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Seismicity rates around the Kenya Rift System

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Abstract

This study examines seismic activity trends in Kenya between 1980 and 2025, with a focus on the underlying tectonic drivers and their implications for hazard assessment. Located along the divergent boundary between the African and Somali plates, the region is characterized by moderate to high seismicity, predominantly involving shallow earthquakes alongside notable off-rift events. The research employs frequency–magnitude distribution analyses to assess temporal variations in seismic behavior. The results indicate a dynamic and evolving seismic regime. A cumulative event analysis from 1980 to 2023 reveals a pronounced increase in both low- and high-magnitude earthquakes beginning in the mid-1990s. Complementary Z-map analysis, comparing the periods 1980–2002 and 2002–2023, identifies a clear shift from a dominance of microseismic activity in the earlier interval to a greater occurrence of moderate to large earthquakes in the latter period. This transition is further supported by frequency–magnitude distribution patterns, which show a decline in overall event rates, consistent with findings from b-value analysis. Taken together, these results suggest a significant transformation in the seismic characteristics of the region, marked by an increasing proportion of higher-magnitude events. This evolving pattern underscores a persistent and changing seismic hazard, highlighting the need for a reassessment of regional seismic risk.

Keywords: Kenya rift system, kenya, african plate, somali plate, Z-map (specific analytical/mapping term used as a name)

Introduction

Kenya is undergoing active tectonic rifting driven by extensional stresses and associated seismic activity, forming part of the broader East African Rift System (EARS) (Yang *et al.*, 2010; Kebede and Kulhanek, 1994) [11, 17]. As an active continental rift, a fundamental question arises: is the rate of seismicity within the Kenya Rift System increasing or decreasing over time? Addressing this question is essential for seismic hazard assessment, constraining rift evolution, and understanding the interaction between tectonic deformation and magmatic processes. This study presents a quantitative analysis of seismicity rate patterns within the Kenya Rift from 1980 to 2025 using the International Seismological Centre (ISC) earthquake catalog. The specific objectives are to: (1) generate time-lapse seismicity maps to illustrate the spatial and temporal evolution of earthquake activity, (2) construct seismicity rate curves to identify temporal trends, and (3) determine Gutenberg–Richter a-values and b-values to characterize magnitude–frequency relationships across the rift.

The Kenyan Rift constitutes a major segment of the East African Rift, an intracontinental rift system extending from Ethiopia in the north to Tanzania in the south (Chorowicz, 2005) [2]. As one of the most active continental rifts globally, it serves as a natural laboratory for investigating lithospheric extension, faulting, volcanism, and seismicity. The relationship between rifting and magmatism remains an active area of research, with ongoing debate as to whether magmatic processes drive lithospheric extension or occur as a consequence of it (Ebinger, 2005; Corti, 2009) [3, 4]. Seismicity within the Kenya Rift is generally moderate but exhibits significant spatial variability, reflecting ongoing tectonic deformation and stress redistribution. Early microseismic studies identified the southern Kenya Rift, particularly the Lake Magadi region, as a zone of elevated seismic activity, with temporary seismic networks recording up to ten local events per day (Hollnack & Stangl, 1998; Ibs-von Seht *et al.*, 2001) [8, 9]. Earthquakes are predominantly shallow, occurring within the brittle upper crust along major fault systems that define the rift structure, with hypo-central depths ranging from near-surface to approximately 27 km. These events often coincide with zones of active volcanism, indicating a close coupling between tectonic faulting and magmatic intrusions.

Regional earthquake catalogs compiled from multiple datasets reveal complex spatial patterns of seismicity, with the South Kenya Rift and Nyanza Rift showing the highest levels of activity (Kianji *et al.*, 2024) [12]. Recent comprehensive datasets covering the period 1980–2025 document approximately 7,726 seismic events with moment magnitudes ranging from Mw 2.5 to 7.0. Historically significant earthquakes include the 1928 Subukia event (Ml 7.1) and the 1913 Turkana earthquake (Ml 6.2) (Mulwa *et al.*, 2014; Kianji *et al.*, 2024) [12]. Despite extensive documentation of earthquake occurrences, quantitative assessments of temporal variations in seismicity rates remain limited. In particular, spatial and temporal variations in Gutenberg–Richter b-values across different segments of the Kenya Rift are still poorly constrained (Tesfaye etal., 2023; El-Isa and Eaton, 2023) [16]. In continental rift environments, seismicity rates and magnitude–frequency distributions evolve in response to changing stress regimes, magmatic intrusions, and progressive localization of deformation (Illsley-Kemp *et al.*, 2018; Lyakhovsky *et al.*,

