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MODEL FOR DETERMINING SOCIAL VULNERABILITY AND FLOOD RISK IN THE CHINANDEGA-LEÓN HYDROLOGICAL UNIT (NICARAGUA) AS A STRATEGY FOR ADAPTATION TO CLIMATE CHANGE

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Abstract. The main interest of this research work is to promote scientific exchange on issues of the regional agenda and the socioeconomic development of the Central American region, facilitating a result through a novel model in a practical way, generating new ideas and knowledge that allows the continuous improvement, to face the new challenges and challenges related to climate change and comprehensive disaster risk management. The article shows the conceptual bases, the methodology used, the results and conclusions of a model used to determine social vulnerability and risk of flooding in the Chinandega-León hydrological unit, as a strategy for adaptation to climate change, Nicaragua. As a conclusion in the framework of SDGs 11 and 13, it was evidenced that the proposed model is this research work, it contributes to scientific knowledge for local, regional and national planning that involves mitigation of climate change, adaptation and adaptation. disaster resilience. It is emphasized that the management of social vulnerability was made as a variable of greater importance, since it is where the harmonization of the passive agent (society) with the active agent (natural environment) is based. On the other hand, the quantification of social vulnerability and risk as variables, and that they are directly proportional, is demonstrated. The variables that affect the reduction of vulnerability are those that are related to climate change adaptation variables, resilience (harmonization) and social preparedness.

Keywords: Risk, Climate change, model, social vulnerability, flood, threat.

MODELO PARA LA DETERMINACIÓN DE LA VULNERABILIDAD SOCIAL Y RIESGO POR INUNDACIONES EN LA UNIDAD HIDROLÓGICA CHINANDEGA-LEÓN (NICARAGUA) COMO ESTRATEGIA DE ADAPTACIÓN AL CAMBIO CLIMÁTICO

Resumen: El principal objetivo del presente trabajo de investigación, es promover el intercambio científico en temas de la agenda regional y el desarrollo socioeconómico de la región centroamericana, facilitando un resultado por medio de un modelo novedoso de manera práctica, generando nuevas ideas y conocimientos que permita la mejora continua, para enfrentar los nuevos retos y desafíos relacionados con el cambio climático y la gestión integral del riesgo de desastre. Como objetivos específicos, el artículo muestra las bases conceptuales, la metodología empleada, los resultados y conclusiones de un modelo empleado para la determinación de la vulnerabilidad social y riesgo por inundaciones en la unidad hidrológica Chinandega-León, como una estrategia de adaptación al cambio climático, Nicaragua. Como conclusión, en el marco de los Objetivos de Desarrollo Sostenibles 11 y 13, se evidencio que el modelo propuesto en este trabajo de investigación, aporta a los conocimientos científicos para la planificación local, regional y nacional que involucran la mitigación ante el cambio climático, la adaptación y la resiliencia ante desastres. Se enfatiza el aporte como el manejo de la vulnerabilidad social como una variable de mayor importancia, ya que es donde se sustenta la armonización del agente pasivo (sociedad) con el agente activo (medio natural). Por otro lado, se obtuvo la cuantificación de la vulnerabilidad social y el riesgo como variables, y que son directamente proporcionales. Las variables que inciden en la disminución de la vulnerabilidad, son las que están relacionadas llamadas variables de adaptación al cambio climático, la resiliencia (armonización) y la preparación social.

Palabras clave: Riesgo, cambio climático, modelo, vulnerabilidad social, inundación, amenaza.

Introduction

According to the National Climatic Data Center of the National Oceanic and Atmospheric Administration (National Climatic Data Center, 1999):

> Hurricane Mitch is among the five strongest hurricanes on record in the Atlantic in terms of sustained winds, barometric pressure and duration. Hurricane Mitch was also one of the worst storms in the Atlantic in terms of loss of human life and property. The estimated death toll throughout the region was more than 9,000; thousands of people were reported missing. Economic losses throughout the region were estimated at more than $7.5 billion (U.S. Agency for International Development, 1999) (Smith, et al., 2002, p. 1).

The National System for the Prevention, Mitigation and Attention to Disasters (SINAPRED), in 2019 developed the project "Analysis and Incorporation of Disaster Risk Management in Municipal Planning in Nicaragua", in addition to which the Guidelines for Municipal Plans for Integrated Risk Management (PMGIR) were developed. "The methodology aims to guide and define the minimum procedures required for Disaster Risk Analysis and Management at the municipal level and for the preparation of Municipal Plans for Integrated Disaster Risk Management (PMGIR), in order to ensure their insertion into the municipal development plan (PDM), incorporating disaster prevention and mitigation measures, Land Use Planning and Zoning proposals" (SINAPRED, 2019, pp. 34-39).

In 2011, the Ministry of Environment and Natural Resources, together with the General Directorate of Climate Change, developed workshops linked to the project in the study area (Leon-Chinandega hydrological unit):

> Flood and Drought Risk and Vulnerability Reduction Project in the Estero Real River Basin. The project aimed to reduce the risks of droughts and floods generated by climate change in the Estero Real river basin. Although all of Nicaragua faces the severe impacts of extreme natural phenomena, droughts and floods are combined in the selected region (Marena, 2011, pp. 6-7).

