Preliminary Seismicity Estimates for Kenyan Nuclear Projects

Kaira George Nyagah, Eric Yee *
Department of NPP Engineering, KEPCO International Nuclear Graduate School,
658-91 Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan 45014
**Corresponding author: eric.yee@kings.ac.kr*

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1. Introduction

Kenya lies within the East African Rift System (EARS), one of the world's most prominent continental rift zones, where the African plate is slowly splitting into the Somali and Nubian sub-plates. The EARS extends from the Afar Triple Junction in the north to Mozambique in the south, progressively shaping the region through active faulting, volcanic activity, and frequent seismic events. This ongoing tectonic deformation has significant implications for infrastructure resilience, as moderate earthquakes have been recorded in various parts of Kenya, some resulting in structural damage and safety concerns. This is of concern to nuclear infrastructure, where safety is the utmost importance. Addressing seismic safety in nuclear power plants is generally done through seismic hazard analysis.

An important component of seismic hazard is the recurrence law used, which quantifies the seismicity in the region. The Gutenberg-Richter recurrence law is one of the most widely applied models for parameterizing seismicity. This law describes the relationship between earthquake magnitude and frequency, expressed as $\log N = a - bM$, where N represents the cumulative number of earthquakes with magnitudes greater than M, while a and b are regression coefficients [1]. It illustrates that earthquake frequency decreases as magnitude increases.

The Gutenberg-Richter law plays a crucial role in seismic hazard assessment by describing the statistical distribution of earthquake magnitudes within a given region. This empirical relationship helps seismologists estimate the likelihood of future seismic events, which is essential for designing earthquake-resistant infrastructure and informing disaster preparedness strategies. By analyzing earthquake frequency and magnitude trends, researchers can identify seismically active zones, assess potential risks, and develop region-specific mitigation measures.

Seismic catalogs serve as essential repositories of earthquake data, documenting events with details such as location, depth, and magnitude. These catalogs integrate various magnitude scales, including body wave magnitude (m_b), surface wave magnitude (M_s), and local magnitude (M_L), and moment magnitude (M_W) [2-4].

This study focuses on characterizing the seismicity of Kenya by compiling an earthquake catalog specific to the region, standardizing magnitudes to a unified scale, and estimating the Gutenberg-Richter parameters. The findings will contribute to essential seismic hazard studies for improving earthquake safety and risk assessment in Kenya.

2. Methods and Results

2.1 Data Sources

The earthquake dataset used in this study is sourced from the online Bulletin of the International Seismological Centre, ISC [6-7]. The online bulletin contains global events from 1900 to 2023. The ISC Bulletin also contains data from other seismological agencies such as the United States National Earthquake Information Center, NEIC, and the Global Centroid Moment Tensor project, GCMT. The GCMT catalog contains improved solutions to parameter estimates on a subset of ISC earthquakes with earthquake magnitudes in the GCMT catalog being considered better than those in the general ISC Bulletin. A total of 658 earthquake events were compiled. Fig. 1 shows the epicenters of these earthquakes.

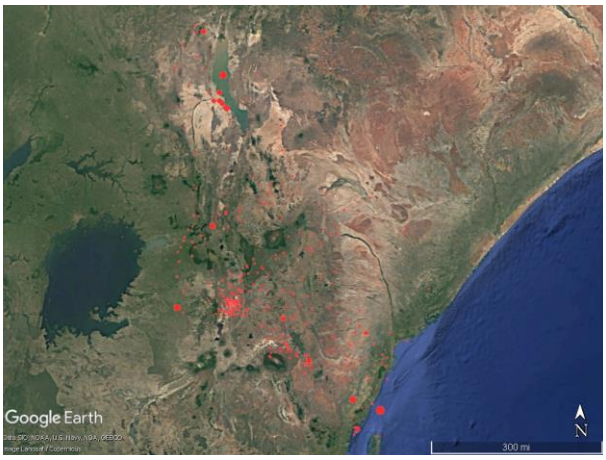

Fig. 1. Epicenters of earthquakes in Kenya shown in red.

2.2 Magnitude Homogenization

Magnitude homogenization is essential for creating a consistent earthquake catalog, as different magnitude scales can introduce biases that hinder statistical analyses and seismic hazard modeling. In this study, all available magnitude types were converted into a unified M_w scale. M_w is widely used in earthquake related studies because it is derived from physically meaningful parameters that provide a stable measure of earthquake energy release across different magnitude ranges. Unlike M_s or m_b, which saturate at large magnitudes, M_w remains consistent.