2012) [10, 13]. Stress regimes play a critical role in controlling rift evolution, influencing fault development, magma migration, and crustal deformation patterns (Morley, 1999; Buck, 2004) [1, 14]. In the Kenya Rift, variations in the regional stress field have been linked to differences in fault morphology, volcanic distribution, and seismic activity. Focal mechanism solutions indicate that seismicity is dominated by normal faulting under WNW–ESE extensional stresses, with fault orientations broadly parallel to the NNE–SSW-trending rift axis (Ibs-von Seht *et al*., 2001) [9].

This study addresses key gaps in understanding the temporal evolution of seismicity within the Kenya Rift System. While previous studies have described earthquake distributions and structural characteristics (Eluyemi *et al*., 2019a; Eluyemi *et al*., 2019b), systematic, multi-decadal analyses of seismicity rate changes remain scarce. It is therefore unclear whether seismic activity is increasing, decreasing, or remaining stable as rifting progresses. Furthermore, spatial variations in Gutenberg–Richter parameters across different rift segments have not been comprehensively evaluated. By analyzing 45 years of ISC earthquake catalog data (1980–2025), this study provides a comprehensive assessment of seismicity rate trends and magnitude–frequency characteristics across the Kenya Rift. The results establish a quantitative framework for understanding ongoing rift dynamics and contribute to improved seismic hazard assessment in the region.

Geology of the study area

The Kenya Rift System (KRS) represents the Kenyan segment of the East African Rift System (EARS) and is one of the most geologically active and extensively studied continental rifts in the world. It is formed as a result of continental extension associated with the divergence of the Somali Plate, which is moving eastward, and the Nubian Plate, moving westward. Rifting in this region initiated during the Miocene epoch, approximately 20–15 million years ago, and continues to the present day. Geographically, the Kenya Rift trends predominantly north–south through central Kenya and typically spans a width of about 50–70 km. It is morphologically characterized by prominent escarpments, notably the Mau and Elgeyo escarpments, a central rift valley floor, and numerous volcanic centers aligned along the rift axis.

The geology of the Kenya Rift System comprises three principal units. The basement complex consists of Precambrian rocks, including gneisses, granites, and schists, which form part of the Mozambique Mobile Belt and constitute the uplifted rift shoulders. Overlying these are extensive volcanic sequences that dominate the rift structure. These volcanic rocks include basalts, phonolites, trachytes, and rhyolites, as well as large caldera systems such as Suswa, Longonot, and Menengai. Volcanic activity in the region spans from the Miocene to the present and is associated with active geothermal systems. The rift floor is filled with thick sedimentary sequences, in some areas reaching several kilometers in thickness. These include lacustrine deposits (silts and clays), fluvial sediments, and volcaniclastic materials. Many of these sedimentary layers are fossil-rich, making the region significant for paleoanthropological studies. Several notable geological features further define the Kenya Rift System. The Lake Turkana Basin contains thick volcanic sequences alongside important fossil records. The term “Gregory Rift” is often used to refer specifically to the Kenyan portion of the EARS. Major volcanic edifices such as the Aberdare Range and Mount Kenya are associated with early stages of rifting. Additionally, the rift hosts numerous lakes, many of which are alkaline-such as Lakes Bogoria and Nakuru-reflecting strong links to volcanic and hydrothermal processes.

