African Journal of Physics, Chemistry, and Medical Laboratory Science (AJPCMLS)

E-ISSN 2978-3348 (Online); ISSN 2978-333X (Print)

Indexed by SABINET and EBSCO

Volume 1, Number 2, December 2025

Pp 101-116

Mapping of Peak Ground Acceleration of the Area Close to Chipinge on the Southern Tip of Great Africa Rift Valley Using the Kawashumi Model

DOI: https://doi.org/10.31920/2978-3348/2025/v1n2a6

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Abstract

Chipinge is situated to the west of the Southern tip of the East Africa Rift Valley; it is approximately 30km away. The seismicity of Chipinge is due to its proximity to the Southern end of the East Africa Rift Valley, which is an active gigantic geological fault. The frequencies of earth shaking in Chipinge influence the ground movement. The main objective of this study is to calculate and analyse the maximum ground motion acceleration (Peak Ground Acceleration-PGA) as the occurrences of earthquakes have been increasing from 1950-2023. The PGA values and intensities vary across different regions, some areas in Asia like West Pasaman Regency in Sumatra experiences quite larger PGA values and intensities. In this study the ground peak acceleration was calculated using the Kawashumi Model.

Keywords: *Kawashumi Model, Peak Ground Acceleration (PGA), Seismicity.*

Introduction

Earthquake is the abrupt movement of the earth's plates caused by tectonic or volcanogenic activity. Due to proximity of Chipinge district to the seismically active Southern Tip of the East Africa Rift Valley, earthquakes are becoming more frequent in the district and likely to cause fatalities in the future and have negative environmental impact.

Chipinge is one of the areas in Zimbabwe that is frequently hit by earthquakes. The ground motion in Chipinge is induced by a very large fault close to it which is in the Mozambique side some few kilometres from the Zimbabwean border (Hlatywayo D.J. 1996). This giant fault is the Great East Africa Rift valley that extends from Southern Jordan in Asia to Southern Africa in Mozambique, and it is approximately 30km wide and 6 500km long. The East African Rift Valley is aastounding and incredible geological structure that has been shaping the African continent for millions of years (Young G.2016). It is a rift system that startin Jordan in the north to Mozambique in the south, passing through many countries including Ethiopia, Kenya, Tanzania.The East African Rift Valley was formed as of tectonic plate movement approximately 22-25 million years ago (Morley et al. 1999).The rift valley system is characterised by the presence of numerous volcanoes in its very long stretch, such as Mount Kilimanjaro and Mount Nyiragongo and that points of the region's intense geological activities. This gigantic geological feature is shielded by very steep fault lines, some faults within it extends up to 2 kilometres above the valley base.It houses several water bodies such as Lake Victoria, Lake Tanganyika, and Lake Malawi (Biggs.J.,et.al, 2021).

The Great East Africa Rift Valley is the most extensive known rift system with significant seismic activity. A lot of seismic events in Africa occur near the Afar Depression, with thestrongest one mostly occurring along or near major border faults (Kearey, 2009). Seismic events along the East Africa Rift Fault in the past century are estimated to have netted a maximum moment magnitude of 7.0 (Chorowicz, Jean 2005). The seismicity trends are prominently parallel to the rift system, with a shallow seated focal depth of 12–15 km beneath the rift axis. Some kilometres away from the rift fault lines, focal depths can be below 30 km (*Siebert, L et al 2010).* The deformation in the source region is oriented toward the northeast and is characterised primarily by normal dip-slip fault kinematics, with concurrent observations of left-lateral movement in some instances (*Corti, G 2014).* In chipinge the earthquakes caused by this Rift Valley faulting System cause damage to houses, environment and other structures.

Mapping ground motion caused by earthquakes using the Kawashumi model is a valuable approach for assessing seismic hazard.

The Kawashumi model is utilised to estimate Peak Ground Acceleration (PGA), a critical parameter in earthquake engineering and seismology.

In this case the Kawashumi model is applied to map ground motion, with special focus being on PGA values and their corresponding intensities. This approach encompasses scrutinising and analysing earthquake data, putting into considering events with magnitudes greater than or equal to 0 Mw and depths less than 50 km.

The Kawashumi model is just one of many models or techniques that can be used to calculate PGA. For example, Ground Motion Prediction Equations (GMPEs) estimate PGA, Peak Ground Velocity (PGV), and Pseudo-Spectral Acceleration (PSA) based on site conditions, distance, and earthquake magnitude. In addition to GMPEs, attenuation relationships—which use empirical correlations between earthquake magnitudes, distance, and local site conditions—can be used to get PGA values.