To achieve magnitude homogenization, empirical relationships offer a systematic approach by utilizing extensive global and regional datasets to develop consistent conversion models. Table 1. below outlines the regression equations used in the homogenization process.This formulas provide a standard reference for converting various magnitude types to a common moment magnitude scale, in this case M_W, using regression equations and associated standard deviations (σ).

(1) NEID MW: $M_W^{PROXY} = 0.964M_W^{NEID} + 0.248$ σ: 0.11
(2) $M_W^{PROXY} = \begin{cases} 0.616M_S^{ISC} + 2.369, & M_S^{ISC} \leq 6.0 \\ 0.994M_S^{ISC} + 0.1, & M_S^{ISC} > 6.0 \end{cases}$ σ: 0.147 (≤6.0), 0.174 (>6.0)
(3) $M_W^{PROXY} = \begin{cases} 0.723M_S^{NEIC} + 1.798 & M_S^{NEIC} \leq 6.47 \\ 0.994M_S^{NEIC} - 0.026 & M_S^{NEIC} > 6.47 \end{cases}$ σ: 0.159 (≤6.47), 0.187 (>6.47)
(4) $M_W^{PROXY} = \begin{cases} 0.707M_{SZ}^{NEIC} + 1.798 & M_{SZ}^{NEIC} \leq 6.47 \\ 0.950M_{SZ}^{NEIC} + 0.359 & M_{SZ}^{NEIC} > 6.47 \end{cases}$ σ: 0.179 (≤6.47), 0.204 (>6.47)
(5) NEIC mb: $M_W^{PROXY} = 1.159m_b^{NEIC} - 0.659$ σ: 0.283
(6) ISC mb: $M_W^{PROXY} = 0.964m_b^{ISC} - 0.142$ σ: 0.317

Table 1: Hierarchical criteria for selection of magnitude for homogenizing the earthquake catalog [5].

2.3 Application of the Gutenberg-Richter Recurrence Law

The plot presents M_W on the x-axis, and the cumulative number of earthquakes with a magnitude greater than the indicated magnitude on the y-axis, but in logarithmic units. After applying magnitude homogenization to unify the earthquake catalog to M_W, a plot of the data was formed by linear regression using the Gutenberg-Richter relationship. The regression analysis shows the relationship between magnitude and the logarithmic value of the cumulative number of earthquakes (Log N). This relationship follows the Gutenberg-Richter law. This is shown in Fig. 2.

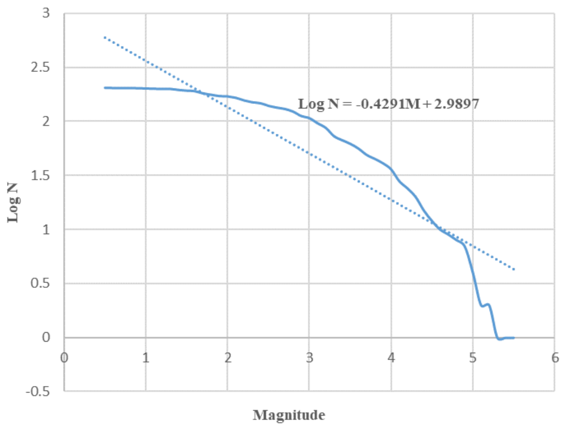

Fig. 2. Gutenberg Richter recurrence relationship.

After plotting the data and applying linear regression using the Gutenberg-Richter relationship, the results yielded a = 2.9897 and b = 0.429. If further analysis confirms this unusually low b-value, it could suggest a higher likelihood of destructive earthquakes, emphasizing the importance of seismic hazard preparedness in the region.

3. Conclusion

Compiling a catalog from ISC and ISC-GEM data sources resulted in 327 earthquakes in Kenya. The various magnitude types from the compilation were homogenized to M_W based on magnitude homogenization regressions derived from a much larger continental Africa dataset. With a unified earthquake catalog, a regression was applied to estimate Gutenberg-Richter parameters, which resulted in a = 2.9897 and *b*= 0.429**.** The Gutenberg-Richter b-value implies that large-magnitude earthquakes are more frequent relative to smaller ones in this region.

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