Methodology

This study adopts a multi-faceted methodological approach to investigate seismic activity trends in Kenya over the period 1980–2025. The analysis is based on a comprehensive earthquake catalog compiled from the International Seismological Centre (ISC) database, covering 45 years of recorded seismic events within the study area. The methodology was designed to first characterize the overall seismicity of the region and subsequently identify and quantify temporal variations in seismic behavior. The dataset includes key parameters such as origin time, hypocentral location, and earthquake magnitude for all recorded events within the specified period. To ensure reliability and consistency, the catalog was carefully curated to address issues related to event duplication, inconsistencies in magnitude scales, and general data quality. A catalog completeness analysis was conducted to determine the minimum magnitude threshold above which all seismic events are consistently recorded throughout the study period. This step is essential for ensuring the robustness of subsequent statistical analyses, particularly those involving frequency–magnitude relationships.

For spatial analysis, earthquake events were plotted on georeferenced maps generated using Mirone software (Figures 1–3). These maps were used to examine the spatial distribution of seismicity and to identify seismogenic zones across Kenya. To enhance interpretation, seismic events were categorized based on focal depth and visualized using a color-coded scheme: shallow events (0–33 km) are represented in red, intermediate-depth events (33–70 km) in green, and deeper events (70–150 km) in blue. This integrated approach enables a detailed assessment of both the spatial and temporal evolution of seismicity within the Kenya Rift System.

To investigate temporal variations in seismicity rates, ZMAP seismological software was employed to compare two distinct time intervals: 1984.19–2002.00 and 2002.06–2023.86. This comparative analysis was based on two principal graphical representations: cumulative and non-cumulative rate plots. The cumulative rate plot illustrates the cumulative number of earthquake events as a function of magnitude for each time period. Variations in the slope and relative position of these curves were used to assess changes in overall seismicity rates and to evaluate shifts in the proportion of small versus large magnitude events between the two intervals.

In contrast, the non-cumulative rate plot presents the frequency of events within discrete magnitude bins, thereby providing a more detailed view of the distribution of seismicity across the magnitude spectrum. This approach allows for the identification of specific magnitude ranges where significant changes in event occurrence have taken place. Together, these plots provide complementary insights into the temporal evolution of seismicity within the study area, as illustrated in Figure 4.