Another option is the Finite Element Method (FEM), which increases the precision of seismic behaviour forecasts by defining realistic dynamic loads in structural models using PGA values.

A factor developed by Idriss (1990, 1991) and Seed et al. (1994) can be used to estimate PGA values by amplifying the motions of bedrock outcrops. One technique for achieving this phenomenon is the use of amplification ratios. Estimates of PGA values are provided by the Kawashumi model, a main technique in this study that sheds light on the degree of seismic activity. This method (or tool) has the capacity to estimate seismic event magnitude, with the results quantified using the MMI scale. The Kawashumi model can be used to determine how PGA values and intensities vary by geography, such as how West Pasaman Regency in Sumatra has greater PGA values and intensities. It is an essential tool for determining earthquake severity and ground motion, which helps to guide preparedness and mitigation plans.

As a precaution to lessen the effects of the earthquakes, the Peak Ground Acceleration chart is necessary. Peak Ground Acceleration (PGA) may be measured with an accelerometre or, alternatively, during an earthquake. Plotting the numbers acquired allows one to see which areas are sensitive to ground movement and which are not. The PGA changes every time an earthquake occurs because of the accumulation of shocks; therefore, the map must be updated frequently.

PGA is a quantifiable disturbance with each seismic occurrence. The greatest PGA is chosen to be mapped in order to gain a better knowledge of the significant consequences of a location.

The largest PGA represents the maximum seismic intensity recorded at a particular site, quantified as the highest PGA value generated by a seismic event. It is more dangerous and likely that an earthquake will occur in a region with a higher PGA value. Many researchers have presented the PGA in different ways. Atkinson and Boore (2003) established an empirical connection between subduction zones and ground motion. Campbell (2003) also calculates ground motion using the Hybrid Empirical Method. Irsham and colleagues (2008) created seismic risk maps for the islands of Jakarta as part of a micro-zoning study.TatiZera et al. (2017) use three different models to compare PGA maps for the Bengkulu area. This study computes and maps the PGA values for the region near Chipinge, which is a site with high seismic activity, using Kawashumi models. Keisuke et al. (2014) used these Kawashumi models to study the 2011 Tohoku Earthquake. The calculated PGA value and the accelerograph data in Cilacap following the 6.1 M earthquake on January 25, 2014, were also compared using this methodology. By examining the ground motion patterns produced by this PGA model over a 17-year period in an area near and east of Chipinge on the southern edge of the rift valley, this study will test Kawashumi's model.

Location of the Study Area

The study area is in the highly mountainous and undulating landscape in the South Eastern boarder of Zimbabwe and Mozambique. The western part of Chipinge is low lying and along the Save river.

Chipinge district is a southernmost district in Manicaland Province, Zimbabwe. Geographically, it is bordered by the Chimanimani district to the north, is contiguous with Masvingo Province to the west, and is adjacent to Mozambique along its eastern margin. The Save River forms the western boundary, draining the western and southern portions of the district, while the Buzi River drains the northeastern part.

The district has a total area of 5,220 square kilometres and a population of approximately 234,133 people, with 25,292 residing in urban areas.

The district's economy is largely based on agriculture, with the eastern highlands that covers Chipinge Town receiving high rainfall, making it suitable for various farming activities. This region is an important agrological hub for the country as it is dominated by large scale crop, tree and animal farming. The town area has vast tracts of lands for both residential and commercial infrastructure, offering business opportunities.

