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Research Article

Ratio of the Dead to Wounded (D/W) Indicators and Associated Factors in Major Earthquakes of America from 1960 to 2011

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The paper presented deals with the casualties, mortality, and morbidity occurred during the major earthquakes of America during a period of 51 years. The work provides statistical evidence that the deaths/wounded (D/W) ratio used for many agencies in the planning of the preparation and response activities to earthquakes does not fit the relation 1 : 3. In addition, a model is presented in order to evaluate the possible association between different analysis variables such as the subregion of the American continent affected, population density, HDI, and the time and magnitude of the earthquake and the effects of these on the death toll, the number of the wounded, and the D/W indexes. Although the model generated it is not robust enough for decision making, it could be useful and improvable in order to apply it in the planning and management of these kinds of natural disasters. For these reasons, we think that it would be interesting to do further progress in this line of research by making a more comprehensive study of the variables associated with mortality and morbidity, using a more representative sample of earthquakes that sure will confirm the results presented in this work.

1. Introduction

Every year there are more than one million earthquakes in the world [1]. In the past decade the earthquakes caused more than 780,000 deaths. Among all natural catastrophes, such as floods, tornados, and avalanches, earthquakes have shown to be associated with higher mortality rates [2]. The impact of these events is increased when their occurrence triggers other events such as Tsunamis. The most conservative statistics have mentioned that, in the last 20 years, earthquakes have led to more than 500,000 deaths and more than 1,400,000 wounded, that is to say, one death for every three wounded [3, 4]. The most recent earthquakes with the higher numbers of deaths have occurred in 2003 in Bam (Iran) [5, 6], in 2005 Kashmir (Pakistan) [7–9], in 2008 Sichuan (China) [10–14], and in 2010 Haiti [15]. Several factors have been described as responsible for the high mortality and morbidity of earthquakes. However, among these factors intrinsic factors like their magnitude, the location (urban-rural), the epicentre, the distance between the population affected to the epicentre, the depth, and the time at which the earthquake occurs (day or night) and extrinsic factors, such as the preparation of the populations for this phenomenon (mitigation measures) [1], the type of house, and the population density, are the most considered influencing and associated variables with the mortality during and after earthquakes [16].

In the specialized literature and technical reports about earthquakes it is considered that for each death counted in an earthquake there are three wounded people (1 : 3) [3]. However, as a consequence of the lack of solid statistical and epidemiological evidences, this is the relation used during the planning of the preparation and the response activities to this kind of phenomena. Despite the extended use of this 1 : 3 relation, in an earthquake the number of the dead and wounded and the D/W index could vary as a function of the regions where earthquakes occur. For these reasons, it is extremely necessary to evaluate whether the behaviour of the D/W index is similar in all America. The purpose of this study was in a first step to evaluate whether the ratio 1 : 3 that defines the D/W index was in agreement with the collected data of the earthquakes in the different subregions of America and in second place to evaluate the variables that could be associated with and affecting this index through its impact on the number of deaths and the wounded during an earthquake from this region.

2. Materials and Methods

2.1. Study Design. This study is an analytical cross-sectional study.

2.2. Population. The population studied is represented by the number of earthquakes with high mortality and morbidity that occurred during 51 years, from 1960 to 2011, in the four subregions of America Continent (North America, Central America, South America, and the Caribbean Basin).

2.3. Sampling Design. A proportional stratified sampling was applied, with the selection of the primary sampling units (subregions of America) in a proportional way and the last units (earthquakes) selected according to their greater impact in terms of the number of deaths and the wounded.

2.4. Sample Size. A sample of each subregion of America was taken, as a function of the mortality of the earthquakes, following the next expression:

$$n = N \times \frac{z_{\alpha/2}^2 P(1-P)}{e^2(N-1) + z_{\alpha/2}^2 P(1-P)}, \quad (1)$$

where N is the total number of earthquakes that occurred in the period analysed for each subregion of America, $z_{\alpha/2}^2$ is 1.96 for a 95% confidence interval, e is the sampling error adjusted to 11.5% because of deficiency of the sample, and P is the prevalence of earthquakes with high mortality and morbidity.

A total of 202 earthquakes in 51 years of study were included and distributed between the different subregions as follows: $N_1 = 70$ in Central America, $N_2 = 94$ in South America, $N_3 = 28$ in North America, and $N_4 = 10$ in the Caribbean Basin. Because of the absence of information about the proportion of earthquakes with a high mortality and high number of wounded people the value of P was set as 50%.