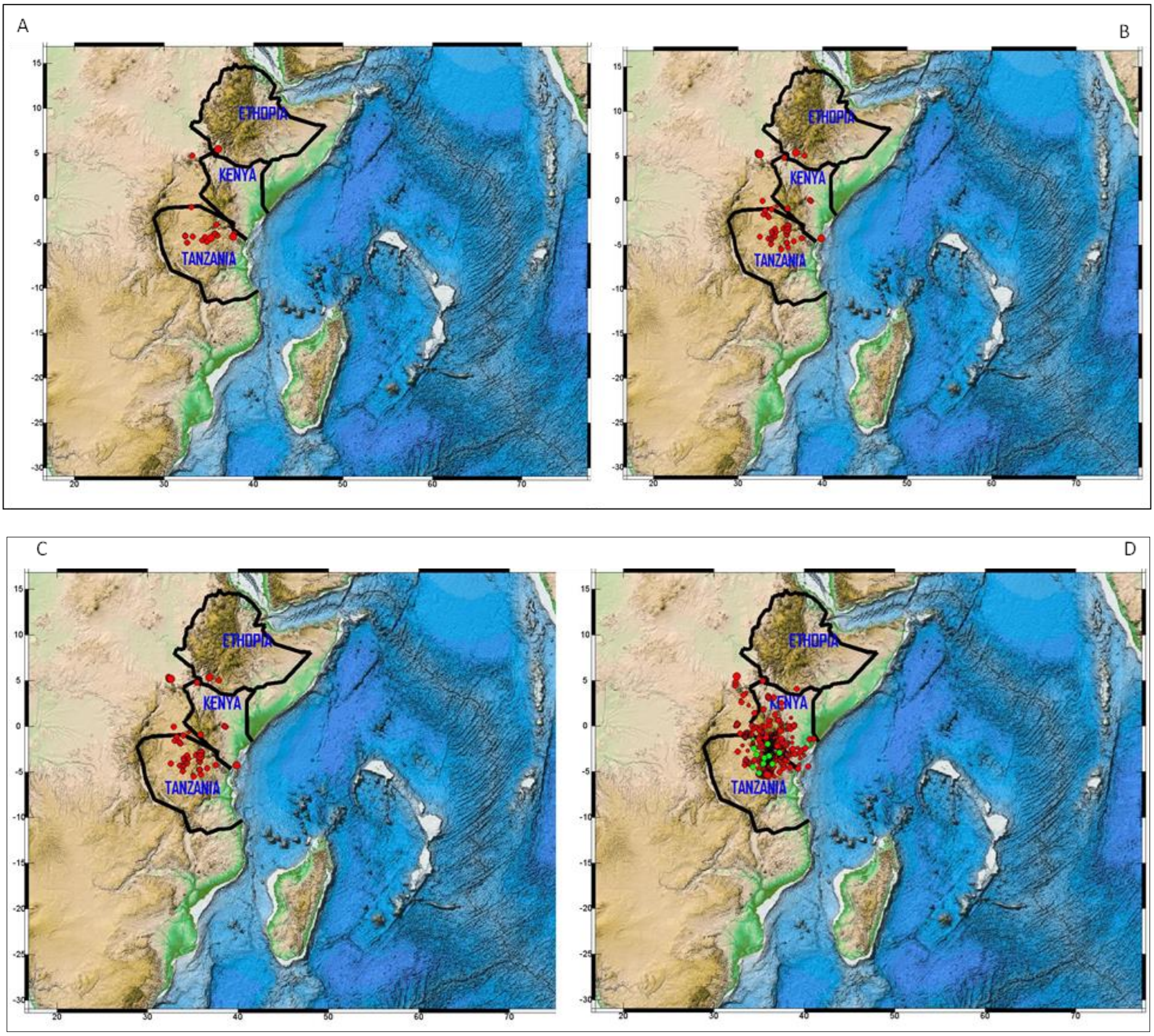
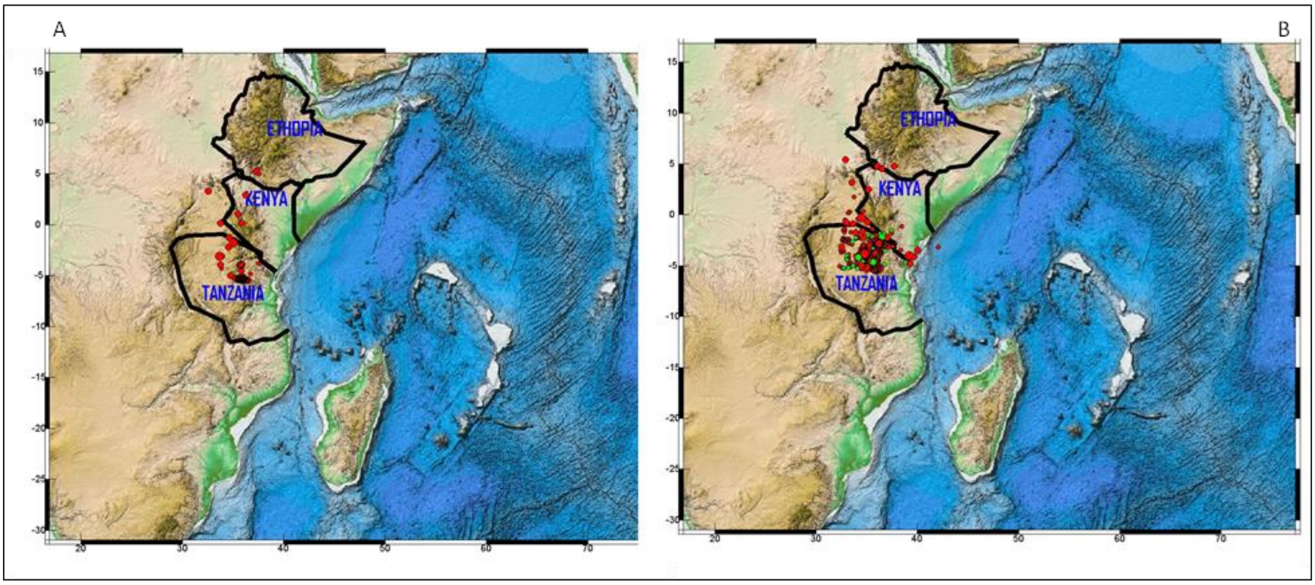