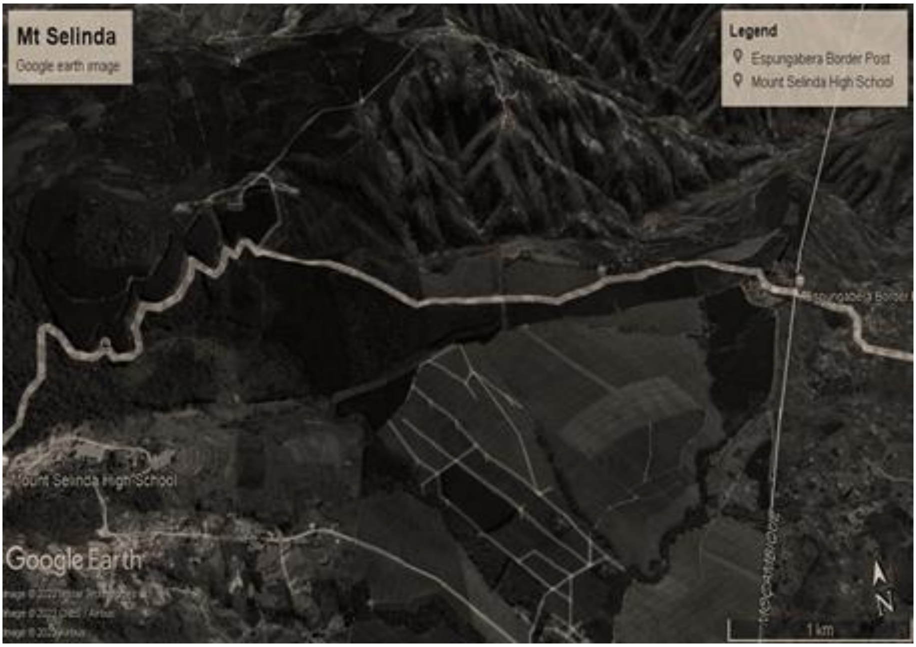

Figure 1: Shows the nature of terrain found at Mt Selinda in Chipinge

The Geology of the Study Area

From a geological perspective, Chipinge is made up of granophyre, dolerite, and fine-grained dolerite that are older than the Karoo System but intrusive into the Umkondo System. The calcareous, quartzite, upper and lower argillaceous, and border series comprise the Umkondo System (Geological Survey of Zimbabwe Bulletin No. 60). The stratigraphic position suggests the sedimentary sequence is chronologically subsequent to the greenstone group. This sequence is geographically situated southwest of the Chipinge region. Fine-grained quartz mica schists that were generated from silty and argillaceous sediments make up the majority of these sedimentary series. Throughout the belt, small bodies of serpentine and talc schist are occasionally observed.

The granites of the basement complex are later and extrusive, exhibiting contamination from the Basement Schist. Concurrently, the Mutare batholiths manifest as a small exposed granitic structure. This massive, equigranular, white to pale grey granitic formation is composed of quartz, transparent microcline, and sericitizedsodic plagioclase. The underground complex's granites are also clearly visible in the Musana neighbourhood near Tanganda Junction. The Mutare batholith, located north of the Wengezi River, shares similarities with the Musani region batholith.

Granitic gneiss underlies the Frontier Series rocks in the northeastern portion of Chipinge, which is in Mozambique. It has a strong ENE foliation and includes parallel streaks and inclusions of hornblende and chlorite schists. Sodic plagioclase and quartz, which has mostly been changed to sericite and epidote, make up its composition. The dark, chloritised biotite and hornblende that are discovered nearby are believed to be the Basement Complex granite that has been impacted by the Limpopo zone's shearing and metamorphism. No granulitic or charnockitic rocks were observed in this region. In an area with approximately 3m thick, the gneiss underlying the Frontier series has been changed by tectonic movements and deformations to sheared, cataclastics, quartz-sericite schist or more rarely quartz-chlorite schists.

The region demonstrates how a protracted erosional process damaged the earlier rocks, turning their surface into a peneplain, before the deposition of sedimentary strata of the Umkondo System. The granite's upper surface exhibits some brecciation and crushing, which may have resulted from tectonic activity. The Frontier series were deposited in a basin on the Mozambican side, east of Zimbabwe. Only a small portion of the sediments from these frontier series, which are the earliest rocks in the Umkondo System, remain.

They create a mountain range, especially the Chimanimani Mountains, which span 26 km in a picturesque direction with an approximate width of 8 km from the Corner Farm in the north to Rusitu Valley in the south. The southern extent is characterised by a disconformable westward dip below the younger Lower Argillaceous Series, leading to its termination. In contrast, the northern extent is marked by pronounced folding and cross-cutting relationships with younger rocks units.

The Frontier Series has been divided into four categories which are, the lower quartzites, the lower Chlorite Schists, the upper quartzites and the upper chlorite schists. (Geological Survey of Zimbabwe, bulletin)

The lower argillaceous series, which extends from Enhoek secondary trigonometric beacon 829 to Mapungani primary trigonometric beacon 3599, dominates the South Eastern portion of the quartzites series, which are situated on the granitic gneiss floor and are divided by a thrust plane from Risitu to Tamandai to the East and Chikore Mission to the South. Pale and dark purple shales and siltstones with bands of cream-white, sugary quartzitic sandstone make up the higher argillaceous group. From Tamandayi near the Busi River in the Eastern Highlands to Chipungu River in the Sabi Valley near Rupise Hotspring, the bedding in quartzite is extremely apparent. Conversely, the white quartzite, while intermittently exhibiting distinct foliation and cleavage planes, is not always readily apparent in the field.