On the other hand, SINAPRED of Nicaragua has a risk management manual, which addresses the subject from the point of view of management, prevention and emergency preparedness. There are publications on the mainstreaming of climate change in Nicaragua (PENUD, 2010), however, the quantification of risk and social vulnerability is not addressed from the point of view of a model for determining social vulnerability and flood risk in the Chinandega-León hydrological unit, as a strategy for adaptation to climate change in Nicaragua.

Within the framework of Sustainable Development Goals 11 and 13, sustainable cities and communities, and climate action, respectively, a model was developed to determine social vulnerability and flood risk in the Chinandega-Leon hydrological unit, as a strategy for adaptation to climate change in Nicaragua. The work was developed in a comprehensive manner, which includes the elements of risk such as hazard and social vulnerability. The model is a tool to strengthen and contribute to plans and programs for flood disaster mitigation; it is based on quantitative mathematical development and qualitative data obtained in situ, using matrices for the collection of information and subsequent processing of data through descriptive statistics.

On the other hand, the results are shown in tables and maps at the basin scale, which show the correlation of risk elements with vulnerability and hazard with risk.

Method

Theoretical Framework

Disaster risk management, and in particular the model proposed in this article, is in line with Sustainable Development Goals 11, 13, since it contributes to increase the scientific knowledge essential for national planning involving climate change mitigation, adaptation and resilience to disasters. The proposed model is a mathematical tool that can be used in territories that lack information from satellites or other sources. By using the model, percentage point values of vulnerability and risk will be obtained from the flood hazard.

As a legal basis, the work is supported by Law 337 of Nicaragua, "Law creating the National System for the prevention, mitigation and attention to disasters. The Law of the National Risk Management System (SINAGER) of Honduras. Law 109-96 "Ley de Coordinadora Nacional para la Reducción de Desastres" in Guatemala. The Civil Protection, Disaster Prevention and Mitigation Law (Decree No. 777) in El Salvador.

According to Tirado, V., & Ugarte, A. (2019). They propose the following risk equation, $R = (\ln(V) + A) * V$ equation 1, where $\ln(V) \geq 1$. On this basis, correlations between elements and vulnerability, hazard and risk, element intervals and qualitative and quantitative scales were constructed, and geographic information systems were incorporated for spatial analysis (vulnerability, hazard and risk mapping) for flooding, resulting in the proposed model.

The threat is considered as an element of the environment dangerous to man, these are originated by magnitudes of external forces, it refers to all phenomena of natural origin, and anthropogenic. A threat can be incident in lesser to greater degree, or from greater to lesser degree, according to the social vulnerability of the territory under study, therefore, vulnerability according to (Pizarro, 2001), "defined as the insecurity and defenselessness experienced by communities, families and individuals in their living conditions as a result of the impact caused by some type of social economic event of a traumatic nature" (p.15)

On the other hand, vulnerability represents the exposure, susceptibility, resilience and preparedness experienced by communities, families and individuals in a local territory. Exposure is considered as the degree to which tangible assets and/or people in a community may be affected by a natural hazard. Susceptibility, considered as an element of risk, refers to the degree of predisposition to an event. Resilience, considered as an element of risk, refers to the capacity of communities, families and individuals to overcome and adapt to critical moments generated by a natural or anthropogenic event. Finally, preparedness, an element that refers to prevention plans and emergency preparedness.

Type of Research

The present work is designed under the methodological approach of the qualitative and quantitative (mixed) approach, since this is the one that best adapts to the characteristics and needs of the research.

The quantitative approach:

It uses data collection and analysis to answer research questions and test previously established hypotheses, and relies on numerical measurement, frequent counting, and the use of statistics to accurately establish patterns of behavior in a series of data (Hernández Sampieri & Fernández Collado, 2014, p. 5).

From the mixed approach, the survey format technique will be used to describe the behavior of the communities in the face of a possible flood hazard.

Execution time

The development of the research, in order to meet the proposed objectives, was carried out in 4 months, from January to April 2021. The first two months were dedicated to collecting primary information, applying the survey instrument to 11 identified communities, as well as obtaining information on precipitation. The third month was devoted to the analysis, interpretation and analysis of the results, and the fourth month was devoted to the final report of the research.

Data Collection Techniques and Methods

Primary Sources

In situ observation: field visit to four communities, verification of the water footprint of the rivers.

Application of the instrument: format designed to collect information on the condition of risk, vulnerability and hazards.

Archives: National Water Authority (ANA), Nicaragua, and Nicaraguan Institute of Territorial Studies (INETER), Directorate of Water Resources.

Universe

In general, these are the communities located within the boundaries of the Leon-Chinandega hydrographic unit.

Population

The study population is made up of those belonging to 11 the communities under study.

Sample

It considers as a sample, the families to which the instrument will be applied, the format of the physical conditions (risk, vulnerability and threats). According to (López, 2004) rescued from (CFR.:MATA et al, 1997) the following equation is used to determine the sample:

$$m = \frac{N}{(N-1)*K^2+1} \text{ equation 2}$$

Where:

m = sample

N = population or universe

K= margin of error for the study 5% expressed in decimals was used

Inclusion Criteria

All families belonging to the communities under study.

