Earthquake prediction through Kannan-Mathematical-Model Analysis and Dobrovolsky-based clustering Technique

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Abstract: Earthquakes are considered to be a continuing source of hazards to the people and infrastructures, especially to those in the Pacific Ring of Fire, which includes Philippines. Seismic data from year 2011 to year 2013 were collected from the Philippine Institute of Volcanology and Seismology (PHIVOLCS) and used in this study. By dividing the Philippine archipelago into latitudinal sections and only taking the earthquakes with magnitude 4 and above into consideration, the Kannan-Mathematical-Model analysis was implemented and validated by identifying a pattern within each region based on the spatial connection theory. A clustering technique based on the formula by Dobrovolsky was used to identify the earthquake radial area of effect, and the mega thrust earthquake effect following the assumption that all nearby earthquake in the region can be an effect of a mega thrust earthquake. A prediction validation was utilized to analyze the data and the predictions which claim to be true. In this research, the Kannan – Mathematical – Model Analysis and Dobrovolsky-based clustering technique are seen to be related and claimed as effective techniques in predicting earthquakes in the Philippines. As a result of the model analysis, multiple data prediction was produced for the days after 2013. Earthquake probability distribution is plotted across time and surface. This model can be integrated with other models for a possible more accurate way of earthquake predictions.

Key Words: Earthquake; Dobrovolsky; Mega thrust earthquake; Clustering; Prediction

1. INTRODUCTION

The processes that have formed the earth that continually act on or beneath its surface such as the movement of plates in the earth's crusts is one of the continuing source of hazards to people and their structure (Besana & Ando, 2005). It goes without saying that earthquake is still an interesting, important and relevant subject matter.

A major tectonic feature of the Philippine region is the Philippine Fault Zone (PFZ). The seismicity of the Central PFZ, comprised of the Guinyanga Fault, Masbate Fault and Central Leyte Fault, is defined by clusters of large and moderate earthquakes (Department of Regional Development and Environment Executive Secretariat for Economic and Social Affairs Organization of American States,

1991). One of the events that exemplify the destructive prowess of earthquakes is the July 16, 1990 - a 7.7 magnitude earthquake triggered by a fault zone movement. It caused 1,677 lives accompanied by extensive damages in the central and northern Luzon (Rantucci, 1994). It is therefore beneficial to develop pattern analysis and earthquake models to predict earthquakes. Aside from developing our own method to predict earthquakes in the Philippines, it is equally important to implement or test other methods which were previously tested only on foreign lands. We tested for the validity of the model when applied to the data of the Philippines.

Present prediction methods uses following categories of precursors: land deformation, tilt and strain, seismic activity, geo-electricity,

geomagnetism, oil flow, micro-seismicity, resistivity, radon emission and Underground Water and Hot Springs (Rikitake & Hamada, 2002). Although widely used in short term earthquake prediction, the use of these precursors is claimed to be still empirical to a large extent. This is mainly due to the many difficulties in understanding the physics of its entirety (Patella, Tramacere, & Di Maio, 1997). In this study some of these played a part in the clustering of earthquakes.

The Kannan-Mathematical-Model analysis was implemented to identify a pattern within each region based on spatial connection theory: earthquakes occurring within a region are related to one another (Kannan, 2013). A Clustering technique was developed and used based on the Dobrovolsky earthquake radial area of effect and the megathrust-aftershock effect

The result of the accumulation of extensive researches on the geological phenomenon that have been performed up to this date has been translated into form that are accessible to non-scientists (Besana & Ando, 2005). The knowledge and results simplified to be understood by non-scientists proves to be remarkably important in reducing damages due to earthquake. It plays a significant role in earthquake preparedness and structural engineering and architecture.

This paper is organized as follows. In §2, we present the ideas, crucial equations and the methods done in the study. Finally, in §3 we present the calculation results, analysis and interpretation.