The lower chlorite schists, which are roughly 180 meters thick in the north and grow to a size of over 610 meters in the south, sit conformably above the lower quartzite. They display silty and argillaceous sediments that have metamorphosed into schists mostly made of fine-grained quartz of various sizes, chlorite, and sericite. In the Mutema tribe territories north of the Tanganda River, near Birirano, its calcareous character is clearly visible. The Umkondo System, which is older than the Karoo system, contains dolerite and granophyne intrusive in the Birirano area, while the Jersey area, Smalldeel, Beacon Hill, and the majority of Chirinda forest have fine-grained dolerite.

The best way to characterise the higher quartzites is as white, fine-grained, and free of red beds. The start of the upper chlorite schists on the Bundi plateau near Chimanimani and north of Binga divides them into two sections. The upper bed is between 152 and 305 meters thick, with schist up to 91 metres thick between the two. The lower bed is about between 90 and 458 meters thick. On the southern end, the lower beds range in thickness from 90 to 305 meters.

Upper Chlorite Schists are fine-grained, greenish-grey rocks made up of quartz, chlorite, and sericite crystals. Compared to the lower Chlorite schists, this deposit contains a greater number of silty beds. Near thrust planes, some ottrelite can be visible. They range from about 90 to 152 metres north of the Bundi River and suddenly rise to over 762 meters southerly in the Rusitu Valley. The aeolian quartzite that was deposited in the sandy ironstone bed on the west side of the Haroni Valley in Chamanimani originated from the severely folded Frontier series, which created a land mass east of the Haroni River.

Along the west side of the Umkondo highlands, a calcareous series is exposed on both sides of the Save River. It thins eastward and outcrops on top of the Frontier series on the west side of the Chimanimani Mountains (Swift, 1962). On the granitic floor on the northern bank of the Tanganda River, the Calcareous Series is clearly nonconformist. The rocks are rich in lime. From the Himalaya plateau to the Tanganda Valley, the Calcareous series outcrop and stretches southwest.