Fig 1: Shows the time lapse seismicity map for the following periods: 1980-1984, 1985-1989; 1990-1994; 1995-1999. Illustrated with the captions A, B, C, and D respectively



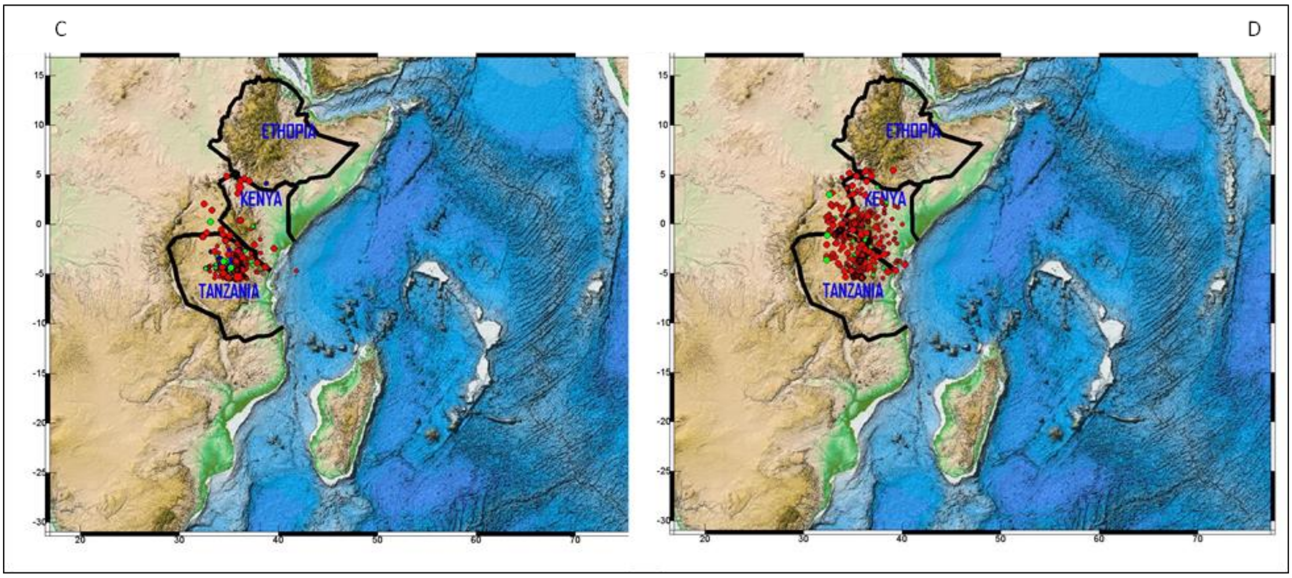


Fig 2: Shows the time lapse seismicity map for the following periods: 2000-2004, 2005 [2]-2009; 2010-2014; 2015-2019. Illustrated with the captions A, B, C, and D respectively

