africa's great Rift Valley Fault, a constructive edge that forms Lake Malawi (Flannery & Rosendahl, 1990). A number of seismic risks are anticipated in Karonga. (Flannery & Rosendahl, 1990), (Ebinger, Jackson, Foster, & Hayward, 1999) show that the sediment load of the fault deepens to 6 km, such a situation is the recipe for a requefication, especially with a raised groundwater level, since most deposits form good aquifers. Flannery & Rosendahl (1990) point to the existence of parallel faults that lead to the reflection of seismic waves in the event of vibrations. Further west of the Karonga District is a hilly topography consisting of Precambrian bedrock elevations along the E-immersing Karonga Fault (Biggs, Nissen , Craig, Jackson, & Robinson, 2010). The western part of Karonga is mainly characterized by hard rock formations (Basement Complex Rocks) around the town and the eastern side of the district; superficial deposits mostly dominate alluvium. Major NW-SE faults that dominate the west side of Karonga City serve as the primary defining features of the region. Lake Malawi, which is distinguished by typical fault patterns with a direction from NW to SE, is located in the eastern portion of the study region. The figure below is map showing geological make up of Karonga.

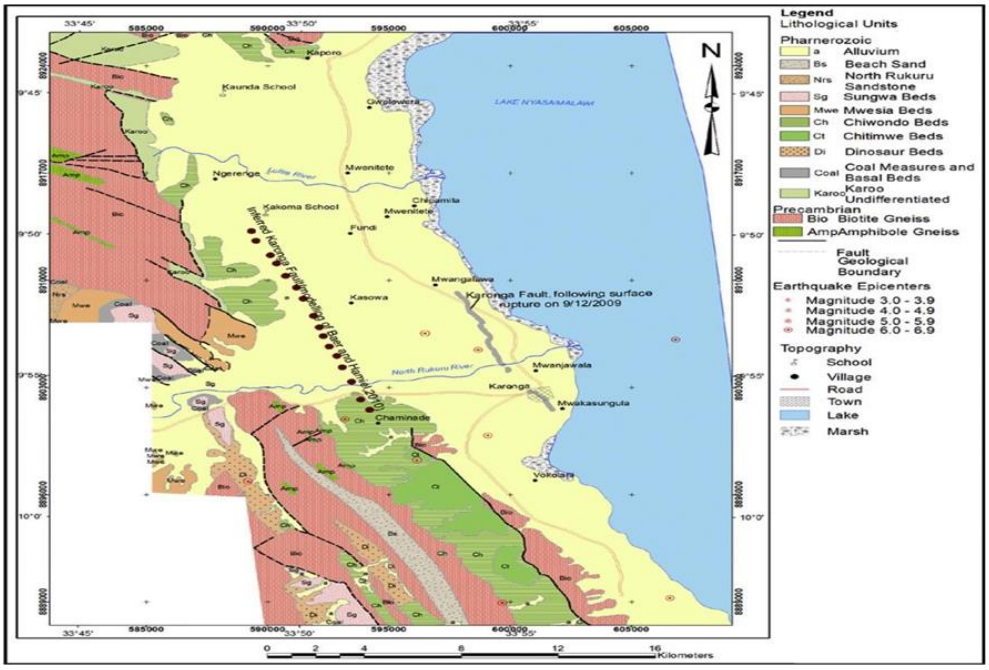


Figure 2: Map of Karonga showing lithology and mapped fault line and a rapture *(Mdala, Map of Karonga showing epicenters, faults and a rapture, 2016)*

2.4. Seismicity in Malawi and Karonga District

Seismicity in Malawi and Karonga District from records show that Malawi experiences light to moderate earthquakes both within the country and in neighboring countries, making it prone to seismic hazards. Scientific research within the Malawi Rift showed that the rift in Malawi opens with less than 3 mm per year (Shillington, 2010). The spatial distribution of the earthquakes in and around the country for the period from 1901 to 2014 shows that northern Malawi is highly active.

3. CHAPTER THREE: METHODOLOGY

3.1. Research design

The study adopted a mixed type of a research where it used both the quantitative and qualitative method and compute the analysis by the use of QGIS 3.4, Microsoft excel and R-CRISIS to answer research questions and the purposes of the study.

3.2. Study area

The study was conducted in Karonga District. The district is located in the Northern region of Malawi. The district covers an area of 3416 km2 and has a population of 365,028 (NSO, 2018).

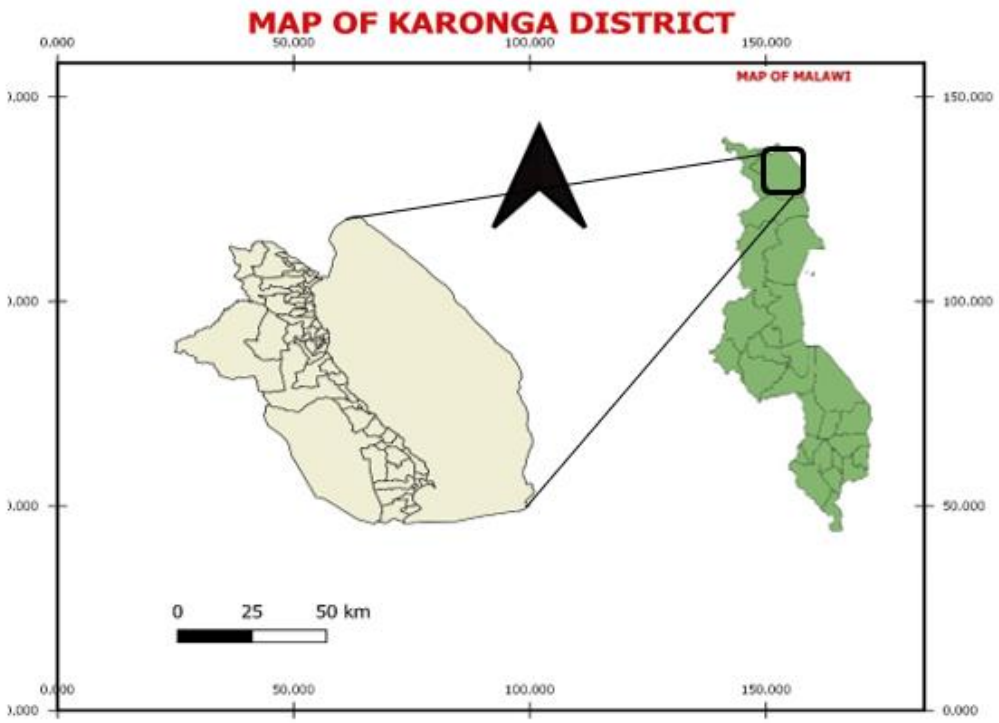


Figure 3: Map of the study area (Karonga District)