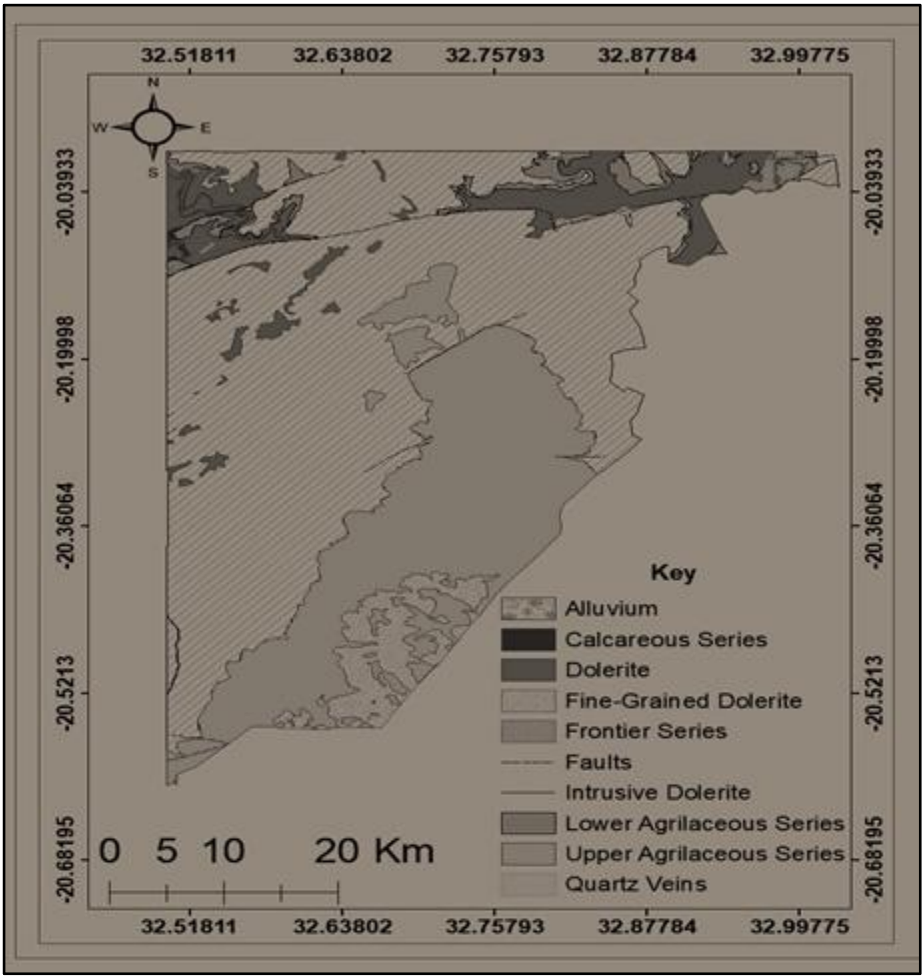

Figure 2: Shows the geological map of the study area

Seismicity of Chipinge

Given the presence of large seismic events situated in the vicinity of the Zimbabwe-Mozambique border, the Nyamandlovu area, and the Zambezi region, the overall seismic hazard of the Zimbabwean Craton is characterised as moderate. The East African Rift System's southernmost point is Zimbabwe (Fairhead& Girdler, 1969; Fairhead & Henderson, 1977, Hlatywayo, 1997). Chipinge is located near the East Africa Rift Valley (fault), which is a major source of seismic activity in the region, on

Zimbabwe's south-eastern border. The nation's seismicity is delineated into three major zones: the Central region, the Zambezi basin, and the Eastern region, the latter of which contains the Chipinge and Chimanimani areas. The Eastern Highlands, the Deka fault zone in the northwest, and the mid-Zambezi basin in Lake Kariba are the main locations for seismic activity. Seismic occurrences with magnitudes greater than 5.0 have been documented in the Zambezi basin, and these events are compatible with typical faulting (Shudofsky, 1985; Hlatywayo, 1995). Similar tectonic activity to that found along the East Africa Rift System to the north was observed in studies conducted in the mid-Zambezi Basin (Fairhead & Girdler, 1969; Fairhead & Henderson, 1977). The western flank of the rift extension from Lake Malawi makes up the southeast region of Zimbabwe (Hlatywayo, 1996).

Since the 1995 assessment, Zimbabwe has seen significant seismic events, such as the Nyamandlovu earthquakes on June 25, 2004, and March 15, 2008, with magnitudes of mb = 4.3 that were felt as far away as Bulawayo, 120 kilometres distant. The earthquake that struck Mozambique on February 22, 2006, with a magnitude of 7.0, killed four people near the Zimbabwean border but on the Mozambican side. Significant damage was caused by this earthquake event, especially in Chipinge and the adjacent areas. The earthquake that struck Chipinge on February 22, 2006, is regarded as one of Africa's most significant seismic events. The 2006 Wedza earthquake, which occurred in a region with very little seismicity, is also noteworthy. The Wedza Earthquake had a magnitude of about ML=4.0. Marondera town, which is around 75 kilometers from the epicentre, was affected by the earthquake. The shaking was so intense around the core of the quaking effect.

Data and Method

Many PGA models have been proposed by a considerable number of specialists and researchers, mostly to compute PGA in bedrock and on the surface. To estimate the peak ground acceleration, Douglas (2001a) and Douglas (2002a) compiled more than 120 seismic-related investigations. But the main emphasis of this study is Kawashumi's model in the form:

$$\log\alpha = M_S - 5{,}4 - 0{,}00084\,(R - 100) + (\log {}^{100/R}) \times \frac{1}{0{,}43429} \quad (1)$$

Where α is the PGA value in gal,

Ms is the earthquake's magnitude at the surface,
R is the distance in kilometers to the hypocentre. The earthquake magnitude must first be converted to a surface magnitude because the computed PGA represents the PGA value at the surface. The distance between the epicentre and the measuring station, as well as the depth of the earthquake center (hypocentre), are used to calculate the R-value.

The incidence of earthquakes in Chipinge with M>0 and a depth of hypocentre (h) < 25 km throughout a 17-year period, from July 24, 2006, to October 15, 2022, served as the data source for this study. Figure 1 displays the data plot on the district of Chipinge's base map, highlighting the area's significant seismicity near its eastern border with Mozambique. The devastating earthquakes were distributed with a high degree of uniformity and spatial breadth across the eastern and western segments of the Rift Valley. Chipinge district is located on the western side, close to the Mozambican border.The data source for this study was the frequency of earthquakes in Chipinge with M>0 and a hypocentre (h) < 25 km over a 17-year period, from July 24, 2006, to October 15, 2022. The data plot on the base map of the Chipinge district is shown in Figure 1, emphasising the region's high seismicity close to its eastern border with Mozambique. The occurrence of damaging earthquakes was broadly and symmetrically dispersed throughout the eastern and western parts of the Rift Valley system. On the western side, near the border with Mozambique, is the Chipinge district.