2. METHODOLOGY

Significant amount of earthquake data exists in global earthquake databases such as those by the Philippine Institute of Volcanology and Seismology (PHIVOLCS). For this research, the data used is the 2011 to 2013 earthquakes observed by PHIVOLCS (Philippine Institute of Volcanology and Seismology, n.d.). Also only earthquakes of magnitude 4 and above were considered.

There are two main parts of methodology in this study. First is the clustering. Due to the many active fault zones in the Philippines, it was found to be very challenging to cluster the earthquakes when the basis is the fault zone. An alternate solution to this comes from the prominence of the role played by earth current anomalous variations prior to earthquakes. The currents can be revealed on the earth's free surface proposes a physical model, capable of explaining the formation anomalous earth current fields prior to earthquakes (Patella et al., 1997). Radon is one of the geophysical forerunners of

earthquake prediction. Being a main component of the physical mechanism of seismogenic electric field generation, the area covered by the irregular fluxes of radon is expected to be of the same order of magnitude as the areas covered by the seismogenic electric field. Consequently, the measured geochemical effects of radon before earthquakes coincide and are completely identical to the affected zone calculated by Dobrovolsky (Saradijian & Akboondzadeh, 2011). With this in mind, the Dobrovolsky equation for radial area of effect was used as a basis and shown in Eq. 1. The magnitude used in the equation is the average magnitude of those earthquakes within the region.

$$Radius = 10^{0.414M - 1.696} \qquad (Eq.1)$$

where:

M is the average magnitude

On 2012, a magnitude 7.6 earthquake ruptured beneath the sea floor of the Philippine Trench. In the wake of the main shock, sensors detected a flurry of 110 aftershocks. A minor revision was made to the Dobrovolsky equation when the idea of the megathrust effect was introduce into the equation. The revised Dobrovolsky Equation changed the magnitude into twice of the average magnitude. The idea was that along that particular region, the earthquakes were a product of a megathrust earthquake. The revised Dobrovolsky equation, we will now call the Dobrovolsky-Megathrust Radius Equation, is shown in Eq. 2.

$$Radius = 10^{0.414(2M) - 1.696} \qquad (Eq.2)$$

where:

M is the average magnitude

A latitudal clustering was introduced to find the geometric center using Eq. 3 and Eq. 4 which was assumed to be the epicenter of the Megathrust earthquake. All earthquake data that are inside the latitudal clustering contributed to the calculation of the average magnitude. The earthquake data was filtered with the use of the calculated area of effect using the Dobrovolsky-Megathrust Radius Equation in such a way that only the earthquakes inside the area were taken.

$$Average\ Latitude = \frac{\sum Latitude}{n} \qquad (Eq.3)$$

$$Average\ Longitude = \frac{\sum Longitude}{n} \qquad (Eq.4)$$

Where:

n = number of data points

The second part was the application of the Kannan-Mathematical Model to the filtered Philippine earthquake data. The theory basis of the

Kannan-Mathematical Model is the spatial connection theory. The spatial connection theory is based on the assumption that earthquakes are related to previous earthquakes that occurred within a fault zone or region (Kannan, 2013). This theory is very significant and related to the subject because Philippines contains so many fault zones. Mathematical functions utilized in this research were the Poisson Range Identifier function (PRI), poisson's distribution, and reverse poisson's distribution.

The PRI function utilizes the data from the spatial connection model to derive PRI values for each earthquake zone. Then, a distance factor was derived using the Poisson's distribution. The prediction was carried out by using the reverse Poisson's distribution and the distance factor for the earthquake zone (Kannan, 2013). The PRI equation is shown in Eq. 5.

$$PRI = \frac{(X1*TL2)}{[(Cos(theta)*X2*TL1)]} \qquad \text{(Eq. 5)}$$

Where:

$X1$ = distance between point 1 and 2
$X2$ = distance between point 2 and 3
$TL1$ = time lag between 1 and 2
$TL2$ = time lag between 2 and 3

To validate the theory, the models were built for the first half of the data and prediction were developed. Then the models for the second half was built, validating the predictions from the initial models (Rantucci, 1994). After validation of the model, a prediction was developed using the second half of the data to conclude this research.