All families who are at risk.

Exclusion criteria

All families that do not belong to the communities under study.

All families who are not at risk.

Method

In stage 1: The flood hazard was identified based on meteorological phenomena, choosing the years of occurrence of the event by obtaining information from the Chinandega hydrometeorological station code 64018 provided by the Nicaraguan Institute of Territorial Studies (INETER), in this case the factor to be studied is precipitation.

Table 1

Hurricanes that partially and totally affected the León-Chinandega hydrological unit

		Rainfall in millimeters												
Year	**Hurricanes**	**Jan**	**Feb**	**Sea**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
1971	Irene	1.9	0.0	0.0	0.0	200.8	175.8	173.7	265.1	627.2	385.6	124.7	1.2	1956.0
1974	Fifi	0.2	0.0	0.0	2.0	163.3	421.7	128.0	213.2	898.6	268.7	5.8	0.0	2101.5
1982	Alleta	6.9	1.8	0.4	0.0	1,685.7	129.2	94.2	15.3	359.2	163.8	9.7	1.6	2467.8
1988	Joan	0.0	0.0	6.1	1.3	216.4	382.3	285.0	734.2	378.0	389.0	49.7	0.9	2442.9
1993	Gert	17.0	0.0	0.0	125.3	458.7	483.0	57.8	226.9	789.7	238.1	9.4	0.3	2406.2
1998	Mitch	0.0	0.0	8.4	24.0	74.2	225.2	393.2	399.8	438.3	1,985.5	229.2	2.9	3780.7
2005	Stan	0.0	0.0	38.7	39.0	187.2	286.6	302.5	272.8	482.4	732.5	34.1	1.9	2377.7
2008	Felix	0.5	6.4	1.8	47.2	440.3	218.2	159.2	470.5	391.9	429.6	9.9	0.1	2175.6
2009	Ida	4.9	0.0	0.0	0.0	180.8	429.3	77.8	105.8	381.7	209.3	135.7	33.4	1558.7
2020	Eta and Iota	0.0	0.0	0.0	0.0	323.4	430.0	165.2	427.2	345.9	300.5	313.5	0.0	2305.7

Note. Summary table based on data from INETER (2021)

For the flood hazard, we work with the average precipitation of the total data for the months of the year for each event (hurricane), then divide by 10 to obtain the magnitude in centimeters and then select the largest of the events to divide by each one and normalize.

In Stage 2: Resilience, preparedness, level of exposure and susceptibility were determined; for this purpose, survey instruments were applied to verify the perception of risk, the instruments or surveys allowed the collection of field information, such as: general data; description of the factor (resilience, preparedness, exposure and susceptibility); exposed population, and vulnerable groups.

With equation 1, social vulnerability and risk were calculated for each event in the established timeline.

In the last stage, correlations and graphs were prepared with Microsoft Excel, and maps of the Chinandega-León hydrological unit were created using QGis software (free software), showing spatially the behavior of the variables under study.

Results

The area under study corresponds to the León-Chinandega hydrological unit. According to data provided by INETER and SINAPRED, this area has been one of those affected by floods with three events per decade.

Map 1 shows the historical floods and flood zones in which the municipalities of Somotillo, Villanueva, Chinandega, Telica and La Reynaga are involved, specifically corresponding to the communities of: Apancuca, Aquespalada, Matapalo, Lourdes, El Bonete, Las Grietes, Ojo de agua, La Sirena, El Piñuelar, Glilao and Mocoren.