Seismic data for a period of 17 years was processed using Geosoft Oasis montaj to produce an image. These data were gridded at a 50-m cell size, using a Minimum Curvature algorithm in Oasis Montaj, to produce a higher resolution image.

Result and Discussion

The PGA calculation using Kawashumi's model with 46 data on the occurrence of destructive earthquakes in Chipingeat the geographical boundaries of 19^{o} 55S - 21^{o} 15S and 32^{o} 20E - 33^{o}E was carried out by making a grid, which resulted in a PGA in the range of 433.25 – 1120.07 m/s^2. This calculation results in the maximum PGA being 1129.09 m/s^2, located at 3.295^{o}N and 95.982^{o}E caused by the 4.5 M earthquake in Chipinge on December 24, 2006. This earthquake has also caused a fatalies in Mozambique and damaged several houses in Chipinge. While the minimum PGA is 433.25 m/s^2 located at 4.438^{o}S, 101.367^{o}E which is caused by the 4.6 M B earthquake on 12 September 2006. The results of the PGA calculation are then mapped to see the ground motion pattern. This map is shown in Figure 3 below.

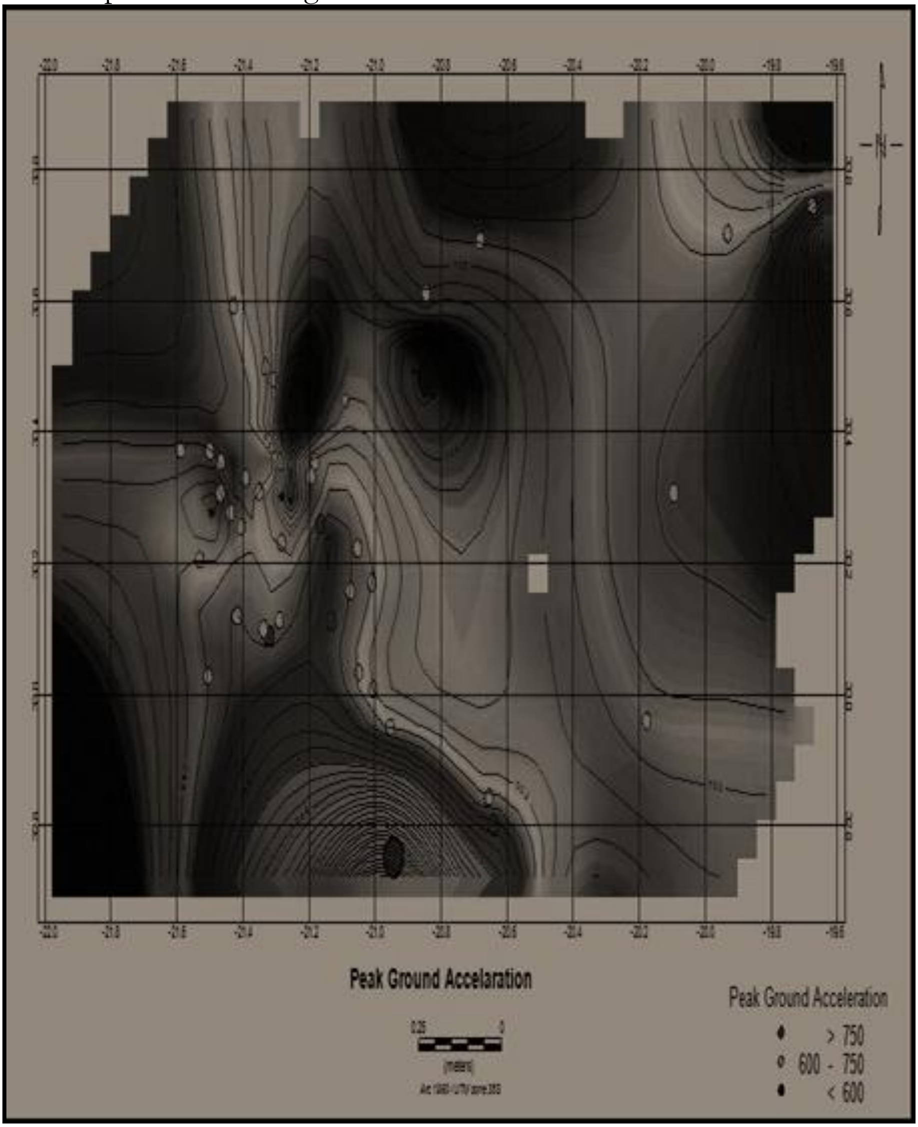

Figure 3: Shows the ground peak acceleration (PGA) of the Southern tip of the Great Rift Valley

Figure 4: Shows the locations of minimum and maximum PGA on Google earth image

The Google earth image shows two locations, that is, location 1 and 2 where the lowest and highest PGA values were recorded.