The application of the latitudal clustering / data sorting, geometric center and Dobrovolsky-Megathrust Radius calculation was coded in a FORTRAN program and was the first program to be run in the whole calculation process.

Time lag calculation, which is an essential factor in PRI calculation, was conducted in Microsoft Excel. The raw data was in latitude and longitude and was processed with the Haversine Formula (shown in Eq. 6) integrated in a FORTRAN program to find the distance between two points a specific requirement for using the PRI equation. The angle between two spatial connections was calculated with the Cosine law (Eq. 7) integrated in a FORTRAN program automated for large data points.

The PRI calculation was also calculated with an automated FORTRAN program. Using the PRI computed values, the mean, standard deviation, variance and cumulative was calculated using Microsoft Excel excluding the outliers (data that gives a PRI value greater than 10). These variables were used to find the distance factor. The distance factor was calculated using the Poisson's distribution function (Eq. 8)

$$a = \left(\sin\left(\frac{\Delta lat}{2}\right)\right)^2 + \cos(lat1) * \cos(lat2) * (\sin(\Delta lon))^2$$

$$\text{distance} = R*\left(2*\text{atan2}\left(\left(\sqrt{a}\right),\left(\sqrt{1-a}\right)\right)\right) \qquad \text{(Eq. 6)}$$

Where:

Δlat = Latitude 2 – Latitude 1
Δlon = Longitude 2 – Longitude 1
$Lat1$ = Latitude 1
$Lat2$ = Latitude 2
R = radius of earth = 6371 km
$Atan2$ = arc tan with 2 arguments

$$\theta = \cos^{-1}\left(\frac{a^2+b^2-c^2}{2ab}\right) \qquad \text{(Eq. 7)}$$

Where:

θ = Angle between line 1 and 2
a = line length from point 1 to 2
b = line length from point 2 to 3
c = line length from point 1 to 3

$$DF = poisson\ dist(PRI, mean, cu) \qquad \text{(Eq. 8)}$$

Where:

PRI = PRI values
$Mean$ = PRI mean
Cu = PRI cumulative or sum

3. RESULTS AND DISCUSSION

Using the data gathered from PHILVOCS in the year 2011, 2012 and 2013, the regional sorting program that uses the Dobrovolsky-Megathrust equation was run. A Google earth model is shown in Fig. 1. Earthquake Megathrust epicenter, Earthquake epicenters included in radial region, and Earthquakes used in the radius calculation but not within radius was marked Blue, Red, and Yellow, respectively.

(a) Earthquake clustered using geometric center calculated from latitude 5-7
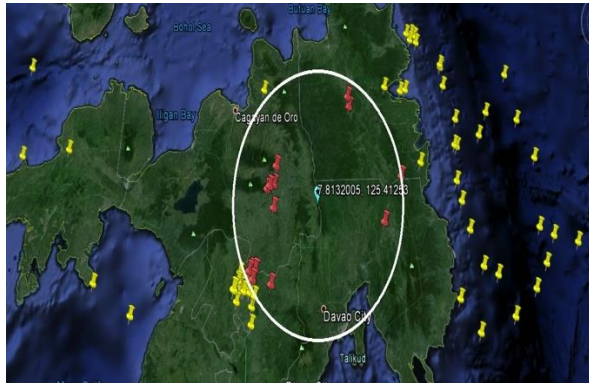
(b) Earthquake clustered using geometric center calculated from latitude 7-9
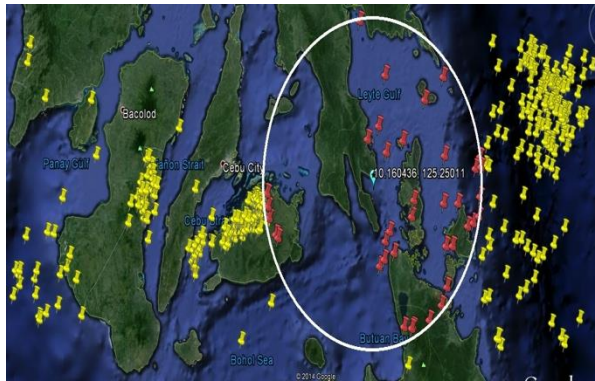
(c) Earthquake clustered using geometric center calculated from latitude 9-11
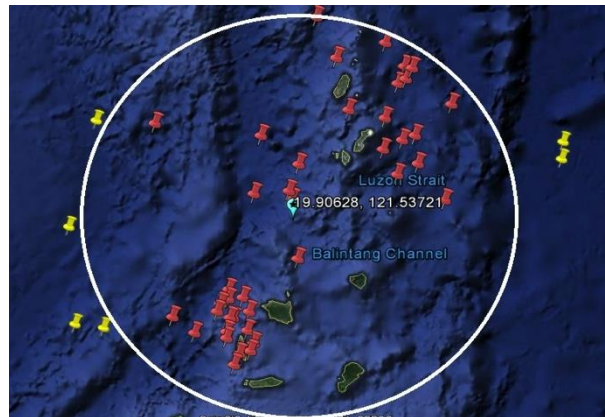