Figure 1

Historical and current flood zones in the Leon-Chinandega hydrological unit

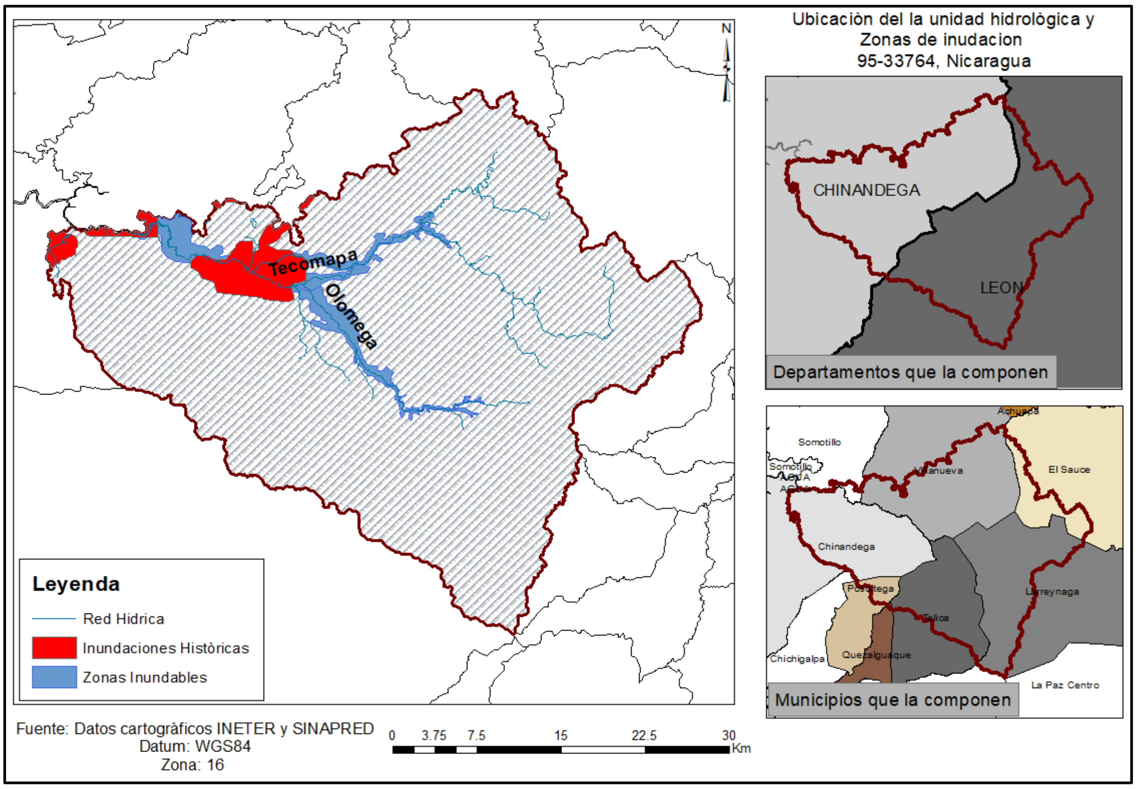


Table 2 shows the results of the average of the different hazard events in mm, cm and normalized. Elements such as exposure, susceptibility, resilience (harmonization) and social preparedness are obtained from field data as percentage scores, vulnerability and risk calculations are observed.

Table 2

Calculation of vulnerability and risk in the Leon-Chinandega hydrological unit

Elements	Threat	Event									
		Irene	Fifi	Alleta	Joan	Gert	Mitch	Stan	Felix	Ida	Eta, iota
	mm	163.0	175.13	205.65	203.58	200.52	315.06	198.14	181.30	129.89	192.14
	cm	16.3	17.51	20.57	20.36	20.05	31.51	19.81	18.13	12.99	19.21
	Normalized	0.52	0.56	0.65	0.65	0.64	1.00	0.63	0.58	0.41	0.61
Exhibition		0.80	0.79	0.78	0.72	0.70	0.69	0.65	0.63	0.60	0.55
Susceptibility		0.80	0.79	0.78	0.77	0.76	0.75	0.70	0.65	0.60	0.55
Resilience		0.50	0.51	0.52	0.53	0.54	0.55	0.60	0.65	0.70	0.75
Social Preparation		0.45	0.46	0.47	0.48	0.49	0.50	0.55	0.60	0.65	0.70
Vulnerability		**0.67**	**0.64**	**0.61**	**0.55**	**0.52**	**0.49**	**0.40**	**0.33**	**0.27**	**0.21**
Risk		**10.71**	**10.98**	**12.34**	**10.85**	**10.02**	**15.18**	**7.47**	**5.57**	**3.11**	**3.68**

Table 3

Item ranges and qualitative and quantitative scales

Elements			Factor Description		
			Intervals		
Exhibition	Average	Deviation	**≤0.61**	**0.61> y ≤0.78**	**0.78&gt**
	0.69	0.08	**BAJA**	**MEDIO**	**ALTA**
Susceptibility	Average	Deviation	**≤0.63**	**0.63> y ≤0.80**	**0.80&gt**
	0.72	0.09	**BAJA**	**MEDIO**	**ALTA**
Resilience	Average	Deviation	**≤0.50**	**0.50> y ≤0.62**	**0.62&gt**
	0.59	0.09	**BAJA**	**MEDIO**	**ALTA**
Preparation	Average	Deviation	**≤0.45**	**0.45> y ≤0.62**	**0.62&gt**
	0.54	0.09	**BAJA**	**MEDIO**	**ALTA**
Vulnerability	Average	Deviation	**≤0.31**	**0.31> y ≤0.63**	**0.63&gt**
	0.47	0.16	**BAJA**	**MEDIO**	**ALTA**

For each element, from the statistical descriptors such as the average and standard deviation, the intervals of the factors are deduced, the intervals of B=LOW green color; M=MEDIUM yellow color; and A=HIGH red color, for the elements EXPOSURE, SUSCEPTIBILITY AND VULNERABILITY; in the case of B=LOW red color; M=MEDIUM yellow color; and A=HIGH green color, for the elements of RESILIENCE and SOCIAL PREPAREDNESS.

