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Magnitude transition probability and casual dependence of local earthquakes

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Abstract: Even though they contribute far less to the total worldwide death toll and damage than their more powerful counterparts, Aswan earthquakes, which have low overall seismicity and magnitudes between 3.0 and 5.6, may be the main source of seismic risk and hazard in the Aswan region. With such earthquakes' potential to cause significant concern in several parts of the world, it is important to study of the casual dependence between the occurrences of earthquake magnitudes in Aswan area. The probabilistic dependence is different from the casual dependence. Earthquakes' probabilistic reliance is not a prerequisite nor an adequate means of establishing a causal connection. Therefore, it is crucial to look at the accidental dependency of earthquake magnitude in the Aswan region. For this purpose, and to verify the stability of the findings, we considered the seismic data from 1980 to 2002 in Aswan area. The statistical and probabilistic methods might be used to examine the features of the dependency between earthquake magnitudes. The probability of both the absolute and conditional earthquake magnitudes, as determined by counting the consecutive observations of earthquake magnitude directly. This article investigates empirically the magnitude transition probability and casual dependence of earthquake magnitude events in Aswan area. The data for 286 consecutive earthquakes felt in the Aswan area with a magnitude of 3.0 or above are utilized in the probability calculations to examine the dependency of earthquake magnitudes on chance. The results show that the magnitudes of subsequent earthquakes in the Aswan area are causally related to one another. Additionally, the results of this study imply that the order in which earthquakes occur in the Aswan region may be governed by some regular connection.

Keywords: Magnitude transition probabilities, casual dependence, Aswan area earthquakes.

1 Introduction

Earthquake is the most dangerous but least predictable natural disaster [1, 2]. Earthquakes are the result of complex geological disasters developing events. Every year, more than 40 powerful earthquakes occur all across the planet. Massive earthquakes have a significant negative influence on the environment in addition to causing great damage and city destruction. The magnitude and length of an earthquake determine the damage it produces. The Magnitude is defined energy liberated during earthquake as a measure. There is no possibility to measure directly the energy, Richter, which is a measure of an instrumental method available earthquake "magnitude" is defined about 1930 [3].
Earthquake prediction is a major challenge to societies exposed to earthquakes damages. The earthquake early prediction depends on the time, magnitude and location. An earthquake's location, duration, and magnitude are all estimated in an earthquake forecast. An alarm zone is a spatial zone that is often estimated as part of earthquake forecasts; it is a zone that is consistently constructed with a constant step in a systematic earthquake prediction [4].
Nowadays, the main task of seismologists is to characterize the characteristics and behaviour of complicated earthquake events. Earthquake predictors claim to be able to anticipate earthquakes based on a variety of observations, such as animal behaviour, temperature changes, radon gas emissions, and observing the activity of occurrences of small earthquakes, etc. [5]. However, the precursors may be appear or not before earthquake [6]. However, a number of methods for earthquake prediction have been put forth [7]. Regression algorithms and cloud-based big data infrastructure were utilized by Cortés et al. [8] to study earthquake prediction in California. The need for seismologists to create a systematic research program on earthquake predictability has grown in recent years. Azimi et al. [9] predicted the blast-induced ground vibration (BIGV) of quarry mining

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using an artificial neural network tuned using a hybrid genetic algorithm. Pandit and Biswal [10] forecasted earthquake magnitudes using an adaptive neurofuzz inference system. From a technological and anthropological standpoint, Tapia-Hernandez et al. [11] investigated earthquake predictions and scientific forecasting (dangers and possibilities). A model for empirical earthquake prediction and analysis in a data-intensive setting was presented by Ahmad et al. [12]. Nievas et al. [13] looked into the statistical study of the effects of earthquakes with a magnitude of small to medium. Pulinets et al. [14] investigated the earthquake predictions using multi-parameter monitoring data. Tehseen et al. [15] studied earthquake prediction based on the systematic mapping technique. Since earthquake prediction is so difficult, several researchers have employed a variety of techniques. In his early study, Ferraes [16] investigated the probability relationship between earthquake magnitude and time interval for Mexico City. Selim et al. [17] did first attempt of the study of statistical correlation between the water level and the seismicity in the Aswan area. Aswan is one of the most seismically active areas of Egypt and its seismicity is limited to the upper 25 km of the Earth's crust. The seismicity was examined by WCC (1985) between December 1981 and July 1982. They stated that there is little seismic activity in the Aswan region. Seismologists in Aswan area have observed and located literally thousands of earthquakes. What can we learn from these observations about the probabilistic casual dependence of magnitudes? Can we compute the conditional probabilities to test the casual dependence of successive earthquake in Aswan area? Ultimately, can our study be extended into the future to make (probabilistic) forecasts or even earthquake prediction of the future seismicity in Aswan area? These are the questions addressed in this article. Determining these probabilities may be thought of as a first stage in the Aswan area earthquake prediction process since the computed values allow us to make inferences about the likelihood of a major shock earthquake occurring as well as the amount of time that will pass before the next earthquake occurs.