3.3. Data collection

The study was conducted to estimate the PGA in Karonga at various return periods by using earthquake catalogue of the region from the year 1920 to 2020. Earthquake data

was collected from the National Earthquake Information Center (NEIC) and the United States Geological Survey (USGS) for Malawi, for the historical events from 1920 until 2020.

3.4. The PSHA formulation

The PSHA formulation is fundamentally concerned with estimating the expected occurrence rate of exceeding a specified value of a random parameter used for characterization of hazard at a site. For this purpose, the original formulation due to Cornell (1968) uses only those combinations of earthquake magnitude and distance, which may cause a specified mean or median estimate of value to be exceeded. However, by considering the random scattering of the amplitudes of hazard parameter around the mean or median estimate, the occurrence rate can be defined using total probability theorem.

Analytical formulation for PSHA is the use of Monte Carlo simulation, in which a very long duration of earthquake catalog is generated from the probability density functions of magnitude, epicentral location, and the inter-event time for each source zone (e.g., Musson, 1999a; Smith, 2003). The amplitudes of the hazard parameter are then computed for all the earthquakes in the simulated catalog using a suitable probability density function for the residuals of the hazard parameter. The annual rate, $\upsilon(Z > z)$, is finally obtained by counting the number of years in which the maximum value of Z exceeds a specified value z, and by dividing it by the total duration (in years) of the catalog. This procedure generally takes much more computational time without any apparent advantage for the case of Poisson occurrences of earthquakes. However, it may sometimes be more convenient to use the simulation to account for the epistemic type of uncertainties (e.g., Musson, 1999b; Smith, 2003).

Steps Involved in PSHA Approach

The four basic steps involved in the implementation of the foregoing PSHA formulation are depicted schematically in Figure 4. The first step is to identify and demarcate the

boundaries of the various seismic sources. Normally, the sources within about 300 to 400 km (depending on the tectonic region) of the site are sufficient for this purpose. Each of the sources is divided into a large number of small-size elements, and the expected seismicity in a source is distributed suitably among all the elements. The epicenters of all the earthquakes in an element are assumed to occur at the geometric center of the element. The probability distribution function $G(R)$ of the source-to-site distance R is then defined using the distances to all the elements as illustrated in the top left panel in Figure 4.

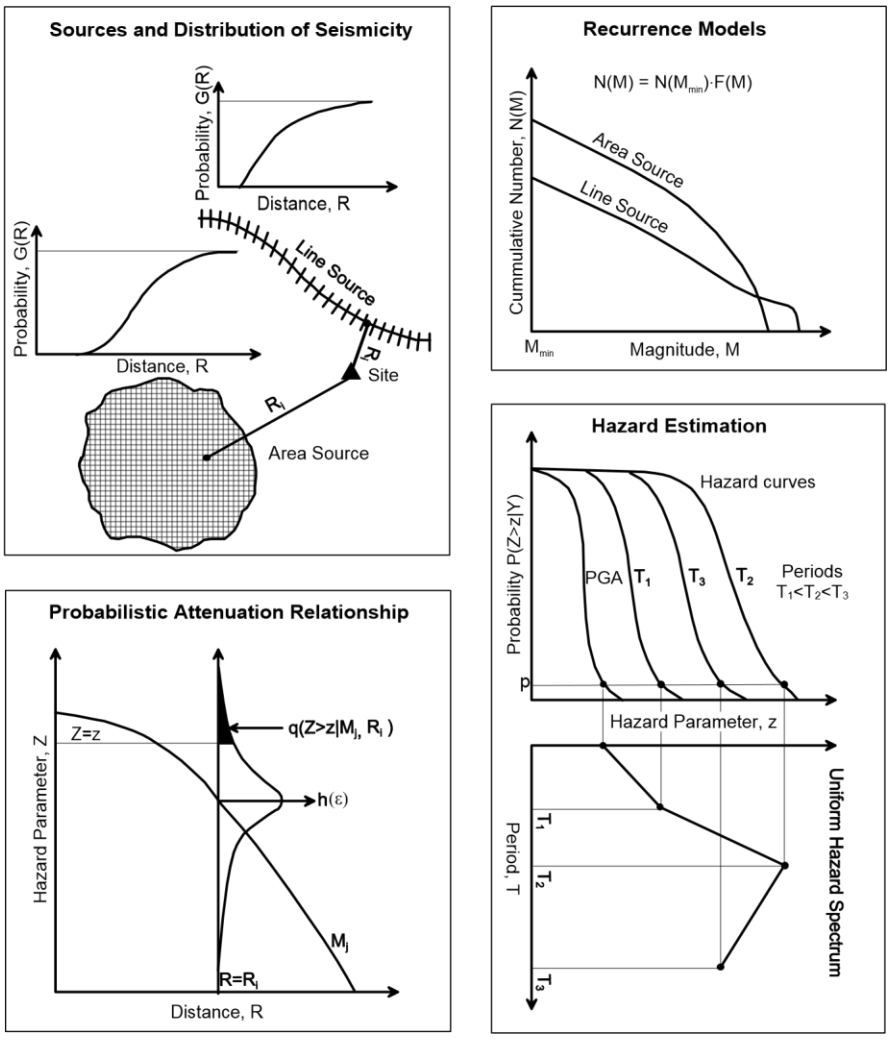


Figure 4:PSHA approach

To estimate the total number, $N_n(M_{\min})$, of earthquakes with magnitude above *M*min in a source zone, the frequency-magnitude relationship due to Gutenberg and Richter (1944) is defined for each source zone in Step 2. A magnitude distribution function, *F*(*M*), is also defined for each source to distribute these numbers among different magnitude intervals between a minimum magnitude, *M*min , and a maximum magnitude, $M_{\max}$. The exponentially decaying magnitude distribution is generally found suitable for area sources, whereas a characteristic earthquake model (Youngs and Coppersmith, 1985) is commonly used for individual faults. Alternatively, one may generate the synthetic catalogs for each source zone by estimating the parameters of the probability density functions for magnitude, occurrence time, and distance, defined from the available earthquake catalog.