2.5. Variables Studied. From each selected earthquake, the number of deaths (D) and the wounded (W) was selected from databases and the D/W index was calculated. In addition, some variables that could be associated with this index were included in the study. Among the variables studied there are (1) the population density of the different subregions of America, (2) the Human Development Index (HDI) of the countries affected, (3) the time slots from 06:00 am to 05:59 pm (day) or from 06:00 pm to 05:59 (night) in which the earthquake took place, and (4) the magnitude of the earthquake according to Richter scale.

2.6. Databases. The values of D (number of deaths) used in this work for the calculation of the D/W indexes were obtained from the databases of the Centre for Research on Epidemiology of Disasters (CRED) while the values of W (number of wounded) were obtained from the five sources of information listed in the Section 2.7.

2.7. Sources of Information. Five sources of information were used in the development of the present work: The National Geophysical Data Centre (NGDC) of the National Oceanic and Atmospheric Administration (NOAA), official reports of the National Emergency and Disaster Agencies of each of the affected countries, official reports of the Ministries of Health of each country affected, technical reports that referred to either of the two previous types of reports, and The United Nations Development Program (UNDP).

2.8. Definitions

Number of Deaths (D). It is the number of deceased people recorded in each report of each earthquake studied.

Number of the Wounded (W). It is the number of injured people recorded in each of the earthquake studied, without any other type of operational definition.

D/W Index. It is the ratio between the number of deceased people and the number of injured people during an earthquake. Theoretically this ratio was set as 1 : 3 and constitutes a lethality indicator of the earthquakes [3].

Population Density. It is the rate calculated as the size of the population affected by an earthquake divided by the geographic extension of each of the territories affected in the year in which the earthquake took place. This variable was built from the population registered by the National Institute of Statistics of each country (census data) at the administrative level required (departmental, regional, state, or province level) and the geographic extension of each territory affected. In the years in which there was no census information, the census data from the most proximate date of the earthquake was used. An average of the population size was used in the cases in which the earthquake affected more than one population.

Human Development Index (HDI). It is a combined index measuring the average of the human development success in

Table 1: Summary of the Richter scale for the earthquakes, their effects, and the estimated frequency of occurrence [18].

Magnitude	Average earthquake effects	Average frequency of occurrence (estimated)
<2.0	Microearthquakes. Not felt or felt rarely by sensitive people. Recorded by seismographs.	Continual/several million per year
2.0–2.9	Minor earthquakes. Felt slightly by some people. No damage to buildings.	>1 million per year
3.0–3.9	Minor earthquakes. Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.	>100,000 per year
4.0–4.9	Light earthquakes. Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage, very unlikely. Some objects may fall off shelves or be knocked over.	10,000–15,000 per year
5.0–5.9	Moderate earthquakes. Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone. Casualties range from none to a few.	1,000–1,500 per year
6.0–6.9	Strong earthquakes. Damage to a moderate number of well-built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly designed structures receive moderate to severe damage. Felt in wider areas, up to hundreds of miles/kilometers from the epicenter. Strong to violent shaking in epicentral area. Death toll ranges from none to 25,000.	100–150 per year
7.0–7.9	Major earthquakes. Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicenter. Death toll ranges from none to 250,000.	10–20 per year
8.0–8.9	Great earthquakes. Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake resistant buildings. Damaging in large areas. Felt in extremely large regions. Death toll ranges from 1,000 to 1 million.	1 per year
9.0 and greater	Near or at total destruction to severe damage or collapse to all buildings. Heavy damage and shaking extend to distant locations. Permanent changes in ground topography. Death toll usually over 50,000.	1 per 10–50 years

three basic dimensions: long and healthy life, knowledge, and standard level of dignified live [17]. In our work the HDI was used operationally as an approach to an index of the housing quality due to the absence of a standardized index of the housing quality for all of countries.

Time Slots of the Earthquake. They represent time or moment in which the earthquake occurred expressed in hours and minutes according to an approximately day-light of twelve (12) hours (from 06:00 am to 05:59 pm) and a night of approximately twelve (12) hours (from 06:00 pm to 05:59 am). The value of this variable was determined through the information obtained from time of the earthquake.

Magnitude of the Earthquake. It is the quantity or amount of energy that is released during an earthquake, measured through Richter scale. Table 1 shows the Richter scale and descriptions of the effects of earthquakes with different magnitudes [18].

