Developing a Social Vulnerability Index (SVI) for Risk Mapping

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ABSTRACT

Objective: To develop a Social Vulnerability Index (SVI) for the El Saltillo community, in Jilotepec, State of Mexico, with risk mapping purposes.

Design/Methodology/Approach: A Social Vulnerability Index (SVI) was developed based on sociodemographic indicators, housing characteristics, and the conditions of the production systems. The information sources for the SVI indicators were obtained from official Basic Geostatistical Area (AGEB) censuses and from an online survey carried out in the community under study. The SVI was cross-referenced with data from four previously published natural hazard studies for risk mapping purposes.

Results: The methodological proposal uses equal weight index statistical techniques to develop the SVI. Using online surveys is a clearly viable option for research studies that require to obtain more detailed data on housing characteristics, as well as the population's perception of certain changes in precipitation and temperature patterns that are happening in their community and the measures, they take to face these natural phenomena.

Study Limitations/Implications: Online surveys are relatively recent, which implies the need to design and implement validation and sampling mechanisms for the results.

Findings/Conclusions: Risk mapping enabled the territorial visualization and identification of the communal vulnerability conditions, which facilitates a conceptual approach to the social reality of the population and will allow the formulation of potential future scenarios of climate change and the implementation of public policies.

Keywords: Online surveys, climate change, natural risks and hazards, social vulnerability.

INTRODUCTION

The impact of natural risks and disasters is directly related to the social vulnerability of the affected populations. The risks and dangers that threaten society and its environment have been approached from different scientific disciplines, including geography —which establishes most of the theoretical and methodological background for the study of risks and dangers and likewise contributes to the understanding of risk perception and phenomena. Principi (2020) points out that the human science of geography has extensive capacity and experience in risk studies from different approaches. Spatial analysis enables predictions about the spatial distributions of the constituent aspects of risk, threat, and vulnerability. Consequently, moving towards an applied geography —through the modeling of future spatial configurations— can be very helpful for decision-making in spatial planning, territorial planning, and rural development.

Since its appearance on earth, humanity has suffered from the attacks of nature in different forms: from storms that devastate buildings and crops, to the impact of droughts on the population. However, the frequency and severity of disasters has recorded such

Citation: Hernández-Rodríguez, V. M., Escalona-Maurice, M. J., León-Merino, A., Pimentel-Aguilar, S., & Ibarrola-Rivas, M. J. (2024). Developing a Social vulnerability Index (SVI) for Risk Mapping. *Agro Productividad*. https://doi.org/10.32854/agrop.v17i17.2556

Academic Editors: Jorge Cadena Iñiguez and Lucero del Mar Ruiz Posadas

Received: March 27, 2023.
Accepted: December 16, 2023.
Published on-line: February 16, 2024.

Agro Productividad, 17(1). January. 2024. pp: 51-61.

an alarming increase in the last 50 years that the United Nations (UN) counts more than 2,000,000 deaths from 1970 to 2019, basically as a consequence of phenomena such as torrential rains, cyclones, floods, droughts, and earthquakes (UN, 2021). The National Center for Disaster Prevention (CENAPRED, 2021) points out that the damage in Mexico has increased both in terms of people affected (deaths) and in its economic cost. In the 2000-2018 period, the annual cost of natural disasters is estimated at $2,357 million dollars —a much higher figure than the $455.3 million cost for the 1980-1999 period. In this same period (2000-2018), 86.7% of the damages and losses had a hydrometeorological origin and the greatest impacts were recorded in the most vulnerable and highly marginalized localities.

Although risks and dangers have long been the subject of many studies throughout the world, there is currently no consensus regarding the definitions of such aspects as danger, vulnerability, exposure, response capacity or resilience, prevention, mitigation, etc. As Principi (2020) mentions, all the different lines of analysis agree that danger and vulnerability cannot be separated from risk.

On the one hand, risk can be defined as the combination of the likelihood of an event and its negative consequences —*e.g.*, deaths, injuries, disruption of economic activities, or environmental deterioration—, resulting from the interactions between natural or anthropogenic threats and environmental vulnerability (Baas *et al.* 2009). On the other hand, the National Center for Disaster Prevention of Mexico (CENAPRED, 2021) defines danger as the probability of occurrence of disturbances of a certain magnitude in a certain period and in a given location. This definition implies that danger is the exposure of the population to the occurrence (threat) of an event that may affect them or alter their daily activities.