A suitable attenuation relationship providing a probabilistic description of the amplitudes of the hazard parameter is required to be selected in Step 3. This should provide the mean or median estimate and the corresponding probability distribution of the residuals for specified earthquake magnitude, source-to-site distance, and site geologic and soil conditions. This is used to estimate the probability as illustrated in bottom left panel in Figure 4. A single attenuation relation may normally be applicable to all the source zones, but different relations may also be used.

The fourth and the final step in the basic PSHA is to compute the hazard curves by integrating over all the magnitudes and distances in all the source zones. Several hazard curves are required to compute the uniform hazard spectra as shown in the bottom right panel in Figure 4 (Anderson and Trifunac, 1977). It may be noted that due to lack of exact scientific knowledge and inadequacy of available data, it may not be possible to establish the first three steps of PSHA in a unique way (Gupta, 2005). For example, there could be several possible choices for the definition of seismic source zones and distribution of distance, type of earthquake recurrence model and the maximum magnitude for each source, as well as for the attenuation relationship for the hazard parameter of interest.

3.5. Probabilistic hazard mapping for Karonga

All the earthquake catalogues were arranged in the same format and then they were merged together into one single earthquake catalogue using EXCEL tools and command furthermore those events which match up together due to similar features like magnitude, coordinates, date and time etc. were also filtered out from the catalogue to get a master catalogue of the earthquake. The earthquake catalog in csv format was processed on QGIS Desktop to develop a map of earthquake spatial distribution in the study area. The source zones were drawn based on the distribution of earthquake epicenters. The seismic area sources zones and earthquake events was clipped on each seismic area sources to get a separate spreadsheet for each area sources zone and to find out number of earthquakes, minimum earthquake magnitude and maximum earthquake magnitude on each area source zone. The Gutenberg-Richter magnitude recurrence relation was drawn for each source zone using Microsoft excel to determine “a” and “b” parameters. Then the earthquake hazard map computation was done by the use of R-CRISIS.

3.5.1.1. Seismic source parameters

Derivation of “a” and “b” parameters from Gutenberg-Richter Model (G-R Model). The models for determining the "a" and "b" parameters are based on the magnitude recurrence relation proposed by Gutenberg and Richter. The Gutenberg-Richter relation for the models is given below

$$Log\ N(M) = a - bMw \quad \text{(Equation 2)}$$

Where “N(M)” is the cumulative sum of earthquakes above specific magnitude and “a” and “b” are constants appropriate for a particular region. The value of “a” is the y-intercept of the Recurrence model or annual rate of exceedance at zero magnitude and “b” value can be obtained from the slope of linear trend line of Recurrence relation. The “a” value is the measure of the overall rate of activity while the b value of a measure of earthquake distribution as function of size; for example, higher b values indicate

relatively more small events than big ones. The following steps were carried out for getting G-R model for six seismic source zone.

- Magnitude "Mw" of earthquake was arranged in descending order for each zone
- The frequency of "Mw" was noted i.e., the number for which that specific "Mw" occurs
- Now the cumulative sum of the frequency of occurrence was calculated
- The G-R Model was plotted between magnitude of earthquakes and logarithm of the cumulative sum value.

3.5.1.2. Computation of probabilistic seimic hazard by Software R-CRISIS

R-CRISIS is a software that works on Windows Operating System and has capability to carry out probabilistic seismic hazard analysis using a fully probabilistic approach as described in section 3.4 above. In are R-crisis the following steps where followed:ollows:

1. Mapfile of Karonga district shapefile contain vector data layer of point feature for which PGA will be computed was added.
2. In site data computation dialog window was chosen the Grind of sites option for performing PSHA was defined origin of the grid and incremented with the number of needed lines to cover all territory in two orthogonal directions. As the base point was chosen coordinates at latitude -11^0 and the longitude 33^0. The grind size was chosen to be equal of 38 vertical and 20 horizontal lines with the increment of 0.1° or 11.1 (km).
3. This screen allows entering the parameters for each spectral ordinate (or, in general, intensity measure) for which seismic hazard will be computed. The values of spectral ordinates for defining fundamental periods for each spectral ordinate was entered. The measure unit is g or cm/s^2. In this case study spectral ordinates are assigned for time periods of 0.01 s(i.e., PGA), 0.2 s and 0.4 s

4. The sources geometry for each seismic area source was selected by importing the georeferenced shapefiles of area sources already processed and digitized in QGIS. The "source is alive" is checked.
5. Seismic parameters for all defined seismic was assigned in "Seismicity Data" button. The modified Gutenberg-Richter seismicity model is used to describe every seismic source. This model is associated to Poisson occurrences, so the probability of exceeding intensity level a in the next T_f years, given that an earthquake with magnitude M took place at a distance R from the site.The following are the seismic input parameters for the computation of hazard map which are calculated based on the equation below.
    - Mean annual rate of exceedance (λ) of minimum specified magnitude earthquakes
    - Alpha-parameters
    - Beta-parameters

$$\boldsymbol{\lambda = e^{(\alpha-\beta mo)} * \left[e^{(-\beta(m-mo))} - e^{(-\beta(mmax-mo))}\right] * \frac{1}{\left[1-e^{(-\beta(mmax-mo))}\right]}} \quad \text{(Equation 3)}$$

