

Mathematical models for estimating earthquake casualties and damage cost through regression analysis using matrices.

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ABSTRACT: The aim of this study was to develop mathematical models for estimating earthquake casualties such as death, number of injured persons, affected families and total cost of damage. To quantify the direct damages from earthquakes to human beings and properties given the magnitude, intensity, depth of focus, location of epicentre and time duration, the regression models were made. The researchers formulated models through regression analysis using matrices and used $\alpha = 0.01$.

The study considered thirty destructive earthquakes that hit the Philippines from the inclusive years 1968 to 2012. Relevant data about these said earthquakes were obtained from Philippine Institute of Volcanology and Seismology. Data on damages and casualties were gathered from the records of National Disaster Risk Reduction and Management Council.

The mathematical models made are as follows:

$$\begin{aligned} \ln \hat{y}_1 &= -13.405 - 0.001x_1 + 2.214x_2 - 0.013x_3 + 0.374x_4 - 0.001x_5 \\ \ln \hat{y}_2 &= -13.426 + 0.360x_1 + 1.899x_2 + 0.015x_3 + 0.444x_4 - 0.001x_5 \\ \ln \hat{y}_3 &= -16.905 + 0.083x_1 + 2.577x_2 - 0.043x_3 + 0.630x_4 + 0.002x_5 \\ \ln \hat{y}_4 &= -17.075 + 0.234x_1 + 2.520x_2 - 0.033x_3 + 0.383x_4 + 0.001x_5 \end{aligned}$$

This study will be of great value in emergency planning, initiating and updating programs for earthquake hazard reduction in the Philippines, which is an earthquake-prone country.

KEYWORDS. *Mathematical Models, Earthquake, Regression Analysis, Matrices, Correlation Coefficient*



1. INTRODUCTION

Earthquakes or called quakes are serious natural hazard in many parts of the world. It is a sudden movement of the earth's crust caused by the release of stress accumulated along geologic faults or by volcanic activity. Throughout the past two decades, earthquakes have caused more than a million deaths, physical damages and injuries worldwide. Since the Philippines is situated within the "Pacific Ring of Fire", it causes the country to have frequent seismic and volcanic activity which may results to a volume of casualties and enormous damages. Moreover, the country sits on the Philippine Plate, which is sandwiched by the Pacific Plate and Eurasian Plate. In this tectonic setting, the country is widely known as an earthquake country.

Earthquake damage depends on what area is hit. If an unpopulated region is struck, there will be low loss of life or property. If it hits a large city, there may be many injuries and destruction. Many of the areas at risk on the Ring of Fire are largely populated. Major earthquakes hitting those areas today could produce terrible damage.

The Philippine archipelago is prone to earthquakes because of its geotectonic characteristics. It is also transacted by numerous faults, foremost of which is the Philippine Fault Zone that runs the length from Luzon through Eastern Visayas to Eastern Mindanao and bounded by several trenches: in the east by the East Luzon Trench, Philippine Trench and Davao Trench; and in the west by the Manila Trench, Negros Trench, Sulu Trench and Cotabato Trench. These tectonic features serve as the major earthquake generators in the country which hosts at least five unfelt to felt earthquakes per day.

2. OBJECTIVE OF THE STUDY

The objective of the study was to formulate mathematical models through regression analysis using matrices to physically quantify the direct damages from earthquakes to human beings and structures given the duration, magnitude, intensity and depth of focus of the earthquakes. These models will be of great value in planning, initiating and updating programs for earthquake hazard reduction and in emergency planning in the Philippines.

The researchers used the variables shown in the figure to make models that assess casualties and cost of damage. Significant relationships among variables were obtained after some verifications. Multiple Regression using matrices was then used to make models that will best estimate the casualties and damaged cost.