The exposure level and fragility of society (and its activities) in the face of natural phenomena is known as vulnerability. Several definitions and theoretical approaches on the subject have been proposed. For example, Carreño *et al.* (2014) mention that vulnerability is composed of three dimensions: physical exposure and susceptibility, the fragility of the socioeconomic system, and finally the lack of resilience that would enable society to cope and recover. Principi (2020) defines vulnerability as "the capacity that the population has to face the occurrence or probability of occurrence of some danger and the possibility of recovery, linked to the characteristics of the population from a certain place, which can be modified by improvements in the quality of life." Turner *et al.* (2003) mention that, within the context of the system formed by the human population and the environment, vulnerability encompasses exposure, sensitivity, and resilience.

Vulnerability varies within social groups depending on space and time (multidimensional variance). However, it also varies at the individual, community, regional, etc. levels (study scale) and varies over time (dynamic). Nevertheless, it is also a precondition that can manifest during an event and every scientific discipline has a different way to measure its intensity. Considering the previous aspects, vulnerability can be applied in different fields of studies, such as natural disasters, sustainability, climate change, urban growth, agriculture and water availability, etc. Each scientific field can interpret vulnerability in a different way and impose its method of analysis.

From the point of view of social sciences, Ramos-Ojeda (2019) mentions that "social vulnerability (SV) raises questions about the planning and management of resilience, in addition to social disintegration and social instability issues, as well as the consequent poverty production processes; vulnerability is not synonymous with poverty but rather the result of defencelessness, insecurity, and exposure to risks, crises and stress." Kaztman (2000) defines social vulnerability (SV) as the "inability of a person or a household to make the most of the opportunities available to different socioeconomic areas, to improve their well-being situation or prevent its deterioration. The SV has its most important sources in the precariousness and labor instability phenomena linked to the operation of the market and the lack of protection and insecurity linked to the withdrawal of the State and the weakening of primary institutions.

Thomas-Bohórquez (2012), Navarro *et al.* (2020) and other researchers have pointed out that, as a consequence of the multiple variables that define social vulnerability, a direct definition and an immediate measurement are almost impossible. This situation has led to the development of indicators that —without losing sight of the specificity of the element that is measured— allow combined assessments that show, to a greater extent, the complex behavior of the variables involved. Therefore, indicators or vulnerability indices must be generated from a multidisciplinary perspective.

Several methodologies attempt to measure some type of social vulnerability. The most common are the Human Development Index (HDI), the Human Poverty Index (HPI), and the Gender Development Index (GDI). The present study calculates the Social Vulnerability Index (SVI) as defined by Natenzon *et al.* (2005): "a quantitative, statistical evaluation that enables the preliminarily identification of administrative units in which different degrees of social vulnerability are distributed in the territory, through a given set of indicators chosen for this purpose."

With respect to the development of SVI, Álvarez-Ayuso *et al.* (2006), Silva-Burgos *et al.* (2009), Thomas-Bohórquez (2012), and Arteaga *et al.* (2012) designed SVI considering the social, environmental, and territorial aspects of various regions and displayed some of the results in thematic maps.

Study area

The El Saltillo community belongs to the municipality of Jilotepec, State of Mexico, approximately 90 km northwest of Mexico City. El Saltillo has an area of 1,384 hectares, divided into 17 geostatistical units (AGEB), locally known as *manzanas* (block). It has 227 houses or production units and 760 inhabitants (INEGI, 2020). The community is purely rural, rainfed corn is the main crop in the area, houses are scattered throughout the territory, and land ownership is communal (*ejidos*).