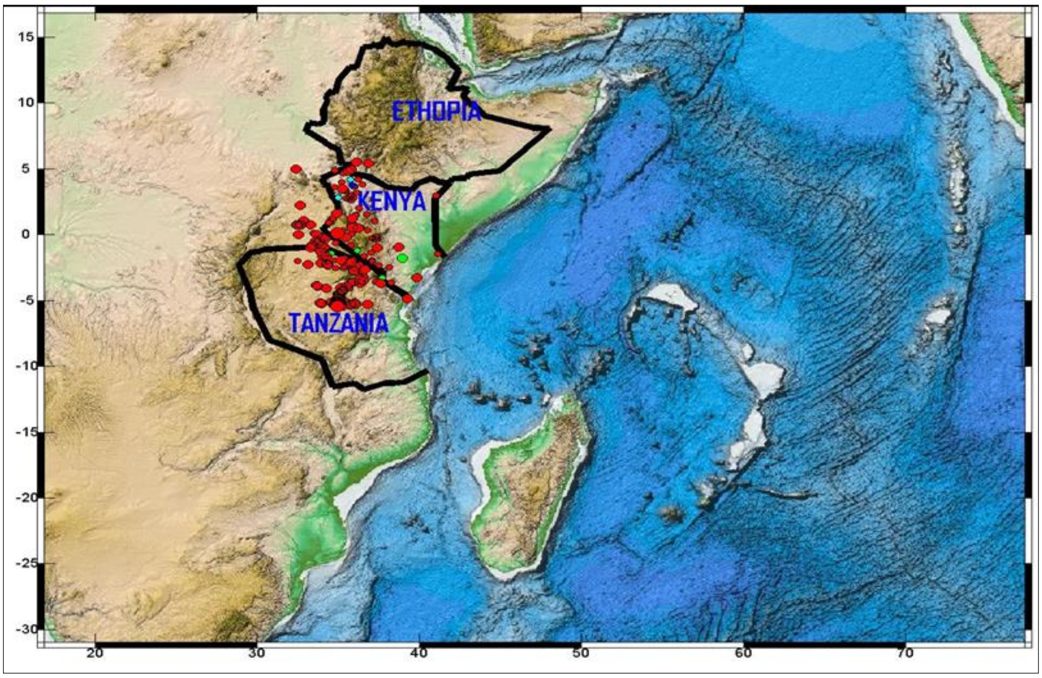


Fig 3: Shows the time lapse seismicity map for the following periods: 2020-2025

Results

The seismicity time-lapse maps (Figures 1–3) illustrate the spatial distribution of earthquake activity within the Kenya Rift System and its adjoining regions. The maps reveal pronounced seismic clustering along the rift axis, extending from Kenya into northern Tanzania. Overall, the seismicity is dominated by low-magnitude events, consistent with typical continental rift settings. However, a general increase in seismic activity over time is also evident.

Figure 4A presents the cumulative seismicity rate plots for the two study periods (1984–2002 and 2002–2023). The upper panel indicates that the cumulative number of earthquakes was significantly higher during the earlier period across most magnitude ranges. This observation is reinforced by the lower panel, which shows a pronounced peak in event frequency around magnitude 2 during the earlier interval-an anomaly that is largely absent in the later period. The reported percentage change (“Change in %: -0.45173”) further confirms an overall decline in seismic event rates with time. In contrast, Figure 4B provides both cumulative and non-cumulative perspectives that highlight a shift in magnitude distribution. The cumulative curves indicate that while the earlier period was dominated by a higher rate of small-magnitude earthquakes, the later period exhibits a relatively greater contribution from moderate to large-magnitude events, with the curves intersecting around magnitude 2.5. The non-cumulative plots further emphasize this contrast: the earlier period is characterized by abundant microseismicity and an isolated increase near magnitude 6, whereas the later period shows a distinct peak around magnitude 2 and comparatively higher frequencies for events exceeding magnitude 4. Collectively, these patterns suggest a transition in the seismic regime from one dominated by small earthquakes to one with a relatively higher proportion of larger-magnitude events.

The Gutenberg–Richter parameters derived for the study area (Figure 5) further support this interpretation. The frequency–magnitude distribution plots display distinct relationships for the two time intervals (1984–2002 and 2002–2023), with calculated *a*-values reflecting changes in overall seismic activity and *b*-values indicating variations in the relative proportion of small to large earthquakes. The differences in these parameters between the two datasets confirm that both the seismicity rate and magnitude distribution have evolved significantly over time, pointing to a measurable shift in the underlying seismotectonic regime of the Kenya Rift System.