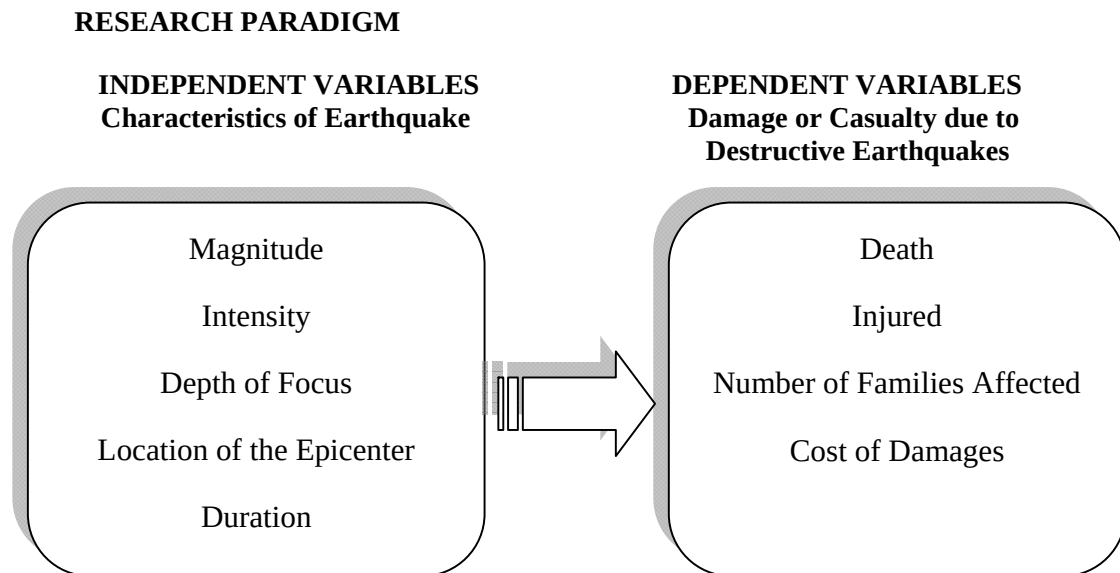


Figure 1. *Research Paradigm of the Study*

3. STATEMENT OF THE PROBLEM

This study is conducted to formulate mathematical models through regression analysis using matrices to estimate casualties and cost of damages due to destructive earthquakes. In particular, the point of the study was to answer the following questions:

1. To what extent are the major earthquakes that strike the Philippines be characterized in terms of:
 - 1.1 intensity;
 - 1.2 magnitude;
 - 1.3 depth of focus;
 - 1.4 location of the epicenter; and
 - 1.5 duration?
2. How much damage can earthquakes produce in terms of
 - 2.1 death,
 - 2.2 injuries
 - 2.3 families affected, and
 - 2.4 cost of damage?

3. What mathematical models can be formulated through regression analysis using matrices that estimate following due to destructive earthquakes.
 - 3.1 death,
 - 3.2 injured,
 - 3.3 families affected, and
 - 3.4 cost of damage?
4. How significant are the formulated mathematical models to assess the possible damages due to an earthquake event?

4. SCOPE AND DELIMITATION

The researchers limit this study only to the destructive earthquakes with magnitude 5 and higher. They also considered the thirty earthquake events in the Philippines that brought enormous casualties and damages. The data were gathered from the Philippine Institute of Volcanology and Seismology[8] and National Disaster Risk Reduction and Management Council[9]. The researchers formulate regression models using matrices by considering independent variables like magnitude, intensity, depth of focus, location of the epicenter and duration of earthquake recorded within 1968 to 2012.

The researchers considered the zone where the epicenter is located. The different zone defined by Sergio Su[4] are the following:

- Zone 1 – East Luzon subduction zone
- Zone 2 – Philippine Trench
- Zone 3 – Philippine fault
- Zone 4 – Double forearc associated with Manila Trench
- Zone 5 – Manila Trench
- Zone 6 – Negros and Sulu Trench
- Zone 7 – Cotabato trench and the Northern Extension of the Molucca Sea Plate

5. REVIEW RELATED LITERATURES

This portion presents a review of several literatures that would be advantageous to the study summarized from previous writings, divulging thorough facts asserted by few people and pioneer in the field of applied mathematics.