2.9. Statistical Analysis

2.9.1. Descriptive Analysis. In order to test the 1 : 3 D/W ratios, the number of deaths and the number of the wounded were determined and D/W indexes were calculated for each earthquake included in the study, and their behaviour was analysed for the different subregions of America (North America, Central America, South America, and the Caribbean Basin). Measures of central tendency (media and median), dispersion (variance and standard deviation) and 95% confidence intervals ($CI_{95\%}$) for the D/W indexes, number of deaths, and number of the wounded were calculated. The data variability required its distribution into tertiles and then three scenarios according to the degree of mortality of the earthquakes were established. Scenario 1 corresponds to earthquakes with the minor number of mortality (tertile 1), Scenario 2 corresponds to an event with a moderate mortality (tertile 2), and Scenario 3 corresponds to earthquakes of high mortality (tertile 3).

2.9.2. Test for Hypothesis Contrast. The statistical significance of D/W indexes was established through testing of population media of these indexes (μ) with a confidence of 95%. The rules of decision for the hypothesis contrast of the D/W indexes for Central and South America were as follows:

$$H_0 : \mu_{(\mathrm{D/W})} = 1 : 3$$
$$H_1 : \mu_{(\mathrm{D/W})} \neq 1 : 3. \quad (2)$$

After calculation of the P value, a value of $P < 0.05$ for the statistics was considered as significant, causing the rejection of the null hypothesis (H_0).

2.9.3. Multiple Linear Regression. A multiple linear regression was used to evaluate the possible association between the analysis variables (subregion of the American continent, population density, HDI, and time and magnitude of the earthquake) and the number of deaths, the number of the wounded, and the D/W index.

The multiple linear regression model used was

$$\ln(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \beta_{k+1} C + \beta_{1c} X_1 C + \beta_{2c} X_2 C + \cdots + \beta_{kc} X_k C + \varepsilon, \quad (3)$$

where β_i are defined as the coefficients of the model, X_i are defined as the regressed variables, and $\ln(Y)$ is defined as the Neperian logarithm transformation of the "dependent variable" expressed as the number of deaths, number of the wounded, or number of deaths out of number of the wounded. Dependent variable was transformed due to the high variability in the number of cases (Table 2). C represents the variable "subregion of the American continent" which adopts discrete values between 0 (Central America) and 1 (South America) and β_{ic} represents the coefficients of the model when interaction of these coefficients with the variable "subregion of the American continent" occurs. These coefficients of interaction were introduced in the model because of the different behavior according to the subregion analyzed.

In the case of the earthquakes from Central America, the multiple linear regression model was expressed as follows:

$$\ln(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \varepsilon. \quad (4)$$

For South America, the expression of the model was

$$\ln(Y) = (\beta_0 + \beta_{k+1}) + (\beta_1 + \beta_{1c}) X_1 + (\beta_2 + \beta_{2c}) X_2 + \cdots + (\beta_k + \beta_{kc}) X_k + \varepsilon. \quad (5)$$

When the variable was qualitative or categorical and binary or dichotomical ("Dummy variable") it was calculated as $Y(X_i = 1)/Y(X_i = 0) = \exp(\beta_i)$ and as $Y(X_i = c + \Delta)/Y(X_i = c) = \exp(\beta_i \Delta)$ if the regressed variable was continuous, where Δ represents the unity or fraction of increase for the regressed variable under study. For these reasons, the exponential of the coefficient $\beta_i(e^{\beta_i})$, represents the increase (>1) or the decrease (<1) of the dependent variable (number of deaths, number of the wounded, and D/W index).

3. Results

3.1. Earthquakes Sampling. As a result of sample calculations, a sample design of $n = 85$ earthquakes must be studied. Earthquakes were distributed between the four subregions of America according to Central America ($n_1 = 36$), South America ($n_2 = 41$), North America ($n_3 = 20$), and the Caribbean Basin ($n_4 = 8$). As a consequence of the very low number of the earthquakes registered in the Caribbean Basin and because of the low mortality of the earthquakes in North America subregion during the study period, the Caribbean Basin and North America were excluded from the study. Then the number of earthquakes samples taken was $n = 77$: ($n_1 = 36$) in Central America and ($n_2 = 41$) in South America.