Table 4

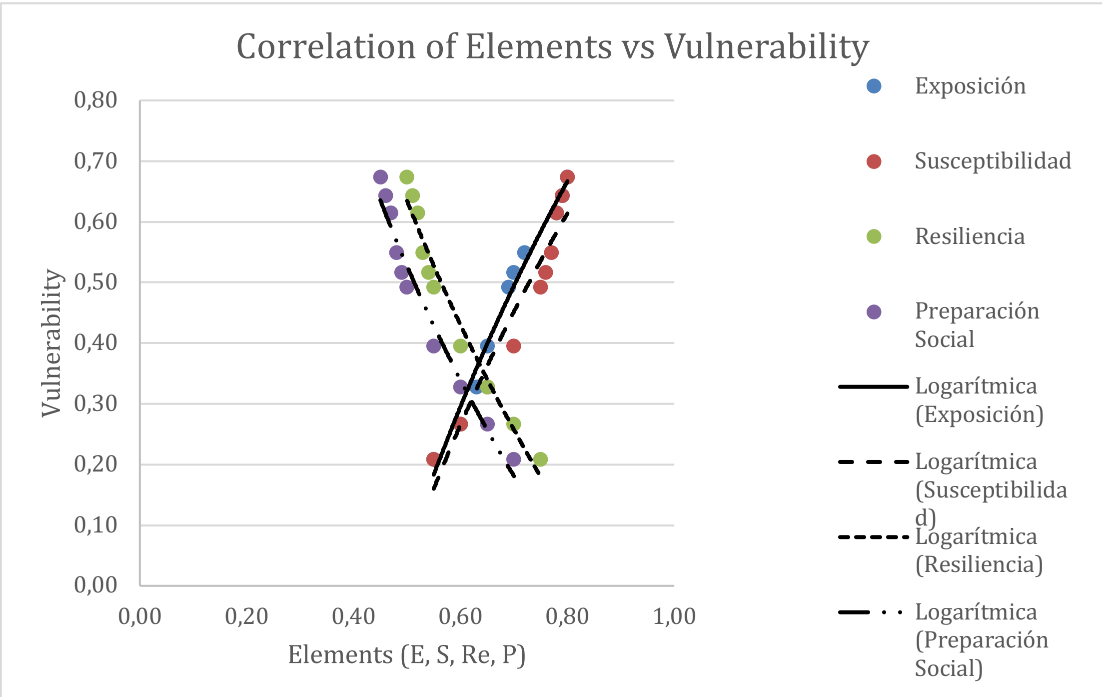
Intervals for hazard, risk and qualitative and quantitative scales

			Factor Description		
			Intervals		
Threat	Average	Deviation	≤14.87	14.87> y ≤24.41	24.41&gt
	19.64	4.77	BAJA	MEDIO	ALTA
Risk	Average	Deviation	≤5.08	5.08> y ≤12.90	12.90&gt
	8.99	3.91	BAJA	MEDIO	ALTA

In relation to the elements THREAT and RISK, with the statistical descriptors, the average and the standard deviation, the intervals of the factors are deduced, the intervals B=LOW green color; M=MEDIUM yellow color; and A=HIGH red color for both elements. There is a directly proportional relationship.

Figure 2

Correlation of elements vs. Vulnerability



The graph represents the correlation of the elements with vulnerability, i.e., for each element studied from the environmental and socio-environmental analysis as a percentage score, it is placed on the X-axis as an independent variable to find the vulnerability on the Y-axis as a dependent variable, therefore, the following expressions and correlation are written:

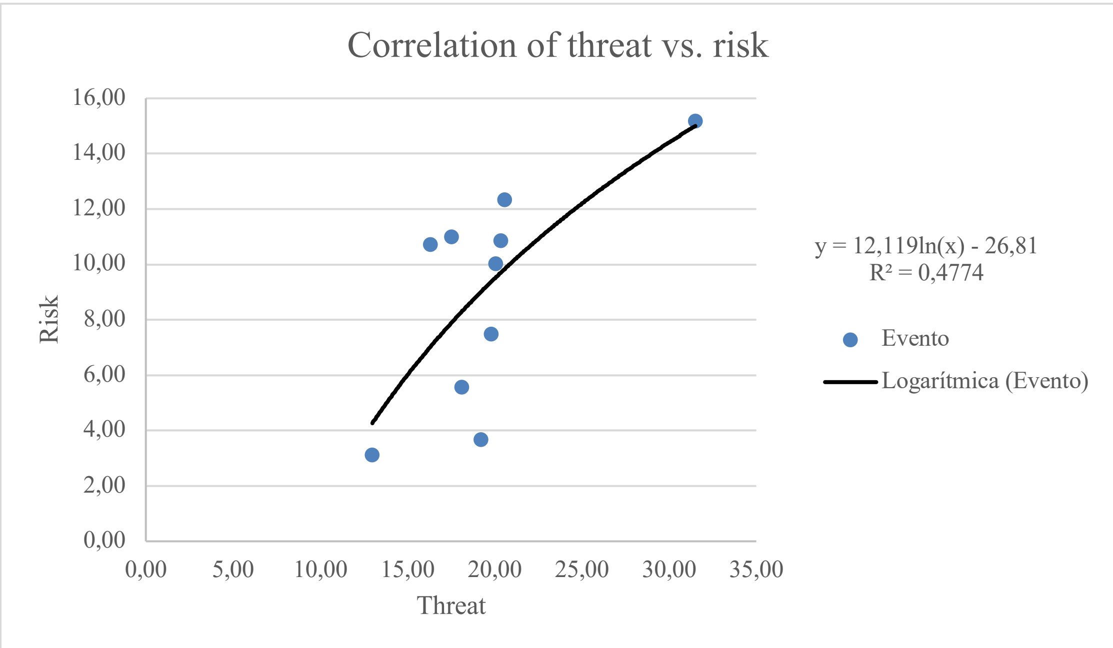
Table 5
Results show the correlation between the different elements and vulnerability