Casualty counts and damages of earthquake may depend on the location where it occurs. Most earthquake-related deaths are caused by the collapse of structures and the construction practices play a tremendous role in the death toll of an earthquake. This was proved in the web article[3].

According to Arnold E.P. [2] that on November 30, 1645, Manila experienced the most destructive earthquake in its history. A number of stone buildings were ruined, and an estimated 3,000 lives lost. This earthquake was noted to compare in magnitude with the greatest recorded in world history.

Numerous other earthquakes occurred in 1743, causing large scale destruction in the Philippines. On January 12, in the province of Tayabas, Quezon, the church and amonastery made of stone were devastated by an earthquake and accompanying landslides. The records show that inhabitants had never previously seen such destruction, with the town rendered uninhabitable and its people forced to move to another place to build a new town.

According to Ma. Leonila P. Bautista[3], There is a research study made by that is related to the current study which estimated the magnitudes and epicenters of 74 moderate-to-large historical earthquakes of the Philippines 1589 to 1896 through relating them to modern earthquakes. This was completed by initially deriving or formulating empirical equations relating surface magnitude (M_s) of recent Philippine earthquake (1987 to 1995) with felt areas enclosed by different intensities.

The said study found that the proposed epicenters of these historical events show expected and at the same time interesting results. While most of these epicenters fall within established and known active tectonic structures, some epicenters fall within established and known active tectonic structures, some epicenters fall within some structures thought to be inactive. For example, the Philippine fault exhibited active seismicity throughout the 300-year record. The Philippine Trench-east Luzon Trench region failed to show such remarkable seismicity but this is probably due to lack of populated towns in the eastern shores of the Philippines that could have reported felt big events.

According to Sergio S. Su[4] that the knowledge of how ground acceleration or velocity attenuates with epicentral distances is essential to the estimation of seismic risk at a given site. In the virtual absence of instrumental data, this attenuation function for acceleration or velocity may be obtained indirectly in two steps: first, through a study of how felt-intensity attenuates with epicentral distance; and second, through empirical correlation of felt intensity with acceleration or velocity.

Using the first step and data from 83 earthquakes in the Philippine region, Su derived an intensity-attenuation equation in the form:

$$I(R) - I_0 = 4.01 - 0.015R - 2.40 \log R$$

Where

$I(R)$ = Intensity as a function of distance

I_0 = Intensity at the epicenter

R = Epicentral distance in kilometers

Paul C. Thenhaus[5]estimated the economic loss from earthquakes to dwellings in a new housing development near Canlubang. Their estimates suggested an average annual loss per dwelling of P 576.00. Because of the lack of historic record of earthquake intensities and resulting damage at the site, the estimate is recognized as having relatively large uncertainty. Assuming $\pm$ Modified Mercalli Intensity (MMI) unit variability in the intensities on which the loss estimate is based, results in bounding estimates of average annual loss per dwelling of P 1,236.00 and P 216.00. An estimate of catastrophe potential, or the largest economic loss that

might reasonably be expected to occur to housing project, is estimated to be P 121,447,471.00 with a 90 % probability of not being exceeded in 250 years. This economic loss is equivalent to a 22 % physical loss to dwelling construction in the housing project.

To assess possible damages due to earthquakes, Dr.Felicisma V. Olaya,[7] proposed mathematical models with predictors intensity x_1 , magnitude x_2 , depth x_3 , and epicenter x_4 . According to her, using stepwise multiple regression analysis, one of the models that predicts death is the combination of magnitude, $\ln(\text{magnitude})$ and epicenter which gave highest $R^2 = 0.563$ and that is

$$\hat{y}_1 = 59578.966 + 11182.497x_2 - 71139.37 \ln(x_2) + 167.795x_4.$$

The model for predicting injuries with highest $R^2 = 0.685$ is the combination of magnitude and $\ln(\text{epicenter})$ with $\ln(\text{injured})$ and that is

$$\ln(\hat{y}_2) = 16.697 + 2.664x_2 + 1.241 \ln(x_4)$$

One of the models that predicts cost of damage is the combination of $\ln(\text{intensity})$ and epicenter with highest $R^2 = 0.611$ and the model is

$$\ln(\hat{y}_3) = -18.787 + 9.477 \ln(x_2) + 0.719x_4.$$

6. RESEARCH METHODOLOGY

The method of research that was used by the researchers was a descriptive type of research through a statistical analysis wherein the study is focused on present and past situations.