3.2. Descriptive Analysis. Although four different scenarios were developed with data from the four subregions of America, data obtained from the number of deaths, number of the wounded, and the D/W index calculation were only useful in the case of the Central and South America subregions. The low number of earthquakes registered in the Caribbean Basin does not allow us to generate a scenario and the use of data generated could result in spurious associations. Furthermore, the low earthquake mortality registered in North America does not allow its use either. For these reasons, only the earthquakes from Central and South America and the three scenarios defined in Materials and Methods were analysed.

The descriptive analysis of the number of deaths and the wounded, for the three scenarios of earthquakes that occurred in Central and South America (Table 2), shows a big variability for Scenario 3. In this regard, the number of deaths in Central America varies from 45 to 23,000 while in South America it varies from 120 to 66,790. The number of the wounded as a consequence of the earthquakes in both subregions shows also a big variability, from 350 to 76,000 (Central America) and 1,200 to 150,000 (South America). Earthquakes from Central America caused an average of 1,332 deaths (SD = 4,475) and 5,632 wounded people (SD = 17,530). In South America the average of number of deaths and wounded people was 1,575 (SD = 8,701) and 5,105 (SD = 23,173), respectively.

Results summarized in Table 3 confirm that in Central and South America, only for Scenario 3 (earthquakes of high mortality), a D/W index of 1 : 3 (1 death per 3 wounded people) could be established. Scenario 1 (earthquakes of very low mortality) shows the highest variability and Scenario 2 (earthquakes with moderate mortality) shows the same behaviour of the D/W index in both subregions of the continent.

3.3. Hypotheses Contrast of $\mu_{(D/W)}$ Indexes. The hypotheses contrast under the null hypothesis (H_0) of a $\mu_{(D/W)} = 1:3$ shows that there are significant differences between the indexes calculated for the subregions of Central and South America ($P < 0.05$). As a consequence of this, H_0 (1 death per 3 wounded people) was rejected and the conclusion is that in Central America the relation 1 : 3 does not apply. As it is shown in Table 3 this result was supported by the fact that the value of $\mu_{(D/W)} = 0.333$ is not included inside the $CI_{95\%}$. In addition this ratio applies for the earthquakes that occurred in South America because the value of $\mu_{(D/W)} = 0.333$ is included inside the $CI_{95\%.}$

3.4. Variables Associated with the Number of Deaths and the Wounded and D/W Indexes. In Table 4 the procedure and the linear regression models of the dependent variables for Central and South America are shown. Table 5 shows the results of linear regression of the variables analysed (population density, magnitude and time slots of the earthquake, DHI, and subregions of the continent where earthquakes occurred).

Table 2: Scenarios for the indicators of deaths and the wounded distributed by tertiles for earthquakes from Central and South America subregions during the 1960–2011 period.

Central America subregion (D/W)					
Deaths	Min.	1	Scenario 1 (1–6)		
	Tertile 1	6		Scenario 2 (7–31)	
	Tertile 2	31			Scenario 3 (45–23,000)
	Max.	23,000			
	Media	1,332			
	Media ($CI_{95\%}$)	(1,310; 1,355)			
	Median	16			
	STD	4,475			
	Variance	20028389			
The wounded	Min.	5	Scenario 1 (5–78)		
	Tertile 1	78		Scenario 2 (96–300)	
	Tertile 2	300			Scenario 3 (350–76,000)
	Max.	76,000			
	Media	5,633			
	Media ($CI_{95\%}$)	(5,588; 5,677)			
	Median	193			
	STD	17,530			
	Variance	307317125			
South America subregion (death and wounded)					
Deaths	Min.	2	Scenario 1 (2–34)		
	Tertile 1	34		Scenario 2 (40–112)	
	Tertile 2	112			Scenario 3 (120–66,790)
	Max.	66,790			
	Media	1,881			
	Media ($CI_{95\%}$)	(1,850; 1,912)			
	Median	64			
	STD	8,701			
	Variance	75701277			
The wounded	Min.	15	Scenario 1 (15–200)		
	Tertile 1	200		Scenario 2 (207–1,000)	
	Tertile 2	1,000			Scenario 3 (1200–150,000)
	Max.	150,000			
	Media	5,105			
	Media ($CI_{95\%}$)	(5,059; 5,151)			
	Median	300			
	STD	23,176			
	Variance	537134047			

As it can be seen in Table 4, when the calculation of the complementary of the ratio $D_{(18:00-06:00 \text{ hours})}/D_{(06:00-18:00 \text{ hours})}$ for the Central America earthquakes is done as follow: $1 - D_{(18:00-06:00 \text{ hours})}/D_{(06:00-18:00 \text{ hours})}$, a value of $0.8842 = 1 - e^{-2.156}$ is obtained. Then we can conclude that, in this subregion, death toll would be reduced by 8.8% when earthquakes occur at night (18:00–06:00) rather than during the day (06:00–18:00). In the case of the earthquakes that occurred in South America subregions, it was necessary to include the subregion factor in the model.

