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Multidisciplinary Evaluation of Vulnerabilities: Communities in Northern Mexico

Francisco Valderrey [1], Lina Carreño [2], Simone Lucatello [3] and Emanuele Giorgi [2,*]

[1] Tecnologico de Monterrey, Business School, León 37190, Mexico; francisco.valderrey@tec.mx
[2] Tecnologico de Monterrey, School of Architecture, Art and Design, Chihuahua 31150, Mexico; lina.carreno@tec.mx
[3] Instituto Mora–CONAHCYT, Mexico City 03730, Mexico; slucatello@institutomora.edu.mx
* Correspondence: egiorgi@tec.mx

Abstract: This article takes a holistic view of vulnerabilities within several communities in northern Mexico. The authors use a mixed-methods approach, combining quantitative and qualitative data collection methods to capture different dimensions of vulnerability. Using the multidimensional vulnerability framework (MVI), they analyze socioeconomic indicators, including poverty rates, income inequality, access to essential services, and economic well-being in the Mexican state of Chihuahua. Environmental factors such as water scarcity, pollution levels, and natural resource degradation are also included to understand the ecological challenges those communities face, and political factors, including governance structures and policies, determine their influence on vulnerability and resilience. The result indicates that the community prioritizes ecological indicators over social ones. However, in each community this is heterogeneous. In both cases, the ecological and social indicators selected allow for a multidisciplinary approach to vulnerability. By identifying and understanding these issues, policy makers, researchers, and community leaders can work collaboratively to design strategies to mitigate the impacts of these vulnerabilities. In addition, architects and urban planners can offer specific interventions to benefit these communities. This research contributes to the broader field of vulnerability studies by demonstrating the importance of a multidisciplinary approach to understanding and addressing the complex web of vulnerability faced by communities in northern Mexico and territories that share similar characteristics.

Keywords: architecture and design; climate change; Mexico; multidimensional vulnerability framework (MVI); sustainable development goals (SDGs); vulnerability

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1. Introduction

Vulnerability has accompanied humankind since our earliest ancestors and, arguably, is still present in every society, extending through some of their inner groups [1]. Vulnerability is inherent to the human being, although each person may face it to different degrees, according to some individual circumstances, mainly associated with their relationship within their societies. Those societies, in turn, are continuously exposed to varying risk elements [2].

Despite its importance, the notion of vulnerability remains elusive to a universal definition; to some scholars, the lack of agreement upon such a concept resembles the Babel Tower due to the myriad of theoretical approaches from different disciplines [3]. There are numerous indicators to measure specific vulnerability factors, but those are often no more than "a leap of faith" [4]. Indeed, a quantitative approach may yield great results when gauging some aspects of vulnerability, such as the lack of food, exposure to extreme temperatures, or harsh scenarios caused by humans or nature [5]. On the contrary, a qualitative analysis may also bring forth relevant results [6]. Thus, vulnerability goes far beyond the potential damage to individuals and populations and the resources that nurture their dwellings and territories.

Tackling vulnerability from a theoretical point of view presents a more complex challenge. The search for its conceptual description has been central to a broad academic discussion [7]. Unfortunately, no general definition may suit the experts in the many fields involved, which limits the benefits of using a common language across different disciplines. Commonly, assisting those in need requires an effort to portray a situation as worthy of intervention from supportive people and organizations [8]. Thus, a conceptual description of vulnerability that may extend satisfactorily across different domains is much needed [9]. Such a definition may encompass other criteria for analyzing populations in territories threatened by multiple potential hazards. Equally important is the quest for proper methodologies to identify risk factors in marginalized communities in urban, rural, and mixed geographical settings.

Finding a multidisciplinary definition of vulnerability and a methodology suiting the needs of the research objectives was crucial to this investigation. First, a literature review helped to clarify the concept, only to realize the impossibility of finding a "one size fits all" type of response acceptable and valuable to all possible fields and situations [10]. Indeed "vulnerability has no universal definition," which leads different areas to find the one that best suits their purpose [11].