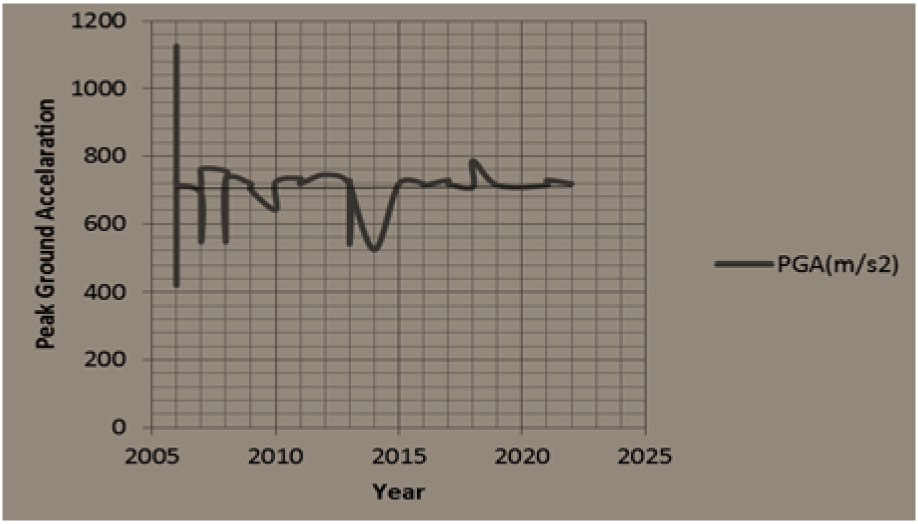

Figure 5: Shows the graph of PGV against the year

On the created map on figure 3, the PGA value decreases in the center and to the NE and SW, while it increases dramatically in the east and west. Pink, red, light blue, and dark blue gradations are used in Figure 3 to demonstrate this. Large magnitudes of PGA are denoted by the colour red on the corresponding map, and they exhibit a higher spatial prevalence within the Central and Southern regions relative to other geographical zones values are represented by red on the PGA map, and they are generally more prevalent in the Central and Southern regions than in other areas. Because of the concentration of high PGA values near the town, Chipinge, a border town, is more likely to experience destructive earthquakes.

Conclusion

Based on a 17-year history of earthquakes at Chipinge, the Kawashumi model used in this work to determine the peak ground acceleration (PGA) value produced a pattern that mirrored the fault setting of the Southern Tip of the Great African Rift Valley. Due to the preponderance of major earthquakes on the western side, the pattern created indicates a progressive increase in the high PGA values to the west and east of the Rift Valley.

The 4.5 M earthquake that struck Chipinge in August 2006, with a depth of 5 km to the epicenter, caused the data to be calculated using the limits utilized, yielding PGA values in the range of 433.25-1 120.07 m/s2 with a maximum value of 1 120.07 m/s2. These values are located at -20.946°S and 32.754°E. The shallower epicentre of the 4.5M earthquake caused substantial damage and a strong peak ground acceleration (PGA) of 1 120.07m/s^2. The 4.6 M earthquake, with an epicenter depth of 20.3 km, caused the minimum value, 433.25m/s^2 gal, at -21.286°S and 33.4°E.

The ground motion risk pattern will resemble this one if the PGA value is converted to the Modified Mercalli Intensity (MMI) scale. MMI computes the effects of earthquakes on infrastructure, people, and the environment. This translation can be carried out in future research using various empirical models.

References

Atkinson, G. M., &Boore, D. M. 2003. Empirical Ground-Motion Relations for Subduction Zone Earthquakes and Their Application to Cascadia and Other Regions. Society, 93(4), 1703-1729.