Analysing the effects of the regression variables on the dependent variables, Table 5 shows that, for each Richter

Table 3: Scenarios for the D/W index distributed by tertiles for earthquakes from Central and South America subregions during the 1960–2011 period.

Central America subregion (D/W)				
Min.	0.003 (1 D : 333 W)	Scenario 1 (1 D : 333 W–1 D : 19 W)		
Tertile 1	0.052 (1 D : 19 W)		Scenario 2 (1 D : 18 W–1 D : 5 W)	
Tertile 2	0.208 (1 D : 5 W)			Scenario 3 (1 D : 4 W–1 D : 2 W)
Max.	0.600 (1 D : 2 W)			
Media	0.178 (1 D : 6 W)			
Media ($CI_{95\%}$)	(0.038; 0.310)			
Median	0.136 (1 D : 7 W)			
STD	0.164 (1 D : 6 W)			
Variance	0.027 (1 D : 37 W)			
South America subregion (D/W)				
Min.	0.011 (1 D : 91 W)	Scenario 1 (1 D : 91 W–1 D : 12 W)		
Tertile 1	0.208 (1 D : 12 W)		Scenario 2 (1 D : 11 W–1 D : 4 W)	
Tertile 2	0.246 (1 D : 4 W)			Scenario 3 (1 D : 4 W–1 D : 0.25 W)
Max	3,860 (1 D : 0.25 W)			
Media	0.368 (1 D : 3 W)			
Media ($CI_{95\%}$)	(0.099; 0.589)			
Median	0.142 (1 D : 7 W)			
STD	0.658 (1 D : 2 W)			
Variance	0.433 (1 D : 2 W)			

Table 4: Linear regression models for the number of deaths and the wounded and D/W indexes that occurred in Central and South America subregions during the 1960–2011 period.

	America subregions
Dependent variables	Central America
Deaths (D)	$\ln(D) = (-2.659 + 0.0015) \times$ P. density $+ (0.951) \times$ Magnitude* $- (2.156) \times$ Time + Error For the analysis of the death toll as a function of the time of the earthquake in Central America, the next procedure was done: $D_{(18:00-06:00\ \text{hour})} = e^{(-2.659+0.0015)\times\text{Population density}+(0.951)\times\text{Richter magnitude}-(2.156)+\text{Error}}$ $D_{(06:00-18:00\ \text{hour})} = e^{(-2.659+0.0015)\times\text{Population density}+(0.951)\times\text{Richter magnitude}+\text{Error}}$ Calculating the ratio $D_{(18:00-06:00\ \text{hour})}/D_{(06:00-18:00\ \text{hour})}$ $D_{(18:00-06:00\ \text{hour})}/D_{(06:00-18:00\ \text{hour})} = e^{-2.156} = 0.1158$
The wounded (W)	$\ln(W) = (-1.000 + 0.0011) \times$ P. density $+ (0.765) \times$ Magnitude* $- (2.047) \times$ Time + Error
D/W indexes	$\ln(D/W) = (40.706 - 5.164)$ HDI + Error
Dependent variables	South America
Deaths (D)	$\ln(D) = (-2.659 + 0.903) + (0.0015 + 0.0006) \times$ P. density $+ (0.951 - 0.084) \times$ Magnitude* $+ (-2.156 + 2.194) \times$ Time + Error $\ln(D) = (-1.756 + 0.0021) \times$ P. density $+ (0.867) \times$ Magnitude* $+ (0.038) \times$ Time + Error
The wounded (W)	$\ln(W) = (-1.000 + 0.0024) \times$ P. density $+ (1.006) \times$ Magnitude* $- (0.094) \times$ Time + Error
D/W indexes	$\ln(D/W) = (40.706 - 5.164)$ HDI + Error

*Richter degrees.

TABLE 5: Results and interpretation of the multiple linear regression of the ln of death toll, number of wounded people, and D/W indexes.