The researchers gathered data on destructive earthquakes that hit the Philippines from 1968 to 2012. The information on the characteristics of earthquakes were collected from Philippine Institute of Volcanology and Seismology[8], which is the main institute studying earthquakes in the Philippines. Data on casualties and cost of damages due to these earthquakes were collected from the files of the National Disaster Risk Reduction and Management Council[9].

6.1. Statistical Treatment

Since there were more than one independent variables involved, multiple regression using matrices was utilized to establish the mathematical model that would be best assess the damage due to destructive earthquakes particularly the number of casualties and families affected and the cost of damage.

All calculations were made using normal equation. Matrix computations were calculated using MATLAB and regression models were verified using SPSS.

In fitting a multiple linear regression model, knowledge of matrix theory can facilitate the mathematical manipulations considerably. Using matrix notation, we can write the equation

$$y = X\beta + c$$

Where

$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, \quad X = \begin{bmatrix} 1 & x_{11} & x_{21} & \dots & x_{k1} \\ 1 & x_{12} & x_{22} & \dots & x_{k2} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ 1 & x_{1n} & x_{2n} & \dots & x_{kn} \end{bmatrix}, \quad \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_k \end{bmatrix}, \quad \epsilon = \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_n \end{bmatrix}$$

Then the least squares method for estimation of β , it involves finding b for which

$SSE = (y - Xb)'(y - Xb)$ is minimized, then the X matrix is

$$A = X'X = \begin{bmatrix} n & \sum_{i=1}^n x_{1i} & \sum_{i=1}^n x_{2i} & \dots & \sum_{i=1}^n x_{ki} \\ \sum_{i=1}^n x_{1i} & \sum_{i=1}^n x_{1i}^2 & \sum_{i=1}^n x_{1i}x_{2i} & \dots & \sum_{i=1}^n x_{1i}x_{ki} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ \sum_{i=1}^n x_{ki} & \sum_{i=1}^n x_{ki}x_{1i} & \sum_{i=1}^n x_{ki}x_{2i} & \dots & \sum_{i=1}^n x_{ki}^2 \end{bmatrix}; \quad g = X'y = \begin{bmatrix} g_0 \\ g_1 \\ \vdots \\ g_k \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^n y_i \\ \sum_{i=1}^n x_{1i}y_i \\ \vdots \\ \sum_{i=1}^n x_{ki}y_i \end{bmatrix}$$

allows the normal equations to be put in the matrix form $Ab = g$. [6]

7. PRESENTATION, ANALYSIS AND INTERPRETATION OF DATA

7.1. Characteristics Of Destructive Earthquakes In The Philippines

7.1.1. Intensity

The table 1 shows the frequency distribution of the intensity of the thirty earthquakes in the Philippines that considered in the study.

TABLE 1
Distribution of the Intensity of the Earthquakes

Intensity	Frequency	Percentage
4	1	3.3%
5	2	6.7%
6	5	16.7%
7	15	50.0%
8	7	23.3%
	n = 30	100%

As shown in the table 1, 50% of the earthquakes were of intensity 7. Earthquakes of intensity 7 were classified by the PHIVOLCS as destructive. Moreover, 23.3% of the considered quakes were of intensity 8 and these were considered as very destructive. Subsequently, 16.7% were of intensity 6, 6.7% were of intensity 5 and 3.3% of the total considered earthquakes were of intensity 4. These were classified by the PHIVOLCS as very strong, strong, and moderately strong respectively.