MATERIALS AND METHODS

Social Vulnerability Index

The SVI in El Saltillo was designed at the Basic Geostatistical Area (AGEB) level —the smallest geographic unit from which data from different population and housing censuses can be obtained in Mexico. Two sources of information were used: 1) the

General Census of Population and Housing (CGPV2020, INEGI), for the microdata modality, at the AGEB level; and 2) an online survey applied to the inhabitants of the study location. An online survey was designed, given the technical and economic impossibility of carrying out the survey on site. To inform and invite the community to participate in the survey, a first contact was made with the *ejido* authorities who, through various WhatsApp groups, extended the population an invitation to participate in the online survey, through a Google Forms document titled "Percepción y adaptabilidad al cambio climático en la comunidad El Saltillo" ("Perception and adaptability to climate change in the El Saltillo community"). The following control mechanisms were used for the surveys: only one person per family was allowed to participate and the address was written down, including the block to which it belongs, because each block is equivalent to the Basic Geostatistical Area (AGEB) of INEGI. As a result, 96 surveys were completed (42.2% of the production systems), distributed among the 17 blocks or AGEB that make up the community.

Because the SVI is an expression of an unequal and unfavorable situation in the geographical space occupied by the population, the selected variables were grouped according to population condition and housing condition (taken from the CGPV2020) and production systems conditions (taken from the online survey) (Table 1).

Table 1 describes the indicators that were measured to develop the SVI. The indicators of the conditions types of the production systems are the average of the results of the online survey by units located in the same block or AGEB. The crop type (A) indicator was established according to the number of crops planted at the same time on the plot: 3 (monoculture), 2 (two crops), and 1 (more than two crops). The education level (B) indicator refers to the education level of the person who answered the survey: 3 (No Education

Table 1. Indicators used to develop the Social Vulnerability Index (SVI).

Indicator	Indicator	Unit of measurement
Population conditions	Total population	Persons
	Population aged 65 and over	%
	Population aged 15 and under	%
	Illiterate population	%
	Population with disabilities to see	%
Housing conditions	Houses without electricity	%
	Houses without computer	%
	Houses without cell phone	%
	Houses without internet	%
Production systems conditions	Type of cros	Index (A)
	Agricultural yields	t/ha
	Variety of livestock	Shannon diversity index
	Level of education	Index (B)
	Climate change adaptability actions	Number of adaptability actions

Source: Table developed by the authors based on data from the 2020 General Population and Housing Census (INEGI) and the "Perception and adaptability to climate change in the El Saltillo community" online survey.

and Only Basic Education), 2 (Secondary Education and High School), and 1 (Graduate and Postgraduate). Livestock variety was measured using the Shannon-Wieber index. The diversification of livestock species represents a process of sustainability for the productive system. It is a survival strategy in the study area: livestock species are considered as an investment in case of an economic need, although they also contribute to the family economy as both live animals or carcasses, as well as milk, eggs, and other non-meat products. At a high value or close to 1, species diversity is greater and vulnerability is lower. The Number of Adaptability Actions to Climate Change refers to the total number of actions taken by the inhabitants to adapt to or mitigate the negative effects of phenomena such as droughts and frosts. According to the perception of the inhabitants of the area, the increase in the frequency and intensity of these phenomena in the last 10-15 years has forced them to take measures to reduce damage to livestock, crops, and their own families.

The statistical management of the data to generate the SVI consisted of the weighting of the variables —a technique used to correct imbalances in sample types after data collection. Nardo *et al.* (2005) point out that "the weighting of variables is key when different dimensions measured on different scales must be subjected to a significant combination, implying a decision about what weight will be used in the model and what procedure will be applied to add the information." Gómez-Limón *et al.* (2010) point out that the preferences of society should be taken into account when social issues (such as sustainability) are involved; assigning different importance to each dimension or indicator included in the composite indicator is required to determine the extent to which weights influence the results.

A weighting factor is the assignment of a specific weight to each variable, based on its importance within the set of variables; however, as is the case with the data of this study, the compensation method was used to designate an equal weight or weighting to all variables. Munda *et al.* (2005) point out that the compensation method calculates weights as scale constants, without an ambiguous interpretation, requiring no significant judgment.

Therefore, the following formula was used.

$$EW = \frac{X_1 * P_1 + X_2 * P_2 + X_3 * P_3 + \ldots + X_n * P_n}{100}$$

Where: EW=equal weighting; X=indicator value; P=weight assigned to the indicator (the value (14) matches the number of variables used to develop the SVI).

The Equal Weighting formula was used to develop the Social Vulnerability Index (SVI) for El Saltillo and each block or AGEB was assigned a value or index.