(a)

	Neperian logarithm of number of deaths (D)			Neperian logarithm of number of the wounded (W)			Neperian logarithm of D/W		
	Coef.	t	Signif.	Coefficient	t	Signif.	Coef.	t	Signif.
Constant	−2.659	−0.891	0.376	1.000	0.374	0.710	40.706	2.088	0.040
Population density	**0.0015**	**2.901**	**0.005**	0.0011	2.272	**0.026**			
Earthquake magnitude (Richter degrees)	**0.951**	**2.186**	**0.032**	0.765	1.965	**0.053**			
Time (18:00–06:00)	**−2.156**	**−3.243**	**0.002**	−2.047	−3.437	**0.001**			
South America subregion	0.903	0.254	0.800	−1.729	−0.540	0.591			
Population density × South America subregion	0.0006	0.280	0.781	0.0014	0.745	0.459			
Richter degree × South America subregion	−0.084	−0.164	0.871	0.241	0.521	0.604			
Time (18:00–06:00) × South America subregion	**2.194**	**2.422**	**0.018**	**1.953**	**2.386**	**0.020**			
Human Development Index							**−5.164**	**−2.231**	**0.029**

(b)

Indicator	Subregion	Variable	Exponential	Relative variation $\exp(B) - 1$	Interpretation
Deaths (D)	Central America	Population density	exp(0.0015) = 1.0015	0.0015	For every unit of increase in the population density, death toll would be increased 0.15%
		Magnitude (Richter degrees)	exp(0.951) = 2.5883	1.5883	For every Richter degree increased, death toll would be increased 158%. The number of deaths would be more than double.
		Time (18:00–06:00)	exp(−2.156) = 0.1158	−0.8842	When earthquakes took place at night (18:00–06:00) death toll would be reduced in 88%.
	South America	Densidad Poblacional	exp(0.0021) = 1.0021	0.0021	For every unit of increase in the population density, death toll would be increased in 0.21%.
		Magnitude (Richter degrees)	exp(0.867) = 2.3787	1.3787	For every Richter degree increased, death toll would be increased in 137%. The number of deaths would be more than double.
		Time (18:00–06:00)	exp(0.038) = 1.0039	0.0039	When earthquakes took place at night (18:00–06:00) death toll would be increased in 0.39%.
The wounded (W)	Central America	Population density	exp(0.0011) = 1.0011	0.0011	For every unit of increase in the population density, the number of the wounded would be increased in 0.11%
		Magnitude (Richter degrees)	exp(0.765) = 2.1490	1.1490	For every Richter degree increased the number of wounded people would be increased in 114% (more than double).
		Time (18:00–06:00)	exp(−2.047) = 0.1291	−0.8709	When earthquakes took place at night (18:00–06:00) the number of wounded people would be reduced in 87.09%.

(b) Continued.

Indicator	Subregion	Variable	Exponential	Relative variation $\exp(B) - 1$	Interpretation
	South America	Population density	$\exp(0.0024) = 1.0024$	0.0024	For every unit of increase in the population density, the number of wounded people would be increased 0.24%
		Magnitude (Richter degrees)	$\exp(1.006) = 2.7348$	1.7348	For every Richter degree increased, the number of wounded people would be increased 173% (more than three times).
		Time (18:00–06:00)	$\exp(-0.094) = 0.9104$	−0.0896	When earthquakes took place at night (18:00–06:00) the number of wounded people would be reduced in 8.96%.
D/W	Central and South America	Human Development Index	$\exp(-5.164 * 0.01) = 0.9497$	−0.0503	For every 0.01 of increase in the IDH, the D/W index would be reduced in 5.03%.

degree raised in the earthquake magnitude, death toll and number of the wounded would be increased by more than 100%, 158% for Central America and 137% for South America subregion. Furthermore, in the Central America subregions, for every unit of increase in the population density, the death toll would be increased by 0.15% and the number of the wounded would be increased by 0.11%. According to the model for the earthquakes of the South America subregion, this increase in the death toll (0.21%) and the number of the wounded (0.24%) was slightly higher than in Central America subregion.