Elements	Equation	Correlation
Exhibition	y = 1.2906ln(x) + 0.9548	$R^2 = 0.983$
Susceptibility	y = 1.2103ln(x) + 0.8836	$R^2 = 0.9293$
Resilience	y = -1.121ln(x) - 0.1427	$R^2 = 0.9664$
Preparation	y = -1.029ln(x) - 0.1863	$R^2 = 0.9678$

The following graph represents the correlation between THREAT and RISK, achieving an equation that best fits the model. For the flood event located on the X-axis as an independent variable, the curve is intercepted and projected to the left, determining the risk on the Y-axis as a dependent variable.

Figure 3

Correlation of threat vs. risk



From the correlation graph, the deduced trend equation is obtained, having a relationship with equation 1, being as follows:

Adapted equation	Deduced equation
$R = (\ln(V) + A) * V$	$\boldsymbol{y = a * ln(x) - b}$

Where:

y = risk, dimensionless
x = threat, dimensionless
a, b = multipliers 12.119, and 26.81 respectively

Application of the magnitudes of risk elements to spatial maps:

Figure 4

Spatial results in the hydrological unit of the degree of exposure and susceptibility to four events: Mitch, IDA, Iota and Eta

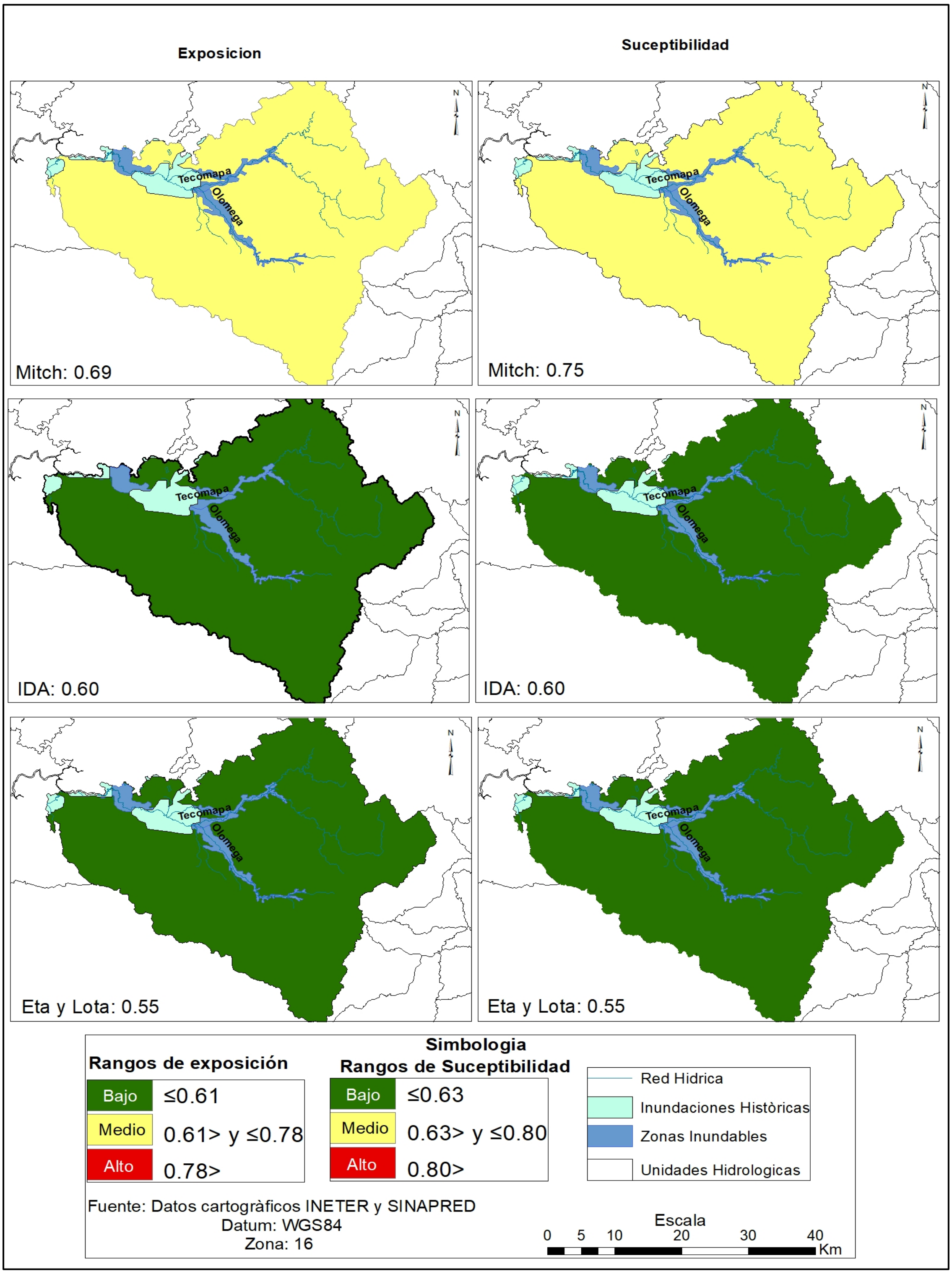


Figure 5
Spatial results in the hydrological unit of the degree of resilience and social preparedness to four events: Mitch, IDA, Iota and Eta