Moreover, vulnerabilities are contextual: social and environmental features vary from community to community [12]. For example, "health" in a specific informal settlement depends on the local phenomena of recognition, discrimination, services framework, livelihoods, violence, and diseases [13]. An analytical and interpretative perspective articulating multidimensionality, the multilevel, and the multidirectional facilitates understanding vulnerability throughout life [14]. Such a view reinforces that research must approach these studies with multilevel and multidimensional analysis of vulnerabilities.

The formulation of policies, decision making, and the design of adaptation strategies more in line with the local context are not only driven by the conditions of vulnerability but are also determined by the local socioeconomic context, which allows for improving the adaptation of disadvantaged populations in different latitudes [15].

Indeed, finding a theoretical definition that will capture all relevant dimensions of such a concept [16] seems to be a fruitless effort. Consequently, the authors elaborated their own to provide theoretical meaning to this investigation. To that purpose, they collected some relevant contributions from the literature. Ultimately, those efforts allow interpretation of the field study results and address the needs of different communities in the northern Mexican state of Chihuahua. Specifically, those communities were of four types: urban, peri-urban, rural, and forest territories. Those findings may add to future research projects in environments bearing some similarities. Understanding vulnerability requires a multidisciplinary approach and the participation of the community to generate a contextual analysis that is closer to the reality of the communities.

1.1. Dimensions of Vulnerability

Vulnerability sits at a cross point of different disciplines, supplying a vast catalog of definitions often aligned to specific areas of interest, such as climate change, risk hazards, or providing essential assistance to those in need. It may be understood simply as exposure to potential physical or emotional harm [17] or the undesirable effects of natural events or human activities [18]. It may be interpreted, as well, as the plausible decline in well-being [19] or any possibility of compromising a previous equilibrium by disturbing events [20]. Vulnerability is conditioned upon the ability of the individual "to cope with, resist, and recover from disaster damage" [21].

Many scholars take a more systemic approach, looking into unsafe conditions inherent to a specific setting [11] and dependent upon factors of a diverse nature [22]. Füssel [9] looks at a system as a whole, while Morales Salgado et al. [23] consider "the predisposition of a system, element, component, human group or any type of element, to be affected by the action of a specific threat situation." Kuran et al. [24] point to distinct elements and circumstances that make a community prone to adverse events, while Gallopin [25] points

to the linkages of the system with resilience and adaptive capacity. Moret [26] focuses on the probability of the system's components preventing adverse outcomes from external influence. Finally, McEntire et al. [27] offer a more holistic view, blending the research results "from physical science, engineering, and social science research." Table 1 collects some of those definitions.

Table 1. Vulnerability, as seen from different angles.

Authors	Definition of Vulnerability
Wolf et al. [17], citing The Oxford Dictionary of English.	"exposed to the possibility of being attacked or harmed, either physically or emotionally." (The Oxford Dictionary of English).
Cardona [18].	Exposure to "the possibility that an undesirable state of reality (adverse effects) will occur as a result of natural events or human activities."
Alwang et al. [19], citing the World Development Report 2000/1: Attacking Poverty.	". . .the resulting possibility of a decline in well-being." World Bank (2000).
Giorgi et al. [20].	"the potential state, whose equilibrium can be compromised by a disturbing event."
Kim et al. [21], citing Wisner, B., Adams, J., and Adams, J. (Eds.) and the World Health Organization.	"people's ability to anticipate, cope with, resist, and recover from disaster damage." (WHO, 2002).
Paul, S. [11].	"*unsafe condition* of an individual or bio-physical or socio-ecological system."
Hufschmidt [22], citing UNDRR. https://www.undrr.org/terminology/vulnerability (accessed on 4 March 2023)	"the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards." (UNDRR).
Füssel [9].	"The degree to which a system is susceptible to, or unable to cope with, adverse effects. . ."
Morales Salgado et al. [23].	"The predisposition of a system, element, component, human group or any type of element, to be affected by the action of a specific threat situation."
Kuran et al. [24], citing UNISDR.	"the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" (UNISDR, 2009).
Gallopín [25].	"vulnerability, resilience, and adaptive capacity (and robustness) are different manifestations of more general processes of response to changes in the relationship between open dynamical systems and their external environment."
Moret [26], citing Turner et al., 2003.	"the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor" (Turner et al., 2003).
McEntire et al. [27].	"vulnerability is based on factors related to liabilities and capabilities, and it has physical and social elements."