Abinger ,Cynthia(April 2005). "Continental break-up: The East African perspective". *Astronomy and Geophysics*. 46 (2): 2.16 – 2.21. doi:10.1111/j.1468-4004.2005.46216.x

Campbell, K. W. 2003. Prediction of Strong Ground Motion Using the Hybrid Empirical Method and Its Use in the Development of Ground-Motion (Attenuation) Relations in Eastern North America. Society, 93(3), 1012-1033.

Corti, G. "The Ethiopian Rift Valley". *National Research Council of Italy, Institute of Geosciences and Earth Resources*. Retrieved 16September 2025.

Chorowicz, Jean (2005). "The East African rift system". *Journal of African Earth Sciences*.43(1):379-410. Bibcode:2005JAfES..43..379C. doi:10.1016/j.jafrearsci.2005.07.019.

Fairhead, D. J. & Girdler, R. W. (1969a). How far does the rift system extend through Africa? Nature,221: 1018 – 1020.

Fairhead D. J. & Girdler, R. W. (1969). Evolution of rifting in Africa. Nature, 224:1178 – 1182.

Fairhead D. J. & Henderson N. B. (1977). The seismicity of Southern Africa and incipient rifting.Tectonophysics, 41:T19 – T26

Hlatywayo, D. J. (1995). Fault-plane solutions of the Deka fault zone and mid-Zambezi basin, Geophysics Journal International, 120 (3): 567 - 576.

Hlatywayo D.J. (1996), Seismicity of Zimbabwe during the period 1959-1990. (Report 3-92). Institute of Geophysics, Seismological Department, University of Uppsala, Sweden.

Hlatywayo D. J., (1997), Seismic hazard estimates in central southern Africa, Geophysics Journal International. 130 (3):737 - 745.

Hlatywayo D. J &Midzi V, (2005), Report on the investigations into the location, causes and the effects of the 25th June 2004 Bulawayo-Nyamandlovu earthquake, Harare: Government of Zimbabwe.

Biggs,J.,et.al, 2021. 'Volcanic activity and hazard in the East African Rift Zone', Nature Communications, vol. 12, 6881. https://doi.org/10.1038/s41467-021-27166-y.

https://database.earth/earthquakes/zimbabwe/manicaland/chipinge

Irsyam, M., et.al., 2008. Proposed seismic hazard maps of Sumatra and Java islands and microzonation study of Jakarta city Indonesia. Journal Earth System Science, (November), 865-878.

MasyhurIrsyamet.al., 2010. Tim RevisiPetaGempa Indonesia, RingkasanHasilStudi Tim RevisiPetaGempa Indonesia 2010, Ristek, LIPI, ITB, PU, Bandung, 1 Juli 2010

Megawati, K., & Pan, T. Chien. 2010. Ground-motion attenuation relationship for the Sumatran megathrust earthquakes. Earthquake engineering Structural Dynamic. (39) 827845. doi:10.1002/eqe

Morley et al. 1999, Introduction to the East African Rift System, in C.K. Morley ed., Geoscience of Rift Systems—Evolution of East Africa: AAPG Studies in Geology No. 44, p. 1–18.

Rhodesia Geological Survey (RGS), (1969). *The geology of the Cashel, Melsetter and Chipinga Area,*

Keisuke Himoto, et.al, 2014. Analysis of Ignitions Following 2011 Tohoku Earthquake Using Kawasumi Model, Fire Safety Science-Proceedings of The Eleventh International Symposium pp.704-717, 2014, doi: 10.3801/iafss.fss.11-704

Kearey et al. (2009). Global Tectonics. John Wiley & Sons. ISBN 978-1-4051-0777-8

Sieh K, Natawidjaja D, 2000. Neotectonics of the Sumatran fault, Indonesia, Journal of Geophysical Research Solid Earth. (105). B12. https://doi.org/10.1029/2000JB900120

Siebert, L.et al (2010). *Volcanoes of the World*. University of California Press.

Widodo, P, 2012. SeismologiTeknik&RekayasaKegempaan. Yogyakarta, PustakaPelajar.

Young G .2016.East Africa's Great Rift Valley: A Complex Rift System.Britannica

ZeraTati, et.al., 2017. Comparison of Three Models Peak Ground Acceleration (PGA) in Bengkulu, Indonesia, IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG). 5. (1). 31-36.doi: 10.9790/0990-0501013136

ZeraTati, M Ocky. 2016. PemetaanNilaiPercepatan Tanah Maksimum (PGA) Berdasarkan Model KawashumidanHasilpengukuranAccelerographStasiunCilacap. Jurnal Al-Fiziya. (9). 2. 116-124.