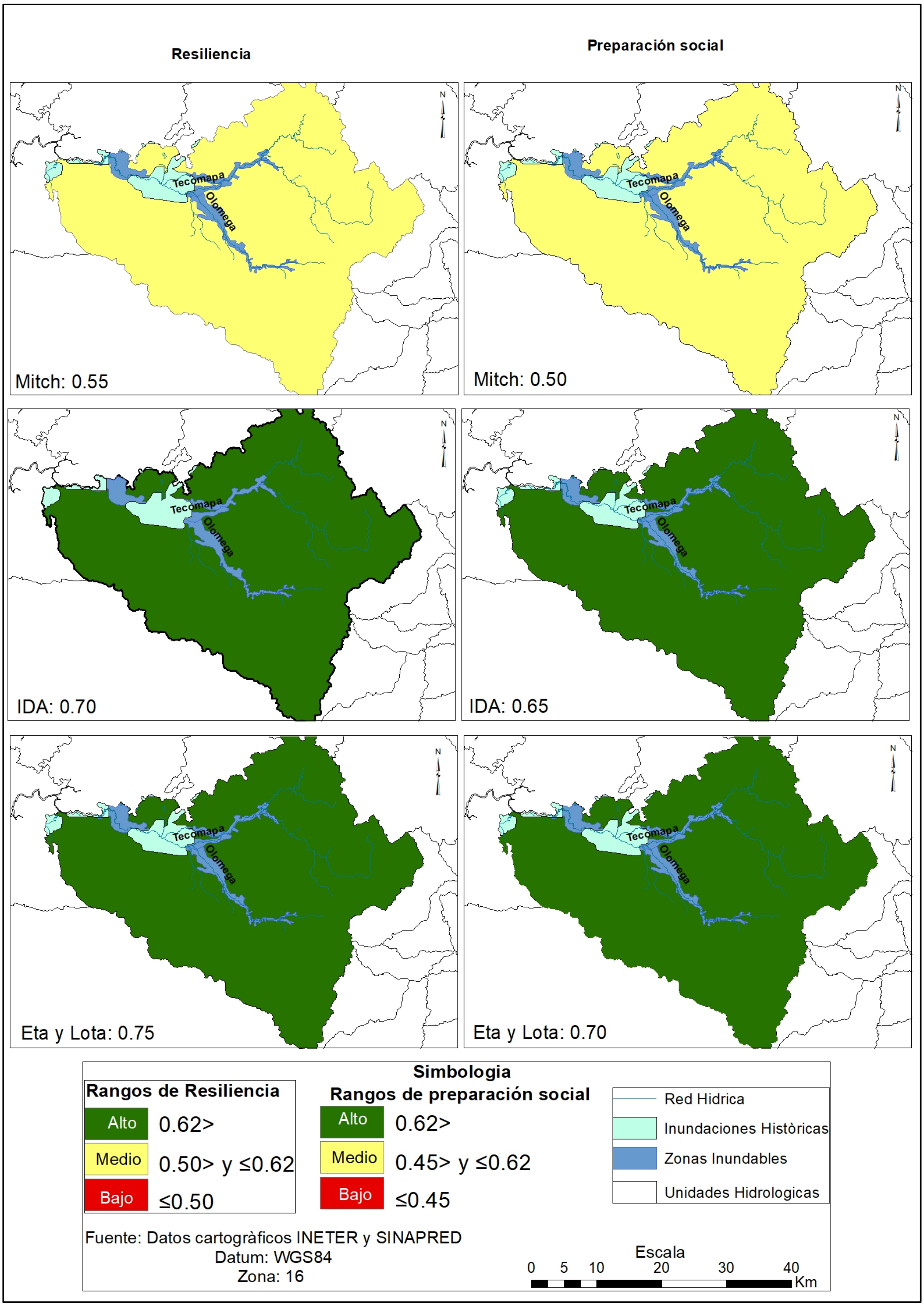
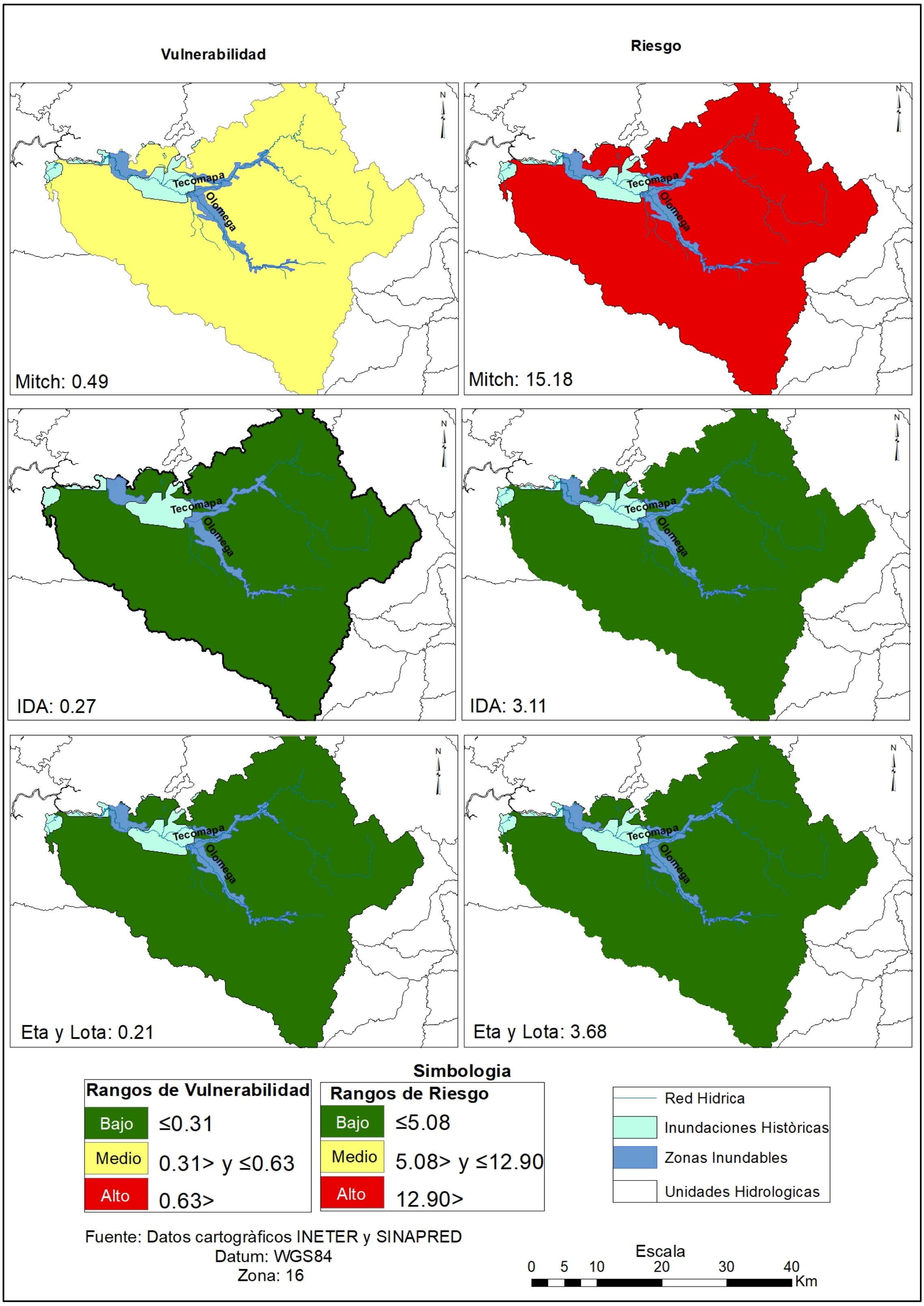