After considering all the previous definitions and concepts from Table 1, it may be said that:

> *Vulnerability is an undesired state of exposure to known or unknown risks, which may result in declining individuals' or populations' well-being due to potential natural events or human action.*

Analyzing vulnerability requires qualitative and quantitative methods and indicators that offer a global vision [28] and a local view of the specific needs and vulnerability factors [15]. The spatial and temporal distribution of the processes and patterns of the socio-ecological vulnerability requires a multidisciplinary perspective that reflects the reality of local contexts [20].

A dimension of vulnerabilities, whose importance is generally underestimated, is related to land protection and valuation. Legislative issues are a key component for the management of our contemporary cities and one of the most important factors influencing urban phenomena. Possession of legal papers allow access to governmental support and credits for housing, as in the case of the Mexican INFONAVIT, which can provide support just in those cases where the ownership of land and buildings are demonstrated by law [29]. Anyway, the possession of legal papers also contributes to the generation of a sense of recognition, which can play a very important role in reducing the vulnerabilities' perception [30,31]. For these reasons, in order to reduce possible vulnerabilities of land consolidation and valuation, new codes and rules are more and more needed in our legislation systems [32,33]. In particular, this is true when legislation faces contemporary challenges, such as migration issues [34].

1.2. Tools to Measure Vulnerability

A full range of tools is available for international comparisons, such as those designed by CARE, The World Bank, the E.U., international organizations, or different NGOs. Still, those tools must undergo a comparative assessment to find the proper combination fitting a specific purpose [35]. The United Nations Multidimensional Vulnerability Index (MVI) sets a standard tool for international statistical comparison. The MVI provides an instrument for a "quantitative benchmark to measure structural vulnerability or lack of resilience across multiple dimensions of sustainable development at the national level, integrating three dimensions of sustainable development," based on the analysis of vulnerability and resilience, to identify potential structural exposure to risk, and assist countries under stress [36].

The MVI has a clear connection with the SDGs. Inequality and social vulnerability were some of the main concerns when compiling the 17 SDGs, although some of those fit better than others within the SDGs scheme [37]. The SDGs face the difficult challenge of meeting their targets while "leaving no one behind" [38] and providing "a shared vision of community that is part of worldwide narration [39]. However, as stated in its master plan, the idea behind the MVI is to focus on specific aspects of vulnerability without spreading the dimensions of interest over a myriad of indicators. As its creators stated, the index is not necessarily aligned with the SDGs [40]. Figure 1 shows the model with its different indicators.

No matter the choice of tools, a widely accepted rule adheres to the formula "Risk + Response = Vulnerability", and, among other principles, assessments should be predictive and flexible enough to be adaptable to a different scale of intervention [26]. Therefore, when looking at vulnerability at a local level, some modifications are necessary, which eventually opens a new set of possibilities. As it happens, on a global scale, specific tools, such as the Community-Based Risk Index, are already available, pointing out and measuring specific risks that a smaller community may face. The Community-Based Risk Index is a full system comprising 47 indicators to measure "physical/demographic, social, ecological and economic vulnerability" [41].

In any event, using indexes or any other instrument to assess vulnerabilities will be fruitless if the acquired knowledge does not impact public policy to face a threat to the individual or the community. Actions are needed to address risk through prevention and

mitigation, providing emergency solutions, and working with such issues with a long-term commitment [42].