α = a*2.303

β = b*2.303

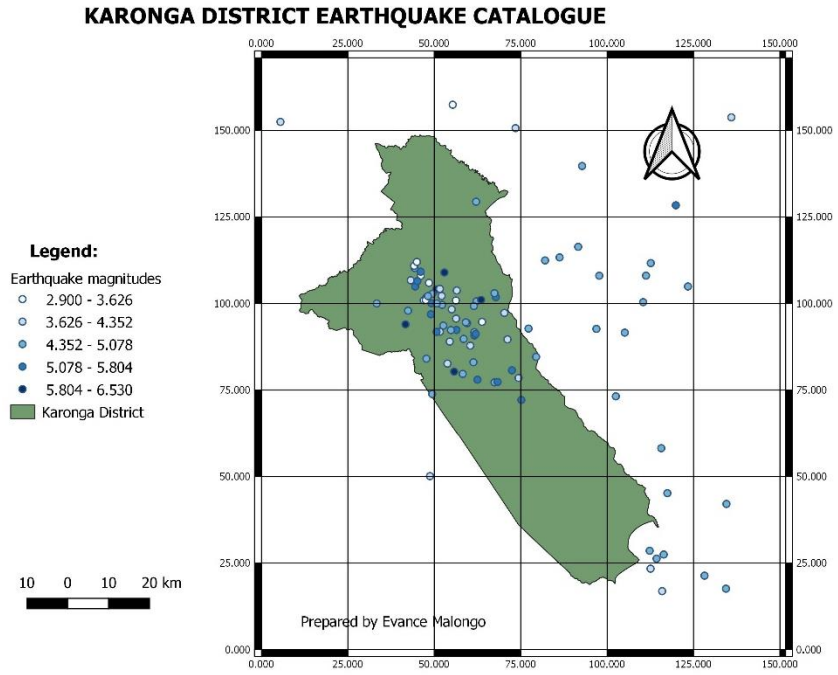
6 Selection of attenuation model was made for each source. The ground motion prediction models (GMPM) are developed after a lot of research. Generally speaking, the GMPM establishes probabilistic relations between earthquake characteristics, intensities and distances at the computation site. In this study a built-in attenuation models > Abrahamson and Silva (1997) is used for all sources.

4. CHAPTER FOUR: RESULT AND DISCUSION

4.1. Earthquake epicenters in Karonga district

The map below shows the distribution of earthquake epicenters in the study area from 1920 to 2020. Distribution of earthquake epicenters in the Karonga District shows that Karonga town has moral earthquake events compared to the other areas.

Figure 5: Earthquake distribution map in Karonga District



4.2. Quantification of seismicity level in Karonga district

4.2.1.1. Consideration of seismic sources

Upon overlaying the seismic sources and the earthquake epicenters the following map was produced as seen in figure below.

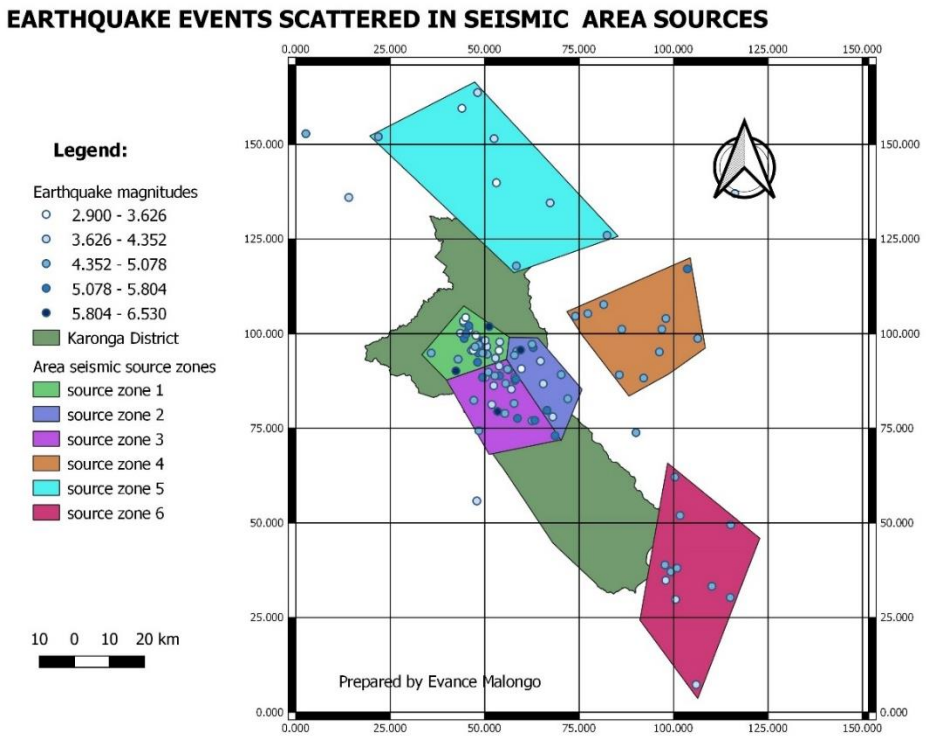


Figure 6:map of Karonga district showing seismic area source zones overlayed with earthquake magnitudes

The following are the tabulated results for earthquake events

Zone	No of earthquakes	Minimum Mw	Maximum Mw
1	28	3.8	5.8
2	12	4.0	5.9
3	24	4.0	6.0
4	11	4.4	5.2
5	8	3.6	4.7
6	11	4.1	4.8

Table 1: Area source zones with number of earthquakes events, minimum and maximum magnitude

4.2.1.2. Seismic source parameters

The seismic parameters shown in Figures below are plots of the moment magnitude Mw (X axis) for the total cumulative earthquake occurrence N (Y axis) and the logarithm of the total earthquake event log N (straight line).