Risks and Dangers

In the study of the threats posed by natural events, the danger indicates the potential occurrence of a phenomenon and the risk becomes an inherent part of human life, since risk is the result of the appropriation and modification of the geographical space by humanity (as a species). Authors such as Aneas de Castro (2000) mention that "risk mapping research has increasingly revealed that danger is an event capable of causing severe losses, but danger likewise implies the existence of humans, who assess what can and cannot damage them; therefore, humans are the protagonists of the definition of natural hazards: their location, actions, and perceptions determine whether a natural phenomenon is dangerous or not."

Studies about the risks and dangers that threaten society and the environment have been extensively studied and analyzed. Global institutions are in charge of studying risks, dangers, and threats from very different perspectives. In Mexico, institutions such as CENAPRED and private and public universities, as well as state and municipal institutions, have worked intensively to understand both the origin and consequences of natural phenomena, aiming to reduce the exposure or vulnerability of the population. The present study compares the results of some of those studies with its Social Vulnerability Index, showing the different types of social vulnerability that are recorded in a particular space, in the form of maps.

The risk and danger studies considered in the present study (Table 2) are related to the results of the online survey applied in the community: according to the participants, phenomena such as droughts and frosts affect agriculture, livestock, and the general population to a greater extent.

As shown in Table 2, the most severe natural risks and hazards in the study area (municipality) have been subjected to hydrometeorological studies; however, within the same municipality, the effects on the population are different at a system of production level, depending on the level of vulnerability. Therefore, it is important to develop an Index that allows the identification of the areas of a given community where a natural phenomenon can cause greater damage and the visualization of the spatial distribution of the risk.

RESULTS AND DISCUSSION

According to the results of the online survey applied to the study community, climatic risks are identified as common and dangerous, while Herrero *et al.* (2020) state that "the risk of impacts due to climate factors is the consequence of the interaction of climate hazards or threats with vulnerability, since both events must take place simultaneously for the risk to exist."

Table 2. Risk and hazard studies considered for risk mapping.

Study	Source	Value-index	Classification
Drought hazard risk	CENAPRED, 2012	0.23	Low
Cold weather risk level	CENAPRED, 2012	0.63	Mid
Municipal vulnerability to climate change	INECC	0.13	Low
Agricultural drought vulnerability level	Espinosa-Rodríguez et al. 2022	0.75	Very high

Source: Table developed by the authors based on data from different sources.

Therefore, risk would be defined by the following formula:

$$Risk = Danger \times Vulnerability$$

Where: *Risk* is displayed in maps that visualize the spatial differences in a community; *Danger* is represented by the values described in Table 2 and *Vulnerability* is the Social Vulnerability Index (Table 3). High values belong to more vulnerable blocks regarding the conditions of their population, housing, and/or production systems. Using the quantile statistical method, the SVI values were classified into High, Medium, and Low social vulnerability levels.

Figures 1, 2, 3 and 4 show the risk mapping, combining the information from hazard maps (various sources) with the Social Vulnerability Index (SVI) developed for the present study.

Figures 1, 2, 3 and 4 enable the spatial visualization of the levels of vulnerability that exist in the same community. This information is necessary for the planning of rural development policies, because these differences increase the accuracy with which the various needs within the same population are measured, regardless of their size. The largest blocks (blocks 4, 6, and 11) have the largest population and consequently high levels

Table 3. Social Vulnerability Index.

Block	Social vulnerability index (SVI)		Social vulnerability to drought	Social vulnerability to cold weather	Social vulnerability to climate change	Social vulnerability to agricultural drought
	Val	Class				
1	0.089	Low	Low	Low	Low	Low
2	0.11	Low	Low	Mid	Mid	Mid
3	0.139	Mid	Mid	Mid	Mid	Mid
4	0.183	High	High	High	High	High
5	0.132	Mid	Mid	Mid	Mid	Mid
6	0.195	High	High	High	High	High
7	0.172	High	High	High	High	High
8	0.136	Mid	Mid	Mid	Mid	Mid
9	0.058	Low	Low	Low	Low	Low
10	0.098	Low	Low	Mid	Low	Low
11	0.192	High	High	High	High	High
12	0.075	Low	Low	Low	Low	Low
13	0.14	Mid	Mid	High	Mid	Mid
14	0.148	Mid	Mid	High	Mid	High
15	0.149	High	High	High	Mid	High
16	0.015	Low	Low	Low	Low	Low
17	0.148	Mid	Mid	High	Mid	High