TABLE 2**Summary of Means and Standard Deviations of the Independent Variables**

Variable	Mean	Standard Deviation
Intensity (x_1)	6.83	0.99
Magnitude (x_2)	6.65	0.69
Depth of Focus (x_3)	23.67	15.73
Location of the Epicenter(x_4)	3.7	1.66
Duration (x_5)	481.21	734.59

7.1.2. Magnitude

The table 2 shows that the mean magnitude of the earthquakes was 6.65 Ms with standard deviation of 0.69. According to the Richter magnitude scale used by the PHIVOLCS, seismic activities with magnitude 6 to 7 are strong earthquakes and accompanied by local damages near the epicenters. First class seismological stations can observe them wherever they occur within the earth.

7.1.3. Depth of Focus

The above table 2 divulges that the average depth of considered earthquakes was 23.67 kilometers with standard deviation of 15.73. Shallow earthquakes are those quakes with depth ranges from 0 to 70 kilometers. The earthquakes with shallower depths bring more damages than those who have greater depths.

7.1.4. Location of the Epicenter

The table below shows the frequency distribution of where the considered earthquakes were located.

TABLE 3
Epicenter Locations of the Earthquakes

Zone	Frequency	Percentage
Zone 1	2	6.67%
Zone 2	6	20.00%
Zone 3	6	20.00%
Zone 4	9	30.00%
Zone 5	1	3.33%
Zone 6	4	13.33%
Zone 7	2	6.67%
	n = 30	100.00%

As shown in table 3, the most number of earthquakes had epicenters located at Zone

4. The thirty percent (30%) of the total earthquakes considered in the study had epicenters at West Luzon Trench, whereas the double forearc associated with the Manila Trench. This implies that Luzon is very prone to be stricken by the earthquakes or any seismic activities.

7.1.5. Duration of the Earthquake

The average duration of the earthquake considered in the study was 481.21 seconds with standard deviation of 734.59 as shown in table 2. Earthquakes with longer time duration bring more damages than those with shorter one.

7.2. Damages Caused By Earthquakes

The table 4 underneath shows the mean, median and standard deviation of the different dependent variables.

TABLE 4
Summary of Means, Medians and Standard Deviations of the Dependent Variables

Variables	Mean	Median	Standard Deviation
Death (y_1)	187.03	4.5	720.65
Injured (y_2)	468.27	27.5	1732.31
Affected Families (y_3)	13,188.73	0	43687.49
Total Damage Cost (y_4)	466.65	4.98	2229.16

As shown in table 4, the mean death owing to earthquakes was 187.03 as associated to the median 4, which is more lifelike estimate of death. The most number of deaths aroused during the Moro Gulf earthquake in August 17, 1976 which left 3,792 persons dead. It was an earthquake that resulted in enormous destruction of properties and huge loss of lives. The

tsunami produced by the earthquake added immensely to the devastation. The great number of casualties during the incident could also be ascribed to the tremor that occurred just after midnight when most people were sleeping.

The mean of the number of people injured was 468.27 while the median was 27.5. The largest number of injured happened on Moro Gulf earthquake in 1976 which wounded 9,240 persons.

The cost of property damaged had a mean of P466.65M and a median of P4.98M. The largest cost of damages occurred in July 16, 1990 earthquake with epicentre at Cabanatuan City. It was of Intensity VIII at the epicentre and had a magnitude of 7.8 in the Richter scale. The earthquake left in its wake about P12.252M of damages to buildings, infrastructures and properties in Baguio-Cabanatuan-Dagupan area. It is deemed as the most devastating earthquake to strike the northern Philippines in the 19th century.

7.3. Relationships Of The Independent And Dependent Variables

The relationships of the independent to the dependent variables were ascertained using Pearson's coefficient of correlation, as shown in the table below.