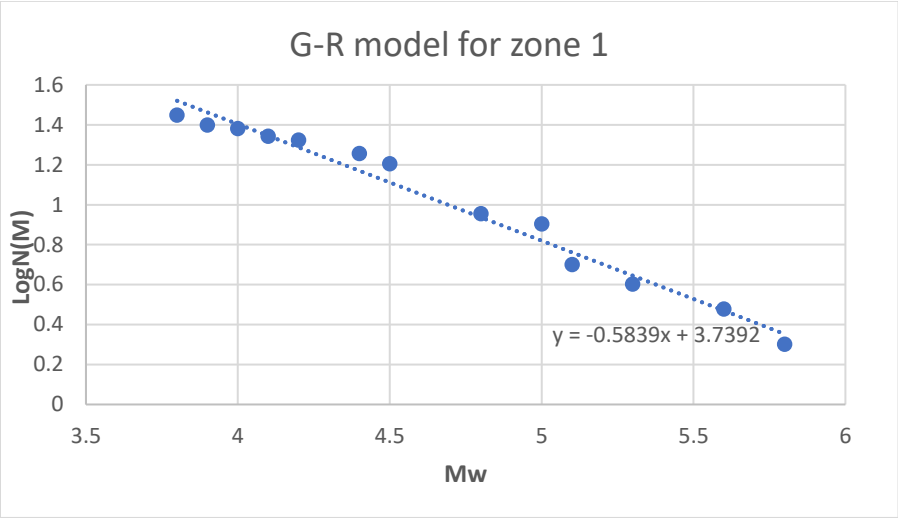


Figure 7:G-R model for zone 1

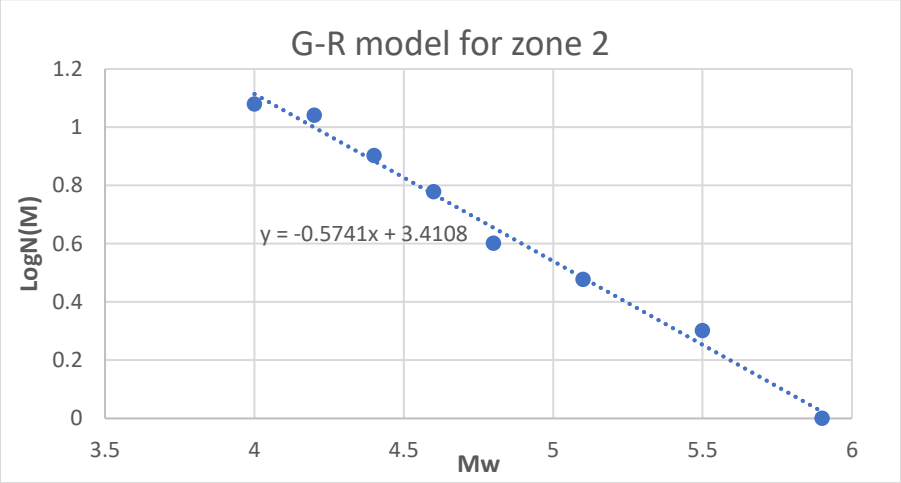


Figure 8:G-R model for zone 2

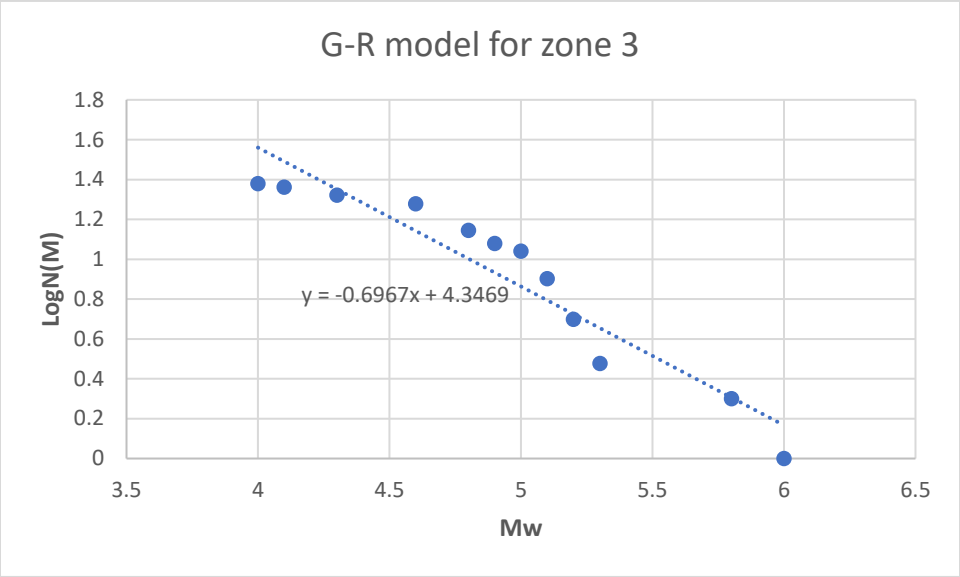


Figure 9:G-R model for zone 3

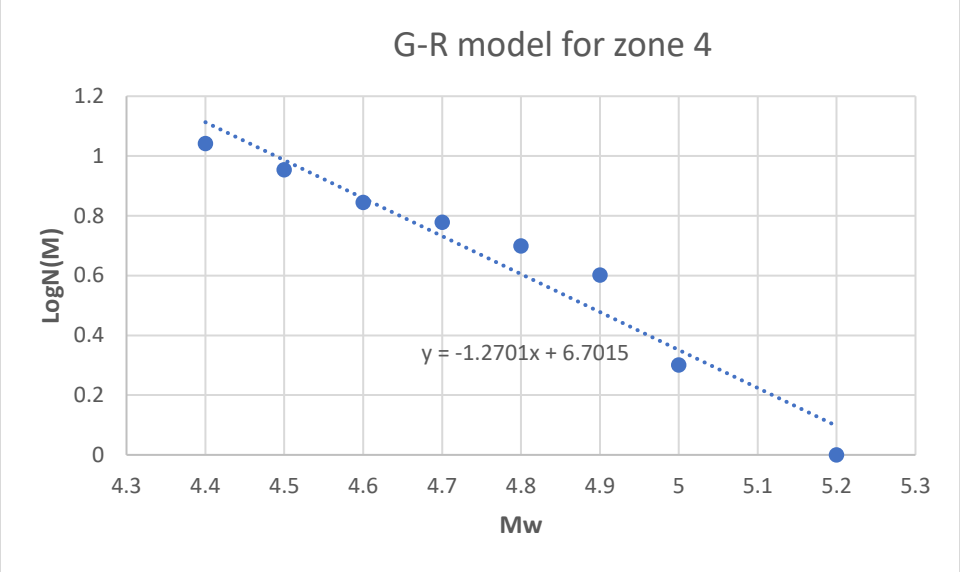


Figure 10:G-R model for zone 4

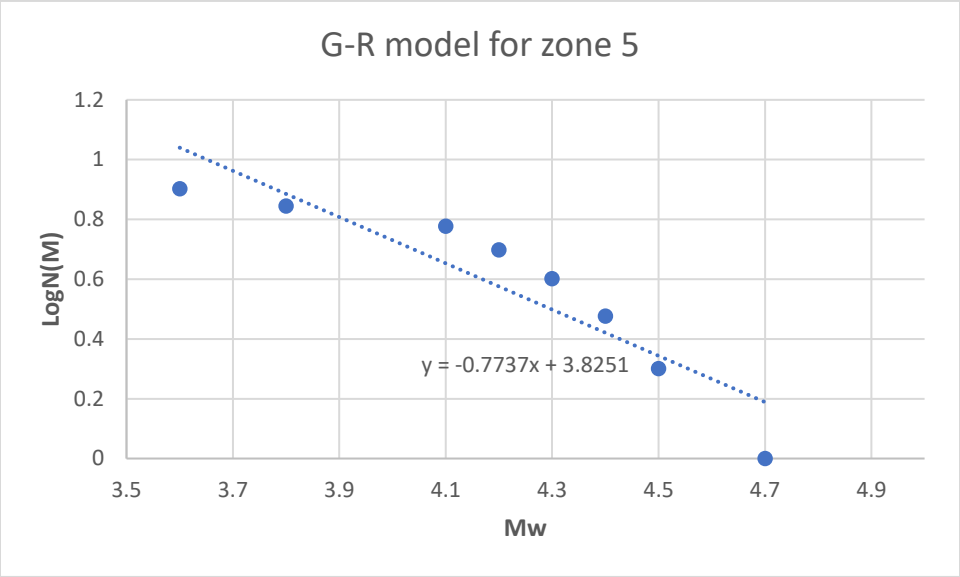


Figure 11:G-R model for zone 5

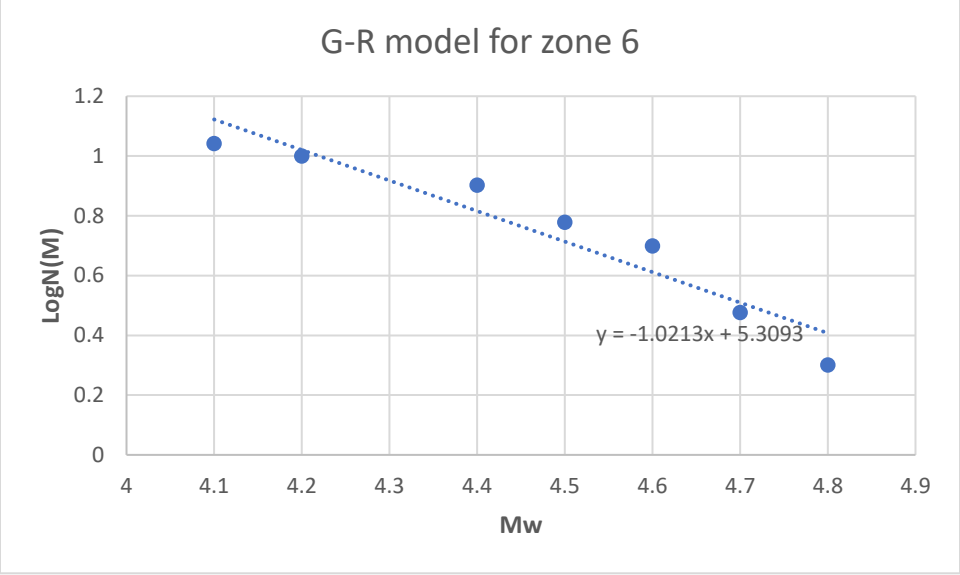