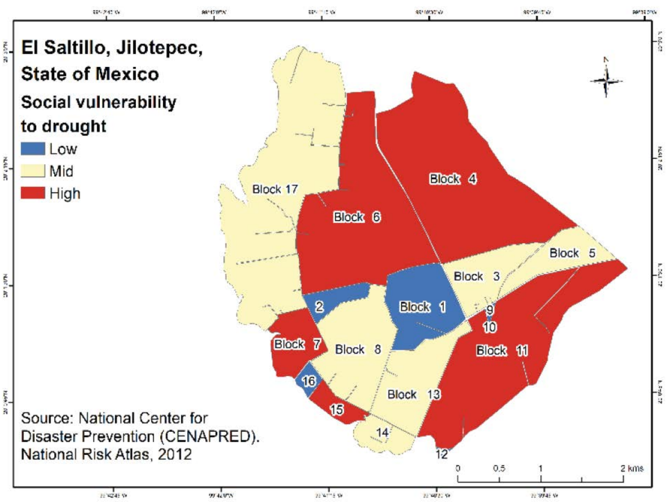

Figure 1. Level of social vulnerability to drought.

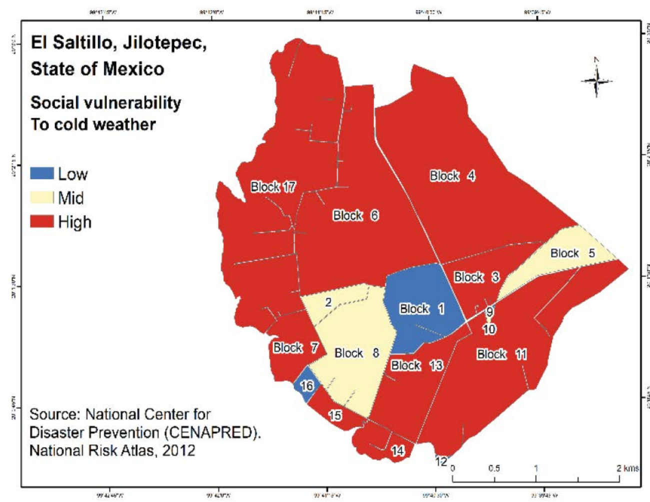

Figure 2. Level of social vulnerability to low temperatures.

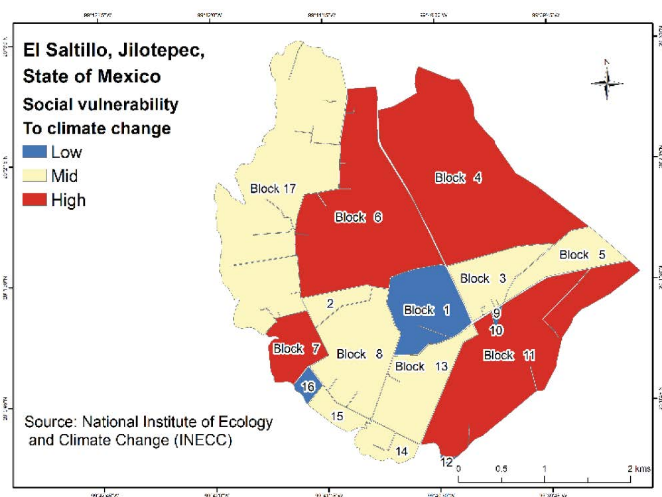

Figure 3. Level of social vulnerability to climate change.