2 Seismicity of Aswan area

Due to the Lake Nasser which created by the High Dam in Aswan city, the area is becomes one of the active regions in Egypt. Concern over the seismic activity around the Aswan High Dam region has grown. Studies on nemours had been carried out to gauge the degree of seismic activity and the danger associated with it at the Aswan High Dam. [17–24]. According to earlier research, the region has seen a number of seismic occurrences. The biggest one was on November 14, 1981 (M 5.3), 20 km below the Wadi Kalabsha embayment, which is Lake Aswan's western extension. Since then, there has been a great chance to examine the spatiotemporal distribution of seismicity in the region thanks to ongoing seismic activity monitoring. Less than 12 kilometers separated the depths of nearly all earthquakes from this zone [25]. The Aswan Seismological Center (ASC) has been continuously recording earthquakes since June 1982. With the exception of the primary shock and the subsequent aftershocks, which happened under Gebel Marawa at a depth of between 15 and 30 km, the majority of earthquakes occurred at depths between 0 and 30 km (Figure 1) [18, 26, 27].

3 Analysis of Aswan area data

The data of Aswan area's seismic catalogue used in this study, from the earthquake catalogue of Aswan area for the period 1980-2002. The data were extracted from Bulletins of ACS. About 286 successive earthquakes felt in Aswan area, with magnitude $\geq$ 3.0 and less than 30 km deep were analysed (Figure 1). The hypocenters of these seismicity were computed using HYPO71 computer program (Lee and Lahr, 1975) from primary waves that were recorded by Aswan Earthquake Regional Research Center network. The epicenters are concentrated in Aswan seismic area with extends from 32.3° W to 33.2° W longitude and from 23° N to 240 N latitude.

4 Theory

Absolute probability: If an experiment's sample space S is made up of a finite number of equally likely outcomes (points), that are equally likely, then the probability $P(A)$ of an event A is:

$$P(A) = \frac{\text{Number of points in } A}{\text{Number of points in } S}. \tag{1}$$

Thus, in particular $P(S) = 1$. In numerous real-world scenarios, there are infinitely many equally plausible outcomes, for instance, occurrence of earthquake magnitude in specific area, we have a larger number n of trial, take the relative frequency $f_{rel}(A)$ as an approximation of unknown probability $P(A)$. Here, by definition,

$$f_{\text{rel}}(A) = \frac{\text{Number of times } A \text{ occurs}}{\text{Number of trials}}. \tag{2}$$

Conditional probability: Finding the likelihood of an occurrence B on the assumption that an event A happens is often necessary. This probability is known as the conditional probability of B given A and may be expressed as follows:

$$P(B/A) = \frac{P(A \cap B)}{P(A)}. \tag{3}$$

where $P(A \cap B)$ represents the probability of the occurrence of both A and B together.