Figure 12:G-R model for zone 6

The figure below is the general G-R model for Karonga district. Which was used for comparisons with other models for all the sources.

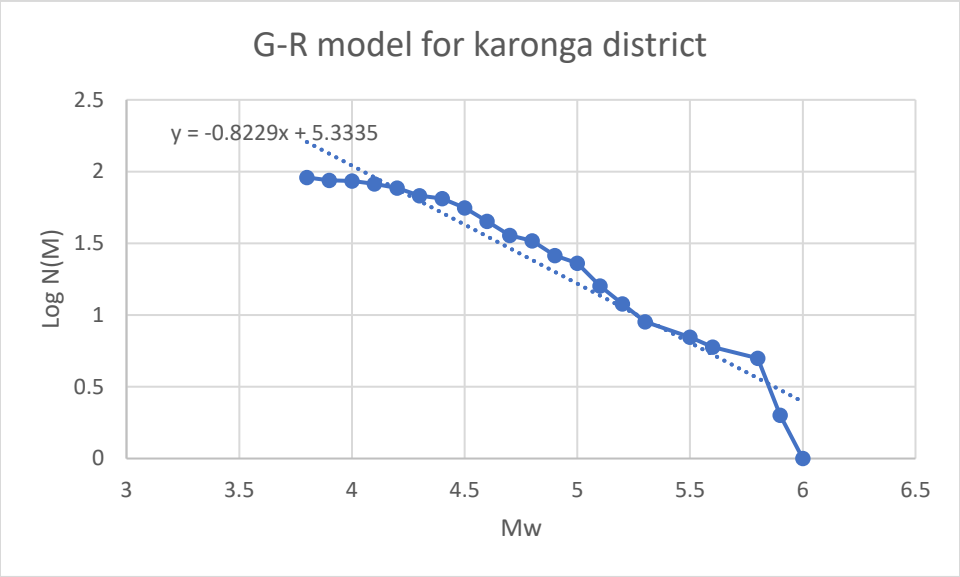


Figure 13: Gener G-R model for Karonga district

4.3. Seismic parameters used in R-CRISIS

The table below shows the seismic parameters for each source zone as calculated on the basis of equation 2.