Figure 6

Spatial results in the hydrological unit of the degree of vulnerability and risk to four events: Mitch, IDA, Iota and Eta



With the development of the model, it is possible to map the results obtained from the application of the instrument (survey). Based on the quantified magnitudes of the risk elements such as vulnerability, preparedness, exposure and susceptibility, spatial maps are generated for four maximum events, modeling the extent that a flood could generate in the communities studied.

Discussion and conclusions

Within the framework of Sustainable Development Goals 11 and 13, it became evident that the model proposed in this article contributes to scientific knowledge for local, regional and national planning involving climate change mitigation, adaptation and disaster resilience. It is important to emphasize that the management of social vulnerability was made as a variable of major importance, since it is where the harmonization of the passive agent (society) with the active agent (natural environment) is sustained.

By means of the mathematical model, it was possible to demonstrate the quantification of social vulnerability and risk as variables, and that they are directly proportional variables. The variables that influence the reduction of vulnerability are those related to climate change adaptation variables, resilience (harmonization) and social preparedness.

Specifically, according to the results, very important findings are evidenced, such as: the generation of vector maps from the application of the survey instruments, and the quantification of the indicators to obtain a deduced equation of risk as a trend related to the different elements of risk.

Recommendations

The proposed model can be applied at different spatial scales, from regional, basin, municipal and local, incorporating it as a strategy for determining social vulnerability and disaster risk in any part of the Central American region.

The mathematical model developed in this work can be adapted to other natural and anthropic events such as: hurricanes, earthquakes, tsunamis, volcanic eruptions, landslides, tornadoes, tidal waves, forest fires, environmental pollution, armed conflict, terrorism, overpopulation, social problems, drugs, insecurity, marginalization and poverty.

The spatial representation of the results through maps can be used in community workshops related to Climate Change and Integrated Disaster Risk Management in the study area developed by decision makers.

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