(d) Earthquake clustered using geometric center calculated from latitude 11-13

(e) Earthquake clustered using geometric center calculated from latitude 13-15

(f) Earthquake clustered using geometric center calculated from latitude 15-17

(g) Earthquake clustered using geometric center calculated from latitude19-21

Figure 1. Clustered Earthquake Data points

Table 1. Calculated Poisson Range Identifier

Latitude initial	Latitude Final	Mean PRI	Cumulative PRI
5	7	2.090	37.560
7	9	1.100	2.200
9	11	1.270	7.540
11	13	2.040	21.600
13	15	0.510	0.510
15	17	23.110	46.210
17	19	0.553	3.320
19	21	1.760	12.330

9-11	105	365	21
	90	385	44
11-13	75	145	131
	90	145	126
15-17	60	10	78
	60	20	67

Through the calculations made in the data, the clusters have shown a number of predictions that coincided within the parameters. Table 2 shows some of the predictions that coincided with the margin of error.

Data calculation for PRI value and distance factor for the 1st half of the data for each cluster was calculated. The predictions were validated by using the 1st half of the data for each cluster to predict the data presented in the 2nd half. In the first run of calculations, a big number of predictions per cluster was seen but then, through setting a margin of error in predicting the data, only a number was considered as a valid prediction. The predictions were then proved to be true.
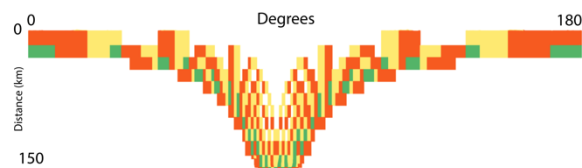

Figure 2. Sample plot of probabilities of earthquake occurrence within 30 days after the October 15, 2012 in South Cotabato. (scale: green=high, orange=mid, yellow=low)

In this research, a margin of error for the distance, time lag and theta were set that for any prediction that coincided within the parameters will prove that the prediction is true. The distance's parameter is 10 km, time lag's parameter is 10 days and theta or the angle was also set into 10 degrees. Results showed that there is an identifiable pattern in predicting earthquakes in the Philippines. The Kannan-Mathematical model analysis and the Dobrovolsky clustering technique is therefore related and an adequate method in predicting earthquakes in the Philippines.

Table 2. Predictions that coincided within the margin of error.

Cluster	Latitude	Longitude	Timelag
5-7	15	15	175
	45	35	132

4. CONCLUSIONS AND RECOMMENDATION

The performed research validated the Kannan-Mathematical model analysis, together with the Dobrovolsky clustering technique, as a method for predicting earthquakes. This research can be improved by changing the assumptions; such as considering the earthquakes that occur with a magnitude below 4.0 and by having different divisions of the area to be studied. The margin for error set for proving the prediction to be valid may also be varied to show other results that can possibly coincide with the set parameters: distance, time lag, and theta.

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