Source zone	A	B	α	β	Mo	Mw(max)	λ
1	3.7379	0.5839	8.608384	1.344722	4	5.8	25.26694
2	3.4108	0.5741	7.855072	1.322152	4	5.9	13.01969
3	4.3469	0.6967	10.01091	1.6045	4	6	36.33968
4	6.7015	1.2701	15.43355	2.92504	4	5.2	41.82078
5	3.8251	0.7737	8.809205	1.781831	4	4.7	5.375658
6	5.3093	1.0213	12.22732	2.352054	4	4.8	16.7618

Table 2:seismic parameters used in R-CRISIS

4.4. Seismic hazard maps

Having all input information described above in chapter three section five, for all 6 seismic sources that affect Karonga district, computation of seismic hazard for the return period of 50 years and 100 years was conducted and the following results were obtained, as indicated by the seismic hazard map of Karonga district in terms of Peak Ground Acceleration and Spectral Acceleration for periods of 0.01 *s*, 0.5 *s* and 1 *s*.

The results of the earthquake hazard analysis with a return period of 50 years and with the spectral acceleration of T=0.01 second, T=0.5seconds and T=1second is shown on the figure bellow. Seismic hazard analysis results show that the highest PGA values in red are in the Karonga town followed by PGA values in the nearby areas.

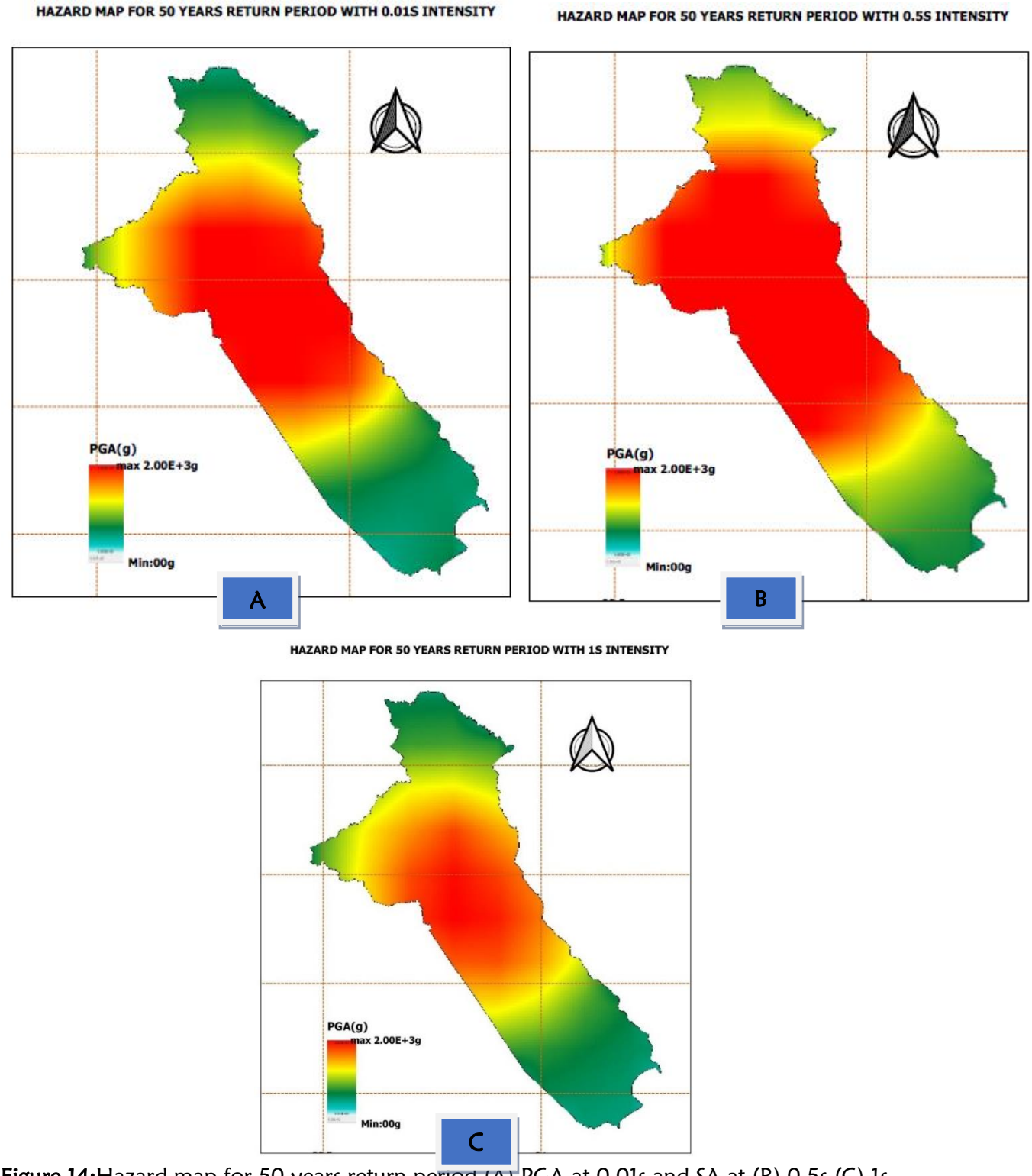
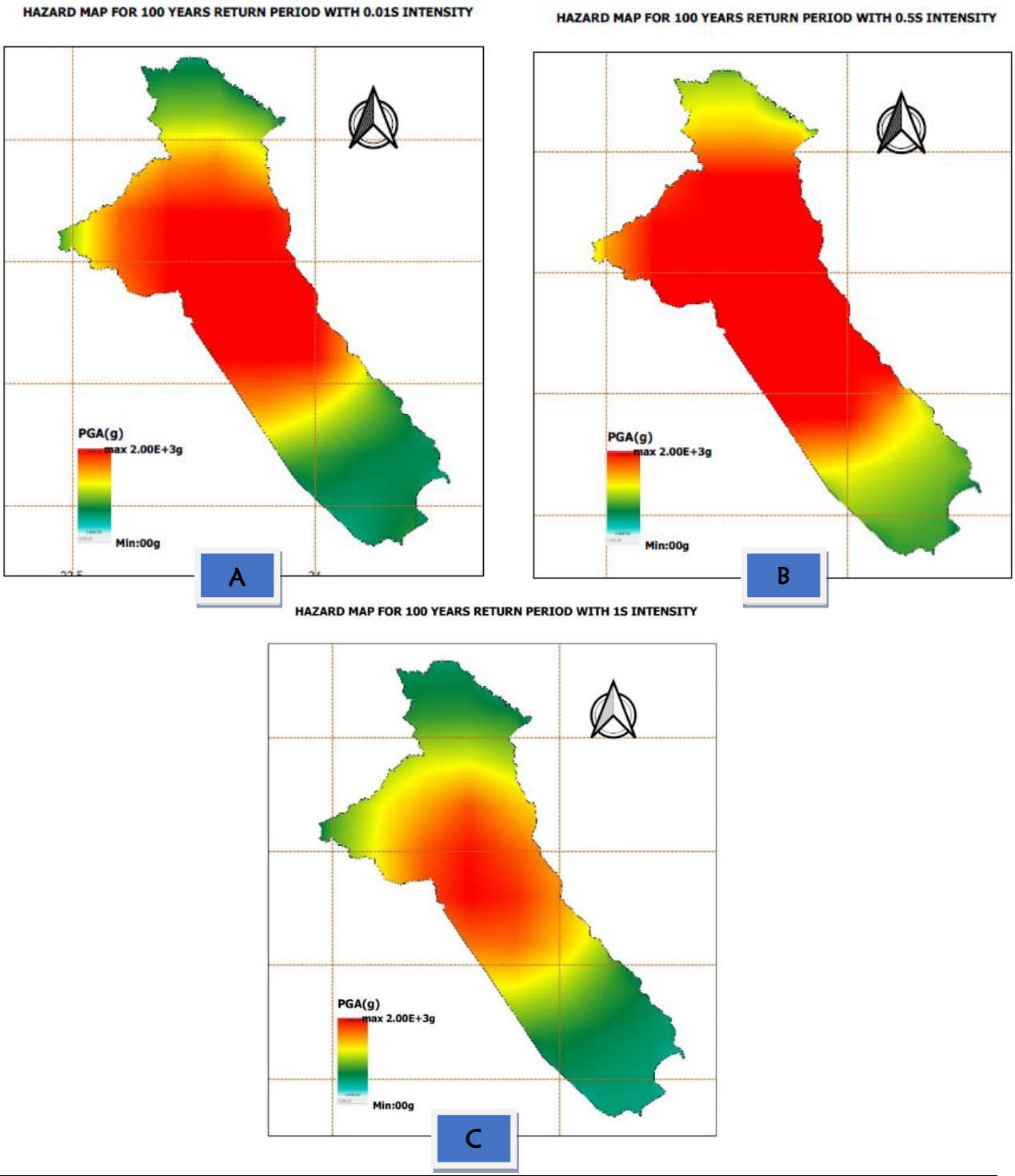