When the effect of the variable time in which the earthquakes occur (or in other words if the earthquake occurs during the day or the night) was analysed, a different behaviour could be found between the two subregions under study. In Central America when the earthquakes take place at night (18:00–06:00 hours), a decrease by 88% in the death toll and by 87% in the number of the wounded was registered. In contrast in the South America region, if the earthquakes take place at night (18:00–06:00 hours), the death toll increases by 0.39% and the number of the wounded decreases by 8.9%. These differences between Central and South America subregions could be explained by the variability registered for the median of the death toll and the number of the wounded (Figure 1).

Analysing the effect of these variables on the multiple linear regression model of the D/W indexes, the only significant variable in the model was the HDI. In this regard, for every hundredth (0.01) of increase in the HDI, the ratio of deaths: the wounded would decrease by 5.03%. The predictive value of the model generated from the variables studied was 53.2% for the death toll and 53.9% for the number of the wounded. The D/W index provided a 44.7% of the prognostic value.

4. Discussion

The analysis of earthquakes that occurred in the last 51 years in Central and South America has shown that the ratio of deaths: the wounded (D/W) was not in agreement with the behaviour 1D : 3W previously described [3]. In this regard, there is a wide variability not only in America but also in subregions analysed (Central and South America). This variability makes it difficult to establish a unique and reproducible ratio for the whole continent and it is only in agreement with the average of the earthquakes that occurs in South America but not in Central America.

As it was explained in Materials and Methods, D/W indexes could not be tested for North America and Caribbean Basin subregions because of the low death toll registered in the North America earthquakes and due to sample deficiency in the case of the earthquakes in the Caribbean Basin. According to our analysis, the death toll and the number of the wounded caused by earthquakes in Central and South America were associated with the population density, the time (day or night) in which the earthquake occurs, and the magnitude of these events. In contrast with the death toll and the number of wounded people, the D/W indexes were only associated with the HDI. In this regard, a concomitant increase in the D/W indexes was a consequence of the increase in the HDI, which means that the number of people wounded increases with regard to the number of dead people.

Although there are wide-ranging evidences about the effect that an earthquake has on the death toll and the number of wounded people as a function of the design and type of construction, the lack of standardized data does not allow evaluating the effects of housing quality over the D/W indexes. For these reasons, it would be interesting to conduct research on this matter. An improvement in the HDI, besides an improvement of the housing, could also bring the best response to the natural disasters, since it has been shown that the impact of mitigation measures of these events have reduced the mortality and morbidity.

In this regard, considering the HDI as an operational approach to the quality of housing, the results obtained in our work allow us to suggest that the improvement of HDI was in close relation with the quality of housing. This information is