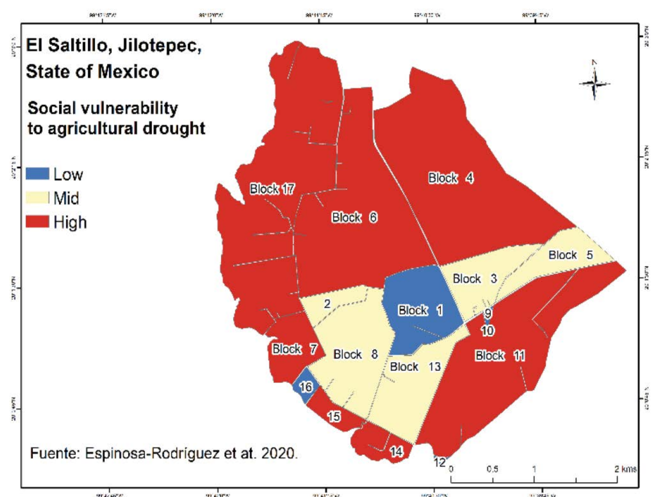

Figure 4. Level of social vulnerability to drought.

Source: Maps developed by the authors.

of vulnerability, both at the population level and in production systems. Block 1 has a low vulnerability because, as the administrative center of the community, it concentrates a greater number of services.

Regarding the population characteristics type indicators, Ruiz-Pérez *et al.* (2012) points out that "social vulnerability to natural disasters is highly dependent on various demographic factors; the characteristics of families and their homes will condition the fragility of the population in face of the effects of disasters, as well as their ability to cope with them." In this sense, outstanding aspects include a highly illiterate population (7-15%); only 3 blocks have 0% illiteracy, which is a challenge during a catastrophe. This limitation hinders resilience, as a result of its connection with the level of education of the population: a population with a low educational level will hardly be well informed and will not be able to anticipate the danger or react to an emergency. Additionally, illiteracy also influences the sensitivity and levels of awareness against disasters. High values are also present among the older members of the population (65+ years old), as well as among the young population (<15 years old). These two parameters play a critical role in the ability to cope with a catastrophe and these two groups are considered highly vulnerable or not very resilient, due to their need for special food and/or medicine, mobility restrictions, and their dependence on other people.

In terms of housing characteristics, many houses lack electricity, home computers, and cell phones. However, the most acute problem is the lack of Internet access, which affects >50% of the houses. This is an indicator of the capacity of the population to be informed of the events that take place in the community or region; accurate and timely information can be a determining factor in the reduction of the negative effects of disasters. Cell phones and internet are indicators of the population's communication capacity: the greater the number of services, the lower the level of vulnerability.

Regarding the characteristics of the production systems —which were established through the online survey—, the existence of monocultures (basically native corn, grown under a rainfed system), coupled with the lack of implementation of agroecological practices, increases the overall vulnerability of the production system to phenomena such as drought or frost. Livestock variety is an aspect of the sustainability of the production system: high values indicate that this sector is essential for the local way of life. There is a high diversity of species of cattle, sheep, and poultry. Owning animals is an investment in case of an economic need, although some producers specialize in raising livestock to be marketed as carcass or live, as well in selling milk and other dairy products. Regarding the actions of adaptability to climate change, the population that answered the survey states that the intensity and frequency of phenomena such as droughts and frosts have increased in the last 10-15 years. Without describing them as effects of climate change, producers have been forced to implement some measures to address these changes, such as building of open ponds to store water for agricultural and livestock purposes, storing water for domestic use in cisterns or water tanks, improving stables with hermetic roofs and floors to avoid drastic temperature changes in the livestock, improving the construction conditions of the houses to make them warmer and cooler, and even increasing the efficient use of stored rainwater through the implementation of drip irrigation in the plots.

CONCLUSIONS

The information obtained from the Social Vulnerability Index (SVI) enable the research team to visualize the spatial distribution of the differential vulnerability levels in El Saltillo, despite the relatively small territory of this community. The identification of the areas with the largest vulnerable population shows that the conditions of the population exposed to risk are not homogeneous, since they have different qualities and abilities to face an extreme event.

The proposed methodology is based on the combination of different sources of information (2020 General Population and Housing Census, from INEGI, at the microdata level, and an online survey in the study community) and the application of a multi-criteria model to weight the variables involved in the design of a Social Vulnerability Index. Contrasted with values from natural risk studies (from different sources), the SVI allows the development of risk mapping to visualize the spatial differences of vulnerability.

The online survey application is an option for research works that require data about the characteristics of the homes, as well as the population's perception about some natural phenomena that are happening in their community. Therefore, the application of online surveys is a feasible and timely option which can be easily quantified, graphed, interpreted, and analyzed, although validation and sampling mechanisms must be implemented.

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