Figure 14: Hazard map for 50 years return period (A) PGA at 0.01s and SA at (B) 0.5s (C) 1s

Based on an earthquake hazard analysis with 100 years return period, Figure 14 shows the hazard map of Spectral acceleration at the intensity of T=0.01seconds, T=0.5seconds and T= 1second. The highest PGA values are mostly located in Karonga town.

Figure 15: Hazard map for 100 years return period (A) PGA at 0.01s and SA at (B) 0.5s (C) 1s



The main aim of this research was to assess earthquake hazard in Karonga district. This followed both practical doing and by the reviewing of other research done in this area to see of the result found and valid. The Information obtained from the geological surveys reports indicates that Karonga experiences seismic waves every year and in many years so many times. The epicenters of the earthquakes are wide spread in Karonga and are felt by neighboring countries of Tanzania and Zambia. Going through the records it was found that Karonga Town had been experiencing seismic waves since as way back as 1904 when the town was established as a trading center. Mostly the epicenters for most earthquakes have been along the Karonga fault and the western shelf of the Lake Malawi on Karonga coast. Adequate understanding of the earthquakes in Karonga dates back from 1956 and since then information has been corrected for the seismic waves. Mostly the epicenters have been located on the western parts of Karonga but the Town has had the most serious readings due to the rapture which is associated with the Karonga fault

This is in line with result obtained which shows that Karonga town is at the high risk of earthquake hazard both of 50years and 100years return period. This has great impacts on the project are being made in this area.

The evidence on the ground shows that most houses damaged by 2009 earthquakes have low quality construction material which easily fail when earthquakes occur (Richardson, 2011). The process of rebuilding is solely left in the hands of household owners who are often undergoing economic hardships (Richardson, 2011). In view of this there is need to make sure that the house builds in this area following building cods to avoid being affected by the hazard.

5. CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study was designed to assess the earthquake hazard in Karonga district by maximising the use of Geographical Information System (GIS). The results of the study focused on find the peak ground acceleration in the area if the maximum attainable earthquake is to occur in the return periods of 50 years and 100 years. It was found that Karonga town is at the higher risk compared to the other areas. These results are in line with result done by other researchers which shows that Karonga town is always at the risk due to kits geographical position which is at the centre of the fault. The information obtained from the study was found to be useful for implementing sustainable management in general and town planning.

5.2. Recommendation

Since Karonga Town is situated on a fault line, it is still susceptible to shocks made worse by earthquakes. Different stakeholders have different perspectives on the nature and scope of the earthquake event. Some people think that tectonic processes are what generate earthquakes, while others think that earthquakes are the spirits' way of punishing people for their transgressions. These various viewpoints will not be able to sufficiently lessen the effects and aftereffects of earthquakes in Karonga. For better planning of the growth and extension of Karonga Town, adequate education and training in the subject of earthquakes is necessary. Developers should have access to Karonga Town's hazard map in order to minimize and prevent building along the fault line and rapture. Civics instruction is necessary the application of building regulations and norms should

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