TABLE 5
Pearson's coefficient of correlation

	Intensity	Magnitude	Depth	Location	Duration
Death (y_1)	0.121	0.448*	-0.013	0.350	-0.089
Injured (y_2)	0.112	0.439*	-0.015	0.375*	-0.095
Affected Families (y_3)	0.242	0.426*	-0.056	0.086	0.126
Total Damage Cost (y_4)	0.233	0.336	-0.003	0.044	0.129

*Correlation is significant at the 0.05 level (2-tailed)

The table 5 shows that the intensity of the considered quakes was not significantly correlated with any of the dependent variables. Unlike the intensity, magnitude of the earthquake was significantly correlated with number of death, injured, and families affected at 0.05 level. The coefficients of correlations of depth and time duration were not significantly correlated with any of the dependent variables but the location of the epicenter was significantly correlated with injured.

This also shows that all the independent variables did not correlate with the total damage cost of damage and as a consequence the independent variables that had considered in the research will not estimate the said dependent.

The assumptions for multiple linear regression guided the researchers to formulate mathematical models that estimate the casualties and cost of damage of an earthquake event. The deviation from linearity guided them to know if there are linear relationships between the independent and dependent variables. Since such assumption of multiple regression did not meet, the researchers decided to transform the dependent variables.

After the transformation, all the assumptions for formulating multiple regression models were satisfied. The assumptions for normality and linearity were tested through graphical method, the test of independence was verified by Durbin-Watson Test, the homoscedasticity was tested by Levene's test, and the multicollinearity was verified through the Variance Inflation Factor (VIF) value.

TABLE 6
Pearson's Correlations Coefficients

	ln_death	ln_injuries	ln_affected_families	ln_total_damage
intensity	.340	.1*	.303	.469**
magnitude	.533**	.562**	.457*	.644**
depth	.016	.52	-.089	-.070
epicenter	.264	.42	.213	.213
duration	-.186	-.107	.509**	.320

**Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The table 6 shows that the transformed variable death was significantly correlated with magnitude. The transformed variable injuries were significantly correlated with intensity and magnitude. The transformed variable affected families were significantly correlated with magnitude and time duration. The transformed variable total damage was significantly correlated with intensity and magnitude.

7.4. Proposed Mathematical Models

7.4.1. Mathematical Model For Estimating Death

The least squares estimating equations $(X'X)b = X'y$

$$\begin{bmatrix} 30 & 205 & 199.6 & 710 & 111 & 14436.4 \\ 205 & 1429 & 1374.7 & 4813 & 758 & 101312 \\ 199.6 & 1374.7 & 1341.62 & 4818.8 & 735 & 100163.82 \\ 710 & 4813 & 4818.8 & 23980 & 2399 & 356200 \\ 111 & 758 & 735 & 2399 & 491 & 50919.8 \\ 14436.4 & 101312.2 & 100163.82 & 356200 & 50919.8 & 22596163.36 \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} = \begin{bmatrix} 56.56 \\ 407.78 \\ 399.52 \\ 1355.08 \\ 237.16 \\ 18521.53 \end{bmatrix}$$

and then, using the relation $b = (X'X)^{-1}X'y$, the estimated regression coefficients are obtained as:

$$b_0 = -13.405; b_1 = -0.001; b_2 = 2.214; b_3 = -0.013; b_4 = 0.374; b_5 = -0.001$$

The coefficients were obtained using MATLAB. Therefore, the number of persons killed in an earthquake event can be computed using the regression equation.

$$\ln \hat{y}_1 = -13.405 - 0.001x_1 + 2.214x_2 - 0.013x_3 + 0.374x_4 - 0.001x_5$$

This regression model yields the coefficient of determination $R^2 = 0.509$ which implied that 50.9% of the variation in the number of death during an earthquake is explained by the regression equation.