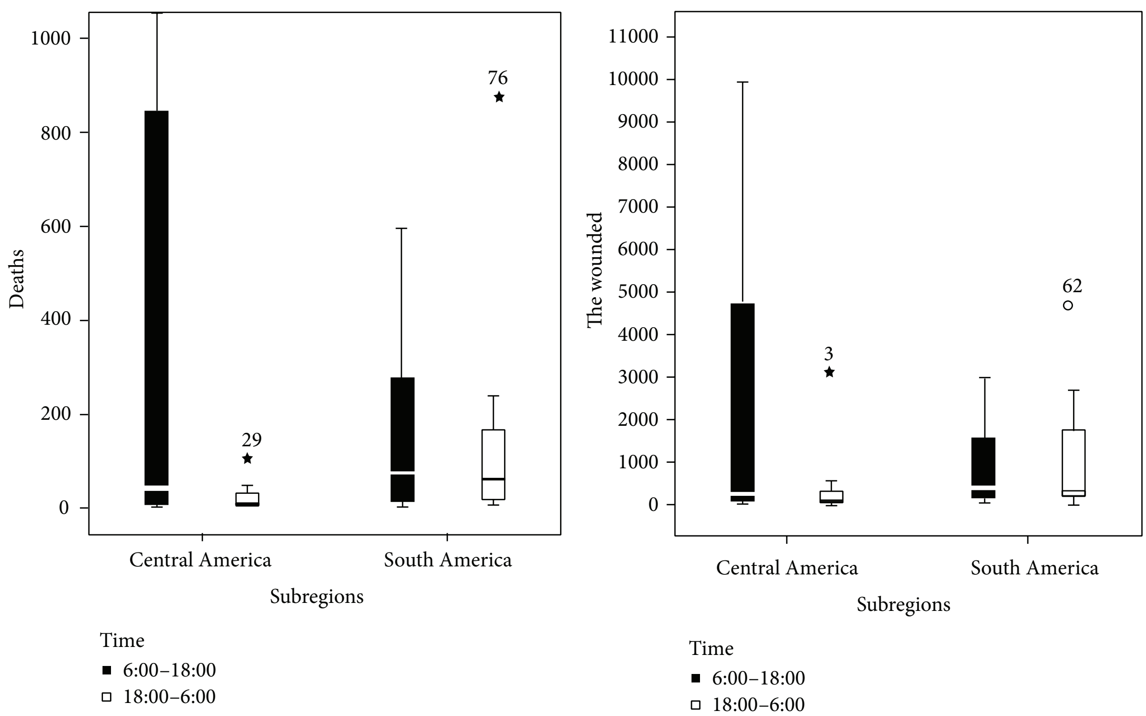

Figure 1: Box-Whiskers plot for the death toll and the number of the wounded in the earthquakes from Central and South America subregions during 1960–2011.

in agreement with some studies that suggest an association between the quality and the height of the buildings and the mortality after an earthquake. These studies have concluded that the higher the quality of housing is, the lower the death toll is [19, 20]. Furthermore, the greater the height of buildings, the greater the death toll that occurs after an earthquake [21].

When the effect of the population density was analyzed through the multiple linear regression, it has been observed that a unit of increase in this variable causes an increase in the death toll and the number of the wounded. Similar results were reported in works about the relationship between population density [22, 23], quality of housing, and mortality [24, 25]. However, few papers discussed the effects of the increase on the number of wounded people.

In our work the effect of the earthquake magnitude on the death toll and number of wounded people was analyzed. Our results of the effect of the magnitude on the mortality are in agreement with Tiedemann [26], Noji et al. [25], and Alexander [3]. Furthermore our results of the effect on the morbidity are in agreement with Tiedemann [26] and Jin et al. [27]. In this regard, a rise of one Richter degree could result in an increase of up to twofold in the death toll and the number of wounded people.

The time of day in which earthquake occurs has also been associated with increased death toll [16]. In this respect, it has been assumed that earthquakes that occur during the day could generate higher mortality. As a consequence of this fact and based on our observations, in our work earthquakes were classified according to the time of occurrence, ranking events produced during the day or in the evening. Results show that, in Central America, the death toll and the number of the wounded were reduced if the earthquake occurs at night, while an opposite effect was observed for South America's earthquakes, in which although the number of the wounded shows a small decrease, the death toll shows a slight increase.

There are some factors considered as determinants of damage to buildings (which is the leading cause of injury and deaths after earthquakes). Among these factors we can describe variables, such as the distance to the epicenter, the geological features of the place where earthquakes occur, and the proximity to health services, which can act as modifiers increasing or decreasing the effect of an earthquake on the death toll [28]. However, the lack of information on these variables not only prevented their inclusion in the model but also the analysis of their effects on the dependent variables studied.

As an example of the influencing effect of these factors, we can mention that in the earthquake occurred in Wenchuan County (South east of China) [27], in spite of occurring in a low population density place, death toll was high due to the poor access to health services.

Despite the fact that in our work these variables could not be included, it could be possible that they interact on the indicators analyzed (death toll, number of wounded people, and D/W indexes) acting as confounding variables of the other variables included in the model such as the time at which the earthquake occurs.

Among the limitations of our study, we can mention the difficulties in finding common standardized indicators for all countries. Furthermore, by analyzing many earthquakes in different geographic areas of America during a 51-year period, there may be confounders or effect modifiers that we cannot quantify. These factors would influence our results and complicate the interpretation thereof.

Finally, despite the limitations of our study, we can conclude that our work provides an evidence that the D/W (1 : 3) managed by some specialized agencies not only is subjected to an enormous variability but also it only fits for the earthquakes occurred in the South America subregion. On the other hand the use of the operational approach of the HDI to the quality of housing [17] could demonstrate that HDI was the only variable associated with the D/W index. In addition, it has also been demonstrated that the number of wounded people and death toll, separately, could be differentially associated with variables such as population density and magnitude and time in which earthquakes occur in Central and South America.

Because of the 44.7% of predictive value of our model, we can also conclude that although it is not robust enough for decision making, it could be useful and improvable in order to apply it in the planning and management of these kinds of natural disasters. For these reasons, it would be interesting to do further progress in this line of research by making a more comprehensive study of the variables associated with mortality and morbidity using a more representative sample of earthquakes that sure will confirm the results presented.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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