# Preliminary Estimates on Seismicity in the Red Sea Region

*Si-yeon Ahn, 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

The Red Sea region is an active extensional plate boundary characterized by frequent seismic activity due to the divergence between the African and Arabian plates. Given the current interest around nuclear power plant development in nearby countries, related agencies will need to conduct seismic hazard assessments to ensure the safety of critical nuclear infrastructure. One element in a properly conducted seismic hazard assessment is the characterization of seismic sources. This makes understanding the seismicity of the Red Sea region an important endeavor.

The most widely used parameterization of seismicity is the Gutenberg-Richter recurrence law [1]. This law describes the cumulative frequency of earthquakes is inversely proportional to earthquake magnitude, typically expressed as $log\ N = a - bM$, where $N$ is the number of earthquakes with magnitude greater than $M$, and $a$, $b$ are regression coefficients.

One of the challenges in characterizing seismicity through the Gutenberg-Richter recurrence law is the need for recorded events. These events are usually listed in various catalogs, based on a variety of criteria. Due to a variety of circumstances, many of these catalogs utilize varying magnitude types to describe earthquakes, such as body wave magnitude, $m_b$, surface wave magnitude, $M_s$, local magnitude, $M_L$, and moment magnitude, $M_W$ [2-4]. These can lead to inconsistencies in seismic analyses. The general practice in mitigating different magnitude types is to apply magnitude homogenization, where regressions are calculated to help convert the different magnitude types to a unifying magnitude type [5].

Therefore, this study attempts to characterize the regional seismicity of the Red Sea area. This involves compiling a target earthquake catalog relevant to the Red Sea, normalizing to a single magnitude type, and estimating Gutenberg-Richter parameters for seismicity. Hopefully, these results can be used in essential studies on seismic safety in the Red Sea region.

## 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. Separate but also related to the ISC Bulletin is another earthquake catalog called ISC-GEM [8]. This catalog contains improved solutions to parameter estimates on a subset of ISC earthquakes. The earthquake magnitudes in the ISC-GEM catalog are considered better than those in ISC. A total of 658 earthquake events were compiled. Fig. 1 shows the epicenters of these earthquakes.

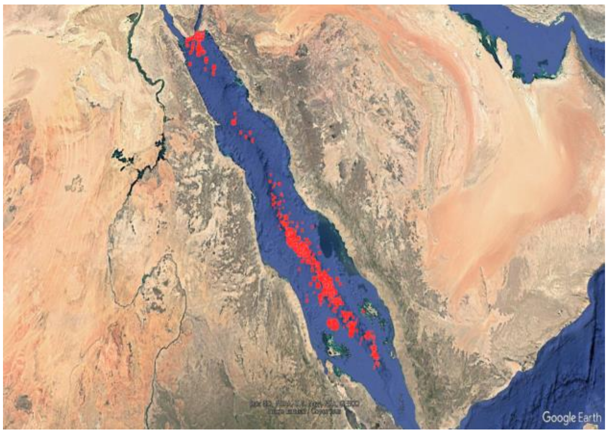


Fig. 1. Epicenters of earthquakes of the Red Sea region shown in blue.

### *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 developed for Africa were applied [5]. It provides a systematic framework for magnitude homogenization by developing empirical relationships based on extensive global and regional datasets. A hierarchical list of the homogenization regressions is shown in Table 1.

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

| Order | Agency/Magnitude | Conversion | $\sigma$ |
|---|---|---|---|
| 1 | ISC-GEM $M_W$ | No conversion | 0.0 |
| 2 | GCMT $M_W$ | No conversion | 0.0 |
| 3 | NEIC $M_W$ | $M_W^{PROXY} = 1.021 M_W^{NEIC} - 0.091$ | 0.105 |
| 4 | NIED $M_W$ | $M_W^{PROXY} = 0.964 M_W^{NIED} + 0.248$ | 0.11 |
| 5 | ISC $M_S$ | $M_W^{PROXY} = \begin{cases} 0.616 M_S^{ISC} + 2.369 & \text{if } M_S^{ISC} \le 6.0 \\ 0.994 M_S^{ISC} + 0.1 & \text{if } M_S^{ISC} > 6.0 \end{cases}$ | $\begin{cases} 0.147 \\ 0.174 \end{cases}$ |
| 6 | NEIC $M_S$ | $M_W^{PROXY} = \begin{cases} 0.723 M_S^{NEIC} + 1.798 & \text{if } M_S^{NEIC} \le 6.47 \\ 1.005 M_S^{NEIC} - 0.026 & \text{if } M_S^{NEIC} > 6.47 \end{cases}$ | $\begin{cases} 0.159 \\ 0.187 \end{cases}$ |
| 7 | NEIC $M_{SZ}$ | $M_W^{PROXY} = \begin{cases} 0.707 M_{SZ}^{NEIC} + 1.933 & \text{if } M_{SZ}^{NEIC} \le 6.47 \\ 0.950 M_{SZ}^{NEIC} + 0.359 & \text{if } M_{SZ}^{NEIC} > 6.47 \end{cases}$ | $\begin{cases} 0.179 \\ 0.204 \end{cases}$ |
| 8 | NEIC $m_b$ | $M_W^{PROXY} = 1.159 m_b^{NEIC} - 0.659$ | 0.283 |
| 9 | ISC $m_b$ | $M_W^{PROXY} = 1.084 m_b^{ISC} - 0.142$ | 0.317 |
| 10 | Pacheco & Sykes (1992) | No conversion | 0.2 |

The table lists a standard deviation of the regression in the final column. This parameter indicates how well the regression is, with smaller values being better. When a catalog event has more than one magnitude type and no $M_W$ listed value, then the homogenization relationship with the lowest standard deviation is applied.

### *2.3 Application of the Gutenberg-Richter Recurrence Law*

After applying magnitude homogenization to unify the earthquake catalog to $M_W$, a plot of the data was formed. 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. This plot is presented as a red line in Fig. 2. The black line is generated by applying linear regression using the Gutenberg-Richter relationship through the data points. This results in $a$ = 5.378 and $b$ = 0.724.

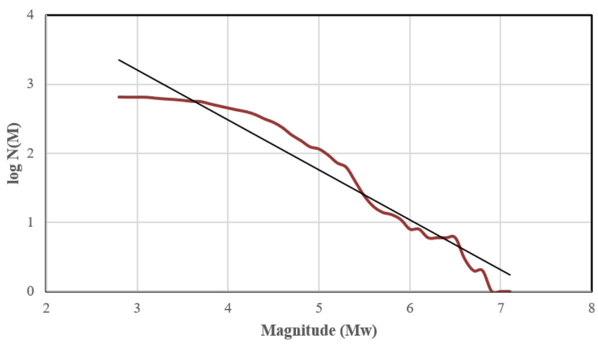


Fig. 2. Gutenberg Richter recurrence relationship.

The relatively low b-value suggests that larger earthquakes are less frequent in the Red Sea region, compared to tectonically active areas with higher b-values (typically around 1.0). The transformation process improved the linear fit of the Gutenberg Richter relationship, demonstrating that magnitude homogenization enhances the reliability of seismicity assessments. By ensuring consistent magnitude representation, this study provides a more accurate basis for seismic hazard modeling in the region, particularly for critical infrastructure planning such as nuclear power plant safety.

## 3. Conclusions

Compiling a catalog from ISC and ISC-GEM data sources resulted in 658 earthquakes in the Red Sea region. 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 $a$ = 5.378 and $b$ = 0.724. The Gutenberg-Richter $b$-value suggests that the Red Sea region does not experience many large magnitude events, although this is a relative parameter.

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