7.4.2. Mathematical Model For Estimating Injuries

The least squares estimating equations $(X'X)b = X'y$

$$\begin{bmatrix} 30 & 205 & 199.6 & 710 & 111 & 14436.4 \\ 205 & 1429 & 1374.7 & 4813 & 758 & 101312 \\ 199.6 & 1374.7 & 1341.62 & 4818.8 & 735 & 100163.82 \\ 710 & 4813 & 4818.8 & 23980 & 2399 & 356200 \\ 111 & 758 & 735 & 2399 & 491 & 50919.8 \\ 14436.4 & 101312.2 & 100163.82 & 356200 & 50919.8 & 22596163.36 \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} = \begin{bmatrix} 97.95 \\ 696.84 \\ 677.83 \\ 2481.22 \\ 389.79 \\ 41805.14 \end{bmatrix}$$

and then, using the relation $b = (X'X)^{-1}X'y$, the estimated regression coefficients are obtained as:

$$b_0 = -13.426; b_1 = 0.360; b_2 = 1.899; b_3 = 0.015; b_4 = 0.444; b_5 = -0.001$$

The coefficients were obtained using MATLAB. Therefore, the number of persons injured in an earthquake event can be computed using the regression equation

$$\ln \hat{y}_2 = -13.426 + 0.360x_1 + 1.899x_2 + 0.015x_3 + 0.444x_4 - 0.001x_5$$

This regression model yields the coefficient of determination $R^2 = 0.501$ which implied that 50.1% of the variation in the number of death during an earthquake is explained by the regression equation.

7.4.3. Mathematical Model for Estimating Affected Families

The least squares estimating equations $(X'X)b = X'y$

$$\begin{bmatrix} 30 & 205 & 199.6 & 710 & 111 & 14436.4 \\ 205 & 1429 & 1374.7 & 4813 & 758 & 101312 \\ 199.6 & 1374.7 & 1341.62 & 4818.8 & 735 & 100163.82 \\ 710 & 4813 & 4818.8 & 23980 & 2399 & 356200 \\ 111 & 758 & 735 & 2399 & 491 & 50919.8 \\ 14436.4 & 101312.2 & 100163.82 & 356200 & 50919.8 & 22596163.36 \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} = \begin{bmatrix} 99.30 \\ 716.64 \\ 700.58 \\ 2172.53 \\ 412.56 \\ 95469.76 \end{bmatrix}$$

and then, using the relation $b = (X'X)^{-1}X'y$, the estimated regression coefficients are obtained as

$$b_0 = -16.905; b_1 = 0.083; b_2 = 2.577; b_3 = -0.043; b_4 = 0.630; b_5 = 0.002$$

The coefficients were obtained using MATLAB. Therefore, the number of families that would be affected in an earthquake event.

The number of families that affected during an earthquake event can be computed using the regression equation

$$\ln \hat{y}_3 = -16.905 + 0.083x_1 + 2.577x_2 - 0.043x_3 + 0.630x_4 + 0.002x_5$$

This regression model yields the coefficient of determination $R^2 = 0.466$ which implied that 46.6% of the variation in the number of death during an earthquake is explained by the regression equation.

7.4.4. Mathematical Model for Estimating Total Cost of Damage

The least squares estimating equations $(X'X)b = X'y$

$$\begin{bmatrix} 30 & 205 & 199.6 & 710 & 111 & 14436.4 \\ 205 & 1429 & 1374.7 & 4813 & 758 & 101312 \\ 199.6 & 1374.7 & 1341.62 & 4818.8 & 735 & 100163.82 \\ 710 & 4813 & 4818.8 & 23980 & 2399 & 356200 \\ 111 & 758 & 735 & 2399 & 491 & 50919.8 \\ 14436.4 & 101312.2 & 100163.82 & 356200 & 50919.8 & 22596163.36 \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} = \begin{bmatrix} 65.83 \\ 486.15 \\ 472.67 \\ 1471.57 \\ 271.48 \\ 50130.28 \end{bmatrix}$$

and then, using the relation $b = (X'X)^{-1}X'y$, the estimated regression coefficients are obtained as

$$b_0 = -17.075; b_1 = 0.234; b_2 = 2.520; b_3 = -0.033; b_4 = 0.383; b_5 = 0.001$$

The coefficients were obtained using MATLAB. Therefore, that total cost of damage in an earthquake event can be computed using Thus, the regression equation that estimates total cost of damage is

$$\ln \hat{y}_4 = -17.075 + 0.234x_1 + 2.520x_2 - 0.033x_3 + 0.383x_4 + 0.001x_5$$

This regression model yields the coefficient of determination $R^2 = 0.564$ which implied that 56.4% of the variation in the number of death during an earthquake is explained by the regression equation.