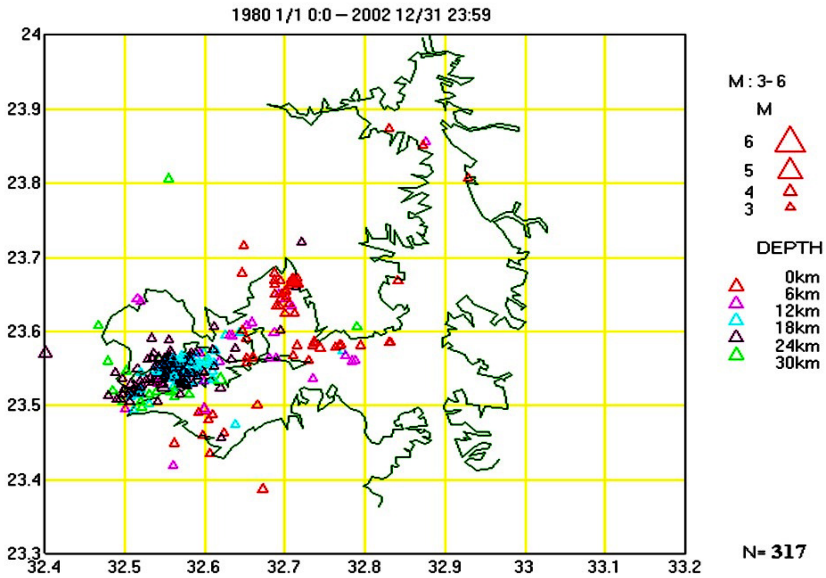

Fig. 1: Seismicity map of Aswan area ($M \geq 3.0$) for the period 1980–2002.

Independent events: if two events A and B are independent then we could write,

$$P(A \cap B) = P(A)P(B) \quad (4)$$

In this case, relation (3) becomes,

$$P(B/A) = P(B) \quad (5)$$

5 Methods

5.1 Conditional probability of casual magnitude

Suppes (1970) investigated the casual magnitude independence using the probability consideration. In addition, Ferraes [1974) reported that, there had been a casual dependence between successive earthquakes occurred around Mexico City. Therefore, the main target of this study is to examine probabilistic dependence of the sequences or seismic events occurred around Aswan area in the period 1980-2002. In other words, this study examines the statistical relationships between the observed earthquake magnitude events in Aswan area. We attempted to investigate and evaluate the idea that if an earthquake of a particular magnitude is very likely to be followed by another earthquake of a different magnitude, then one earthquake magnitude is the cause of another. We employ the conventional conditional probability to calculate this probability. We suppose the conditional probability of an earthquake of midpoint magnitude $(\bar{M}_j)(j = 1.2.3\ldots)$ Considering that, an intermediate-magnitude earthquake $(\bar{M}_i)(i = 1.2.3\ldots)$ has occurred given the quantity of trials in which that number of trials in which $(\bar{M}_j)$ occurred following $(\bar{M}_i)$. This conditional probability of $(\bar{M}_j)$ given $(\bar{M}_i)$ is defined by the following equation,

$$P\left(\frac{\bar{M}_j}{\bar{M}_i}\right) = \frac{\alpha_{ij}\,(\bar{M}_i \cap \bar{M}_j)}{n_i\,(\bar{M}_i)} \quad (6)$$

where $\alpha_{ij}(\bar{M}_i \cap \bar{M}_j)$ is the events number observed with midpoint magnitude $(\bar{M}_j)$ occurred following an event with midpoint magnitude $(\bar{M}_i)$ and $n_i(\bar{M}_i)$ is the total number of events with midpoint magnitude $(\bar{M}_i)$

5.2 Transition matrix of probability of earthquakes sequences

In this work, we use the method of transition matrix of probability (Davis, 1973) to test the sequences of seismicity magnitudes in Aswan area. Let us given a magnitude sequence $M = M_1.M_2.M_3\ldots M_N$ we can construct the matrix $A = \alpha_{IJ}$, where α_{IJ} means the number of times a given magnitude being succeeded by another in the sequence. The transition frequency matrix of M, or matrix A, is a succinct method to represent the occurrence of one magnitude after another. The following magnitude sequence's transition frequency matrix, for instance: M = 3.0, 3.0, 3.7, 3.0, 3.6, 3.8, 3.6, 3.7, 3.8, 3.8, 3.0, 3.0, 3.7, 3.6, 3.0, 3.8, 3.6, 3.0, 3.0 is given in the following Table 1:

Table 1: The transition frequency matrix of a given example

		To			
		3.0	3.6	3.7	3.8
From	3.0	3	1	2	1
	3.6	2	0	1	1
	3.7	1	1	0	1
	3.8	1	2	0	1

If the frequency matrix is converted to decimal fractions or percentages, it becomes more evident how one earthquake magnitude tends to come after another. Therefore, it can be constructed the transition matrix of probability of earthquakes sequences $B = \beta_{IJ}$, as a division of the observed number of earthquakes (with magnitude M_j occurred following an earthquake with magnitude M_i) over the total number of earthquakes with magnitude M_i. This kind of matrix shows how frequently different kinds of transitions with the specified magnitude (M) can occur. Table 2 displays the transition matrix for the current scenario.