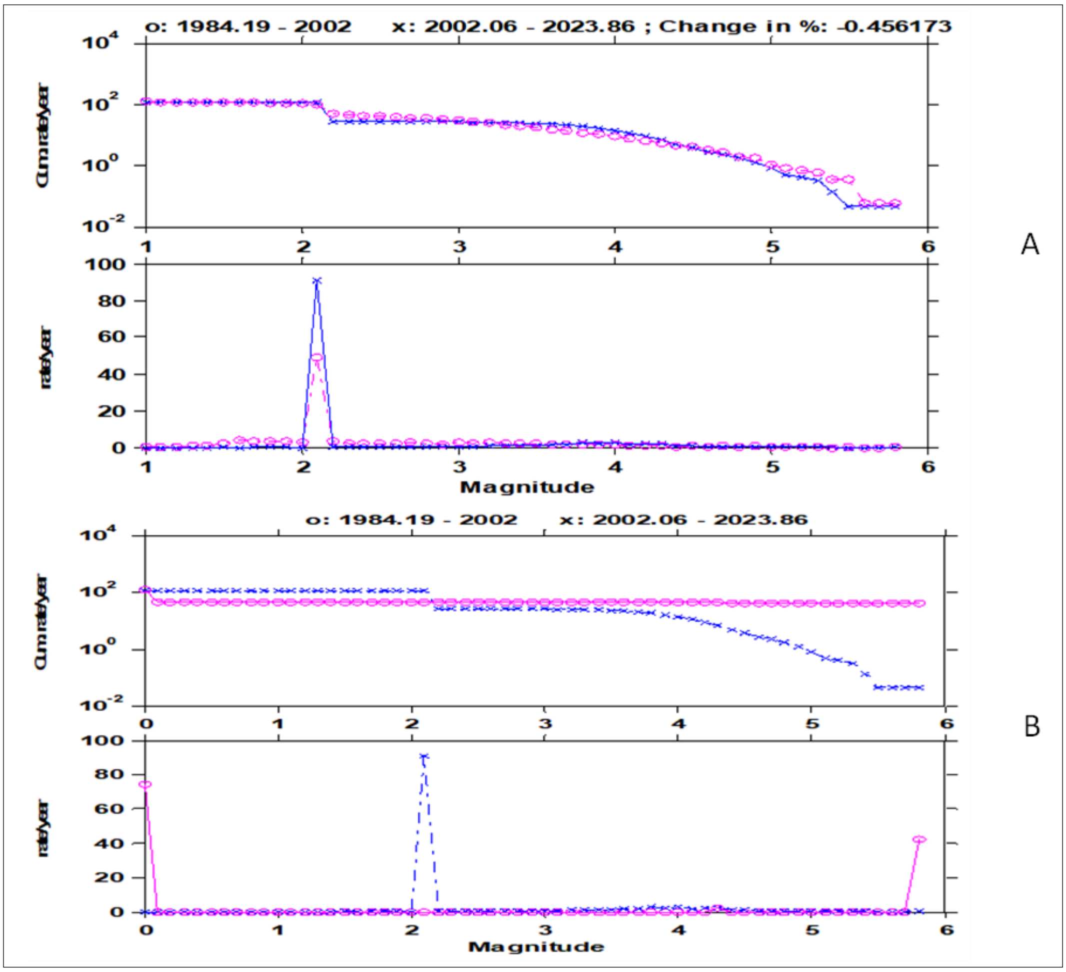


Fig 4: 4A shows the seismic cumulative rate plot between two periods, 1984-2002 indicated in blue line and 2002-2023 indicated in magenta color. 4B Shows the seismic non-cumulative rate plot between two periods: 1984–2002 (magenta circles) and 2002–2023 (blue crosses).