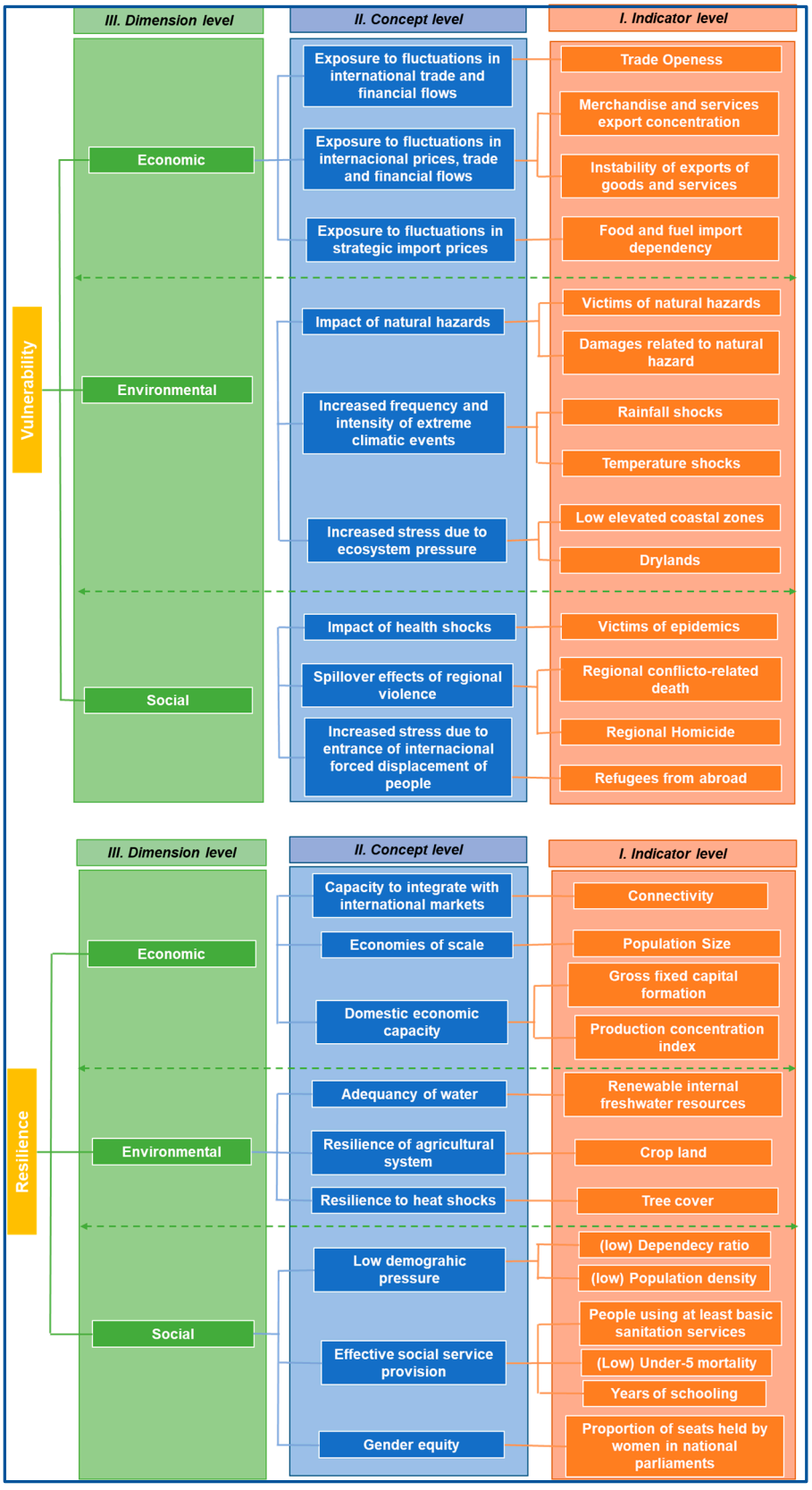

Figure 1. The U.N. Multidimensional Vulnerability Index (MVI) [36], image elaborated by the authors.

A holistic view of the situation with the potential to harm people could be the direction for further analysis of vulnerable communities. An example is the analysis of patterns of vulnerability, showing people "at risk of losing their livelihoods as a consequence of global ecological change" [28]; such a method allows the mapping of vulnerable areas with an ample set of scenarios. Similar methodologies have proven successful at the regional and national levels, as with the combination of mapping techniques and principal component analysis [43]. In a similar case, the primary component analysis was applied to the municipal level in Mexico, where the population bears many dimensions of vulnerability [44]. Another research project in Mexico used satellite imagery and machine learning instead to estimate income vulnerability within a small geographical area [45]. A further study in Mexico took the analysis to an even smaller scale, applying mixed methods to identify the local community's present and potential vulnerability factors [46].