Table 2: The transition matrix of probability of a given example

		To			
		3.0	3.6	3.7	3.8
From	0.38	0.13	0.25	0.13	
	3.6	0.50	0.00	0.25	0.25
	3.7	0.33	0.33	0.00	0.33
	3.8	0.25	0.50	0.00	0.25

6 Results

About 286 successive earthquakes felt in Aswan area were used to construct the transition frequency matrix of the transition frequency matrix of successive earthquakes in Aswan area as shown in table 3. To reduce the scattering and keeping information for the purposes of prediction, the intervals $\Delta M = 0.4$ Richter were used to group the earthquake magnitudes. For the transition matrix of 286 successive earthquakes in Aswan area, which shown in Table, we got the transition matrix of probability of 286 successive earthquakes in Aswan area as shown in the table 4 shown below:

Table 3: The transition frequency matrix of 286 successive earthquakes felt in Aswan area

To $\bar{M}_j$ / From $\bar{M}_i$	3.2	3.7	4.2	4.7	5.2	5.7
3.2	188	37	4	1	0	1
3.7	33	11	3	0	1	0
4.2	6	1	0	0	0	0
4.7	0	1	0	0	0	0
5.2	1	0	0	0	0	0
5.7	1	0	0	0	0	0

Table 4, shows the results obtained about casual dependence of earthquakes in Aswan area. According to the data, there is a good chance that an earthquake of around the same or greater midpoint magnitude will occur after a minor earthquake with midpoint magnitude $M_i \leq 3.2$. The results showed also, that, The low probability of an earthquake having a midway magnitude $M_i = 3.7$ will be succeeded by a seismic events with a midpoint magnitude of around the same or greater. This earthquake is quite likely to be followed by a smaller event with midpoint $M_i = 3.2$. In addition, it can be observed from that, there is a high probability that an event with midpoint magnitude $M_i = 4.7$ will be followed by a seismic events with midpoint magnitude $M_i = 3.7$. Furthermore, it can be seen from the results shown in table 4 that, there is a high probability that an seismic events with midpoint magnitude $M_i = 5.7$ will be followed by an event with midpoint magnitude $M_i = 3.2$. In addition, there is a low probability that seismic events with midpoint $M_i \geq 4.7$ will be followed by a seismic event of the same or higher midpoint magnitude. Finally, the results indicate that there is a causal dependence between the magnitudes of successive seismic events around Aswan area. In the future, it would be necessary to investigate the relations governing the sequence of earthquakes in Aswan area.

Table 4: The transition frequency matrix of 286 successive earthquakes felt in Aswan area

To $\bar{M}_j$ / From $\bar{M}_i$	3.2	3.7	4.2	4.7	5.2	5.7
3.2	0.84	0.17	0.02	0.01	0.00	0.01
3.7	0.65	0.22	0.06	0.00	0.02	0.00
4.2	0.86	0.15	0.00	0.00	0.00	0.00
4.7	0.00	1.00	0.00	0.00	0.00	0.00
5.2	1.00	0.00	0.00	0.00	0.00	0.00
5.7	1.00	0.00	0.00	0.00	0.00	0.00

7 Conclusion:

It is interesting to investigate whether there is any incidental relationship between the occurrences of earthquakes of different magnitudes in the Aswan area, given the risk that comparable earthquakes magnitude represent and the growing anxiety that these events cause in other parts of the world. This article investigates empirically the magnitude transition probability and casual dependence of earthquake magnitude events in Aswan area. In the probability considerations the data for 286 successive earthquakes felt in Aswan area with magnitude 3.0 or greater, are used to test the casual dependence of earthquake magnitudes. The results obtained reports that there is a causal dependence between the magnitudes of successive seismic events in Aswan area. Additionally, this research raises the possibility that a systematic relationship governs the order in which earthquakes occur in the Aswan region. In the future, it would be necessary to investigate in detail the relation governing the sequences of earthquakes occurrence around Aswan for particular Aswan High Dam area, and derive the characteristics of the interdependence between earthquake magnitudes using the statistical and probabilistic models.

Conflicts of Interest

The author declares that he has no conflicts of interest to report regarding the present study.

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