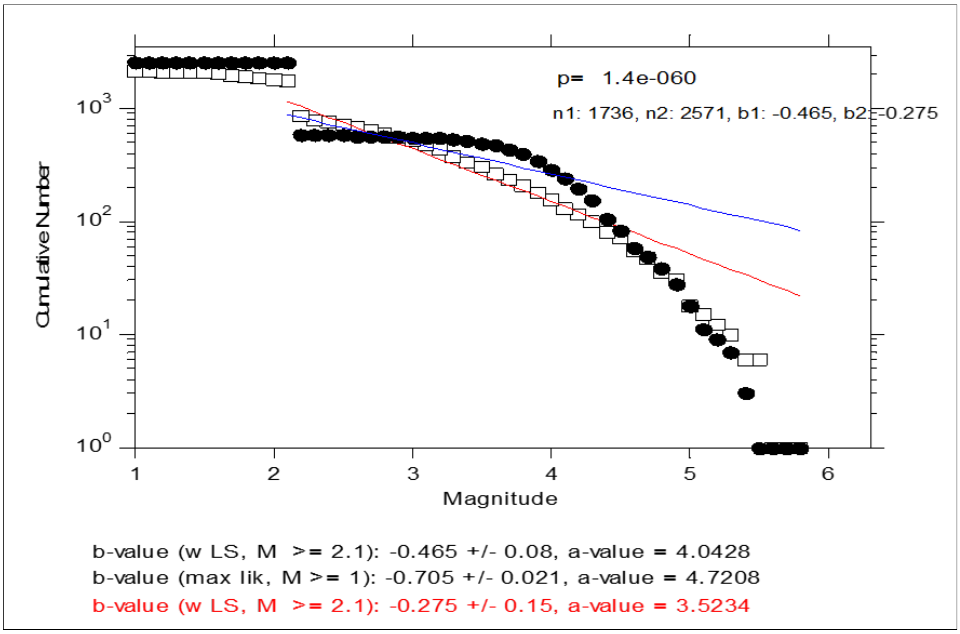


Fig 5: Shows the Guttenberg Richter plot for the two seismic time frames (period) for the study area

In order to quantify the relationship between earthquake magnitude and frequency, a standard frequency-magnitude distribution (FMD) analysis was performed. This method is based on the Gutenberg-Richter law, which is expressed as: log10(N) = a−bM where N is the number of earthquakes with a magnitude greater than or equal to M, a is the activity rate, and b is the slope of the distribution. The b-value, as a tectonic stress indicator (Eluyemi *et al*., 2020), in particular, was calculated for the two seismic time frame (periods) indicated in Figure 5.

Discussion

Since the Kenya rift system is in the active phase, associated with increase seismicity rate, the social, economic, and infrastructural impacts of possibly large magnitude earthquakes in Kenya would be profound, if it occurs. Hence the need for a comprehensive disaster preparedness and response strategies. The current seismic network in Kenya should be expanded and modernized to provide real-time, high-resolution data. A denser network of seismometers would allow for more accurate location and depth determination of earthquakes, which is crucial for understanding the underlying fault structures and stress patterns. Further geological and geophysical studies, are recommended to map active fault lines with greater precision. This would help identify specific structures that may be accumulating stress and are prone to future rupture, which is critical for urban planning and infrastructure development. The findings of this study should be incorporated into Kenya's national disaster management strategies and building codes.

Policies should be updated to reflect the increased risk of moderate to large earthquakes, particularly in rapidly developing urban areas. Ensuring that emergency response teams are well-trained and equipped to handle earthquake-related disasters. Public awareness campaigns are essential to educate communities on earthquake preparedness and safety measures. Accessible information on what to do before, during, and after an earthquake can significantly reduce casualties and property damage. Future research should focus on a long-term seismic hazard assessment that models various scenarios based on the observed shift in the b-value. This would provide valuable insights for engineers and city planners to build more resilient infrastructure capable of withstanding potential strong ground motions. Engage local communities in disaster preparedness and mitigation efforts.

Conclusion

This study reveals a significant and dynamic evolution of seismic activity within the Kenya Rift, a major segment of the East African Rift System. By integrating analyses from Mirone, ZMAP, and frequency–magnitude distributions, the results provide strong evidence for a fundamental shift in the regional seismic regime. Seismic records spanning 1980 to 2023 indicate a clear transition from a regime dominated by high rates of low-magnitude earthquakes to a more recent phase characterized by a relatively higher frequency of moderate to large events. ZMAP analysis shows that although the overall seismicity rate has declined, the proportion of larger, potentially hazardous earthquakes has increased. This trend is further supported by variations in the calculated *b*-values, which reflect a change in the magnitude–frequency relationship consistent with the observed shift.

These findings suggest that the tectonic stress regime within the Kenya Rift is evolving rather than static, with implications for increasing seismic hazard. The growing proportion of larger-magnitude earthquakes represents a heightened risk to infrastructure and population centers. Consequently, there is a critical need for continuous seismic monitoring, updated hazard assessments, and proactive risk mitigation strategies to address the changing seismic landscape of the region.

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