Defining vulnerability is a considerable challenge, but it is no match to deciding how to measure it correctly. Exposure to hazards is often associated with individuals in need of assistance. Still, all communities are exposed to risk, no matter how complex and advanced the system may appear [47]; thus, there is a need for measurement, developing concepts, and indicators.

Traditionally, two approaches have been prevalent in measuring vulnerability: the economic view of poverty and those outside economics [48]. The first area encompassed three main methods based on the household's income, which, as Harttgen and Günther [49] state, are uninsured exposure to risk, expected poverty, and low expected utility. Naudé et al. [48] explain that much progress has been made outside of economics, mainly in estimating the probabilities and consequences of natural hazards, especially at the national and international levels. In addition to climate change or disasters caused by nature, some indexes can investigate social vulnerability, such as the Social Vulnerability Index or the Frailty Index, which come in handy with complex phenomena that may affect individuals or the group of reference [50]. Those indexes may work with techniques developed for nonsocial purposes, such as mapping instruments that will give visibility to a geographical area [51]. Thus, vulnerability results from specific spatial, socioeconomic, demographic, cultural, and institutional contexts [52] and should be measured using different instruments.

1.3. Design for Vulnerable—Research Project

This investigation is part of the "Design for Vulnerable" (DFV) project, which provides a multidisciplinary analysis to understand the different dimensions of vulnerability in four communities in the state of Chihuahua. The six dimensions of vulnerability proposed in the project are (1) sustainable mobility; (2) climate change; (3) gender approach; (4) resource optimization; (5) local businesses; and (6) urban health. The question guiding the project is how architectural design, in conjunction with other disciplines, can contribute to the empowerment of vulnerable communities and foster social inclusion and care in the coming years.

The main objective is to design an easy and affordable way to facilitate the access, dissemination, and appropriation of technological resources in vulnerable communities to overcome the socio-environmental threats that contribute to creating situations of vulnerability and promote the transformation from urban architectural design in cities and communities to make them more sustainable, inclusive and prosperous. In essence, the Design for Vulnerable project pursues the understanding of how architectural design and spatial changes can accelerate and facilitate technological assimilation to reduce vulnerabilities. The results should materialize in the development of startup ventures that aim to spread affordable technology solutions and promote changes in urban architectural dimensions in disadvantaged communities.

1.4. Research Question and Objective

The study aims to present a multidisciplinary descriptive framework of vulnerability in marginalized communities to provide a conceptual reference for measuring social and

environmental vulnerability at the local scale, knowing that vulnerability is contextual and multidimensional. This research has the following goals:

a. To analyze the socioeconomic vulnerabilities prevalent in northern Mexican communities, including poverty rates, income inequality, unemployment, and lack of access to essential services.
b. To evaluate the environmental vulnerabilities in the region, including exposure to natural hazards, climate change impacts, and the degradation of natural resources.
c. To examine communities' health vulnerabilities, such as inadequate healthcare infrastructure, limited access to healthcare services, and prevalent diseases.
d. To assess educational vulnerabilities, including school dropout rates, educational attainment levels, and the availability of quality education.
e. To investigate institutional vulnerabilities, focusing on governance structures, corruption levels, and the effectiveness of policies and programs.
f. To explore cultural vulnerabilities, including the marginalization of indigenous communities, loss of cultural heritage, and social discrimination.
g. To identify the interconnections and interactions between different vulnerabilities, recognizing the complex and interrelated nature of the challenges faced by communities in northern Mexico.

2. Methodology and Materials

This section covers the methodology that suits the research objectives, providing the context of the four geographical areas under scrutiny in the state of Chihuahua, with a birds-eye view of those communities, followed by a concise explanation of the data selection process.

The methodological approach was based on qualitative tools like questionnaires for indicators weighting from experts and community, and literature. Also, the data were analyzed with descriptive statistics.

The study area is the northern Mexican state of Chihuahua, which can be split into two distinctive regions: a semi-arid space and a mountainous region in the Sierra Madre Occidental. The state of Chihuahua is the largest in Mexico, although it is scarcely populated. The main urban areas are Ciudad Juárez and the capital city of Chihuahua. Ciudad Juárez is a border town and a manufacturing hub for "maquiladoras," with close to one and a half million people, more significant than the capital city, with a little less than a million inhabitants. The second region of the territory under study, the Sierra Tarahumara, is famous for its natural landscapes and for being home to an ethnic group bearing the same name, also known as Rarámuris. Figure 2 shows a map of the state of Chihuahua.

Figure 3 provides an image of each community and the four contextual areas in this study: urban, peri-urban, rural, and forest. The semi-arid region includes (I) Paso del Norte (urban) with the coordinates 28°67′41.77″ N, 106°06′90.05″ W; (II) Nueva Delicias (peri-urban) has the coordinates 29°07′19.96″ N, 106°25′16.02″ W; and (III) La Regina (rural) with the coordinates 28°24′45.1″ N 105°27′05.3″ W. Paso del Norte (I) has deficiencies in several areas, mainly in providing public services and mobility equipment. Although it is a suburb of Chihuahua's capital, the type of housing is of low socioeconomic status [53]. Nevertheless, the median income is higher in this area. Nueva Delicias (II) and La Regina (III) focus on agricultural production, on both large and small scales, depending upon the type of product being harvested. The main crops are cotton; alfalfa; walnut; peanuts; maize; chili; oats; wheat; beans; and forages. Cattle farming is also relevant, either for dairy products or meat production. Mining activities concentrate on barium sulfates. Nueva Delicias is located approximately 60 km north of the state capital.

The mountainous region includes the fourth community, Basaseachi (forest), with the coordinates 28°12′14.1″ N 108°12′34.5″ W. Basaseachi is approximately 295 km from the state capital. The climate is subhumid and different from the areas previously mentioned, showing extreme temperatures throughout the year, with an average annual rainfall of 683.3 mm. The main economic activities are forestry, gold mining, and ecotourism.

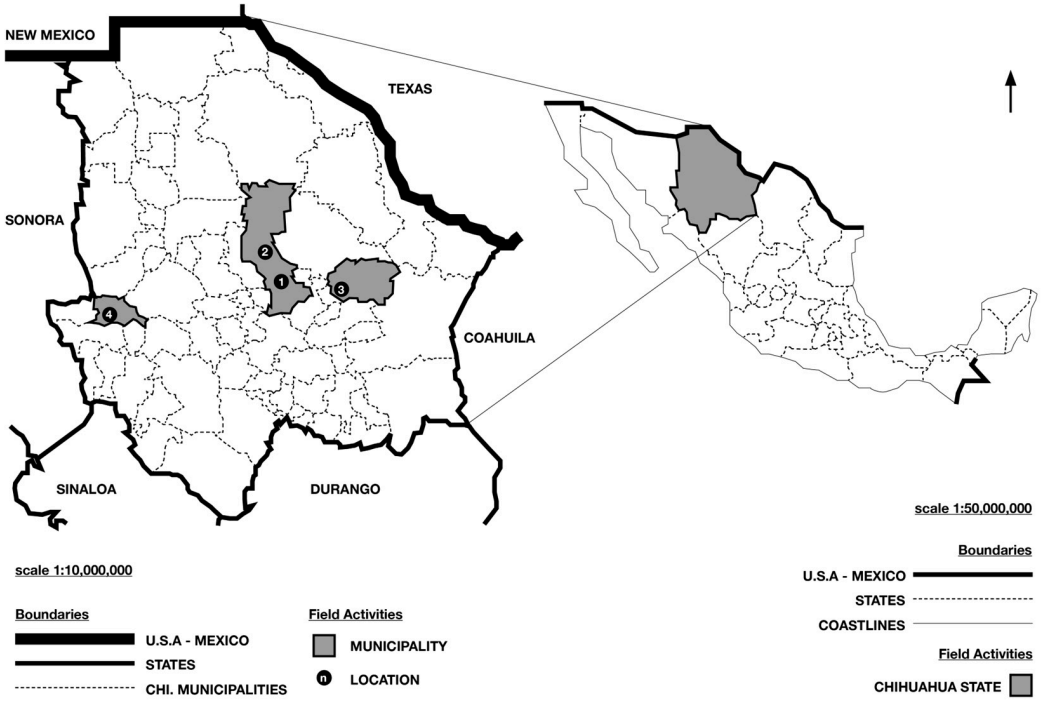

Figure 2. The state of Chihuahua. (1) Paso del Norte; (2) Nueva Delicias; (3) La Regina; (4) Basaseachi (drawing by authors).

Figure 3. The four communities: (1) Paso del Norte (urban); (2) Nuevas Delicias (peri-urban); (3) Julimes (rural); and (4) Basaseachi (forest). (Pictures by the authors.)

2.1. Data Selection Process

This study combines data from the existing literature and fieldwork, as described in Figure 4. The figure shows the four stages of the methodology: (1) identification; (2) screening; (3) weighting; and (4) the final set of indicators, aiming to describe the dimensions and indicators of social and ecological vulnerability in the four communities.

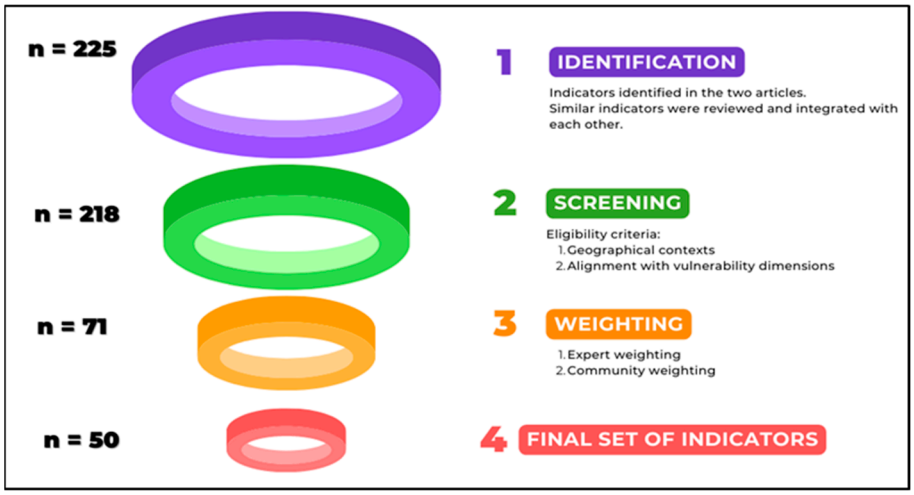

Figure 4. Phases of the selection process and criteria of indicators.

2.1.1. Stage 1: Identification (225 Indicators)

The first stage identified vital indicators, as Alary et al. [54] and Peng et al. [55] suggested. Those indicators were selected according to the following procedure:

- Compiling indicators through a literature review to assess sustainability in different geographical, ecosystem, and productive contexts, filtering by the most recent years of publication.
- Proposing a multiscale and multidimensional framework to assess sustainability and vulnerability from an integrated and strategic approach to address vulnerability.
- Revising and integrating similar indicators to reduce their final number.

2.1.2. Stage 2: Screening (218 Indicators)

The second stage used a qualitative scale to split those indicators into zero (if it applied) and one (if it did not). The selection criteria were (I) congruence with urban, peri-urban, rural, and forest contexts and (II) alignment with the six dimensions of vulnerability defined in the "Design for Vulnerable" project [56]. The categories identified in the previously mentioned study are (1) sustainable mobility (S.M.); (2) climate change (CC); (3) gender approach (G.A.); (4) resource optimization (ROP); (5) local businesses (L.B.); and (6) urban health (U.H.). Thus, the requirements for alignment with the vulnerability dimensions and geographical contexts were met. Figure 5 provides basic information about the ongoing Design for Vulnerable project.