8. SUMMARY OF FINDINGS

From the results of data analysis, the following are the findings of the study:

8.1. Characteristics of Earthquakes:

1. Fifty percent of the total considered earthquake events that hit the Philippines from 1968 to 2012 were of intensity seven. These earthquakes were classified by the PHIVOLCS as destructive.
2. The average magnitude of the earthquakes that were considered in the research was 6.65 Ms with standard deviation of 0.69. According to the Richter magnitude scale used by the PHIVOLCS, those seismic activities with magnitude 6 to 7 are the strong earthquakes
3. The average depth of considered earthquakes from 1968 to 2012 was 23.67 kilometers with standard deviation of 15.73. Shallow earthquakes are those quakes with depth ranges from 0 to 70 kilometers.
4. The thirty percent of the earthquakes considered in the study had epicenters at Zone Four (4) and that is in West Luzon Trench, whereas the double forearc associated with the Manila Trench.
5. The average duration of the earthquake considered in the study was 481.21 seconds with standard deviation of 734.59.

8.2. Damages Caused By Earthquakes

1. The average death owing to earthquakes was 187.03 as associated to the median 4, which is more lifelike estimate of death. The most number of deaths aroused during the Moro Gulf earthquake in August 17, 1976 which left 3,792 persons dead.
2. The mean of the number of people injured was 468.27. The largest number of injured also happened during the Moro Gulf earthquake in 1976 which had wounded 9,240 persons.
3. The average number of affected families was 13,188 families.
4. The cost of property damaged had a mean of P466.65M and a median of P4.98M. The largest cost of damages occurred in July 16, 1990 earthquake with epicentre at Cabanatuan City.

8.3. Proposed Mathematical Models

$$\ln \hat{y}_1 = -13.405 - 0.001x_1 + 2.214x_2 - 0.013x_3 + 0.374x_4 - 0.001x_5$$

$$\ln \hat{y}_2 = -13.426 + 0.360x_1 + 1.899x_2 + 0.015x_3 + 0.444x_4 - 0.001x_5$$

$$\ln \hat{y}_3 = -16.905 + 0.083x_1 + 2.577x_2 - 0.043x_3 + 0.630x_4 + 0.002x_5$$

$$\ln \hat{y}_4 = -17.075 + 0.234x_1 + 2.520x_2 - 0.033x_3 + 0.383x_4 + 0.001x_5$$

8.4. Significance of the Models

The first model estimates number of death and was significant with p-value of 0.003 with has a strong positive linear relationship with correlation coefficient of 0.713.

The second model predicts number of injured persons and was significant with p-value of 0.004 with has a strong positive linear relationship with correlation coefficient of 0.703.

The third model predicts number of families affected and was significant with 0.007 p-value and has a positive linear relationship with correlation coefficient $R = 0.682$.

The last regression model estimates total cost of damage and was significant with 0.001 p-value. This has strong positive linear relationship with correlation coefficient $R = 0.751$

9. CONCLUSION

Based on the findings of the study, the conclusions were drawn:

The assumptions for multiple linear regression guided the researchers to formulate mathematical models that estimate the casualties and cost of damage of an earthquake event. The deviation from linearity guided them to know if there are significant relationships between the independent and dependent variables. Since the assumption for linearity did not meet, the researchers decided to transform the dependent variables and thus, the mathematical models can be used to estimate earthquake casualties and cost of damages.

10. RECOMMENDATION

The researchers propose looking for another transformation process, wherein the researchers will obtain high value of coefficient of determination and also advocate adding more independent variables like local geotectonic settings, aftershocks etc., to assess the possible damages of an earthquake event more accurate.

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- [9] National Disaster Risk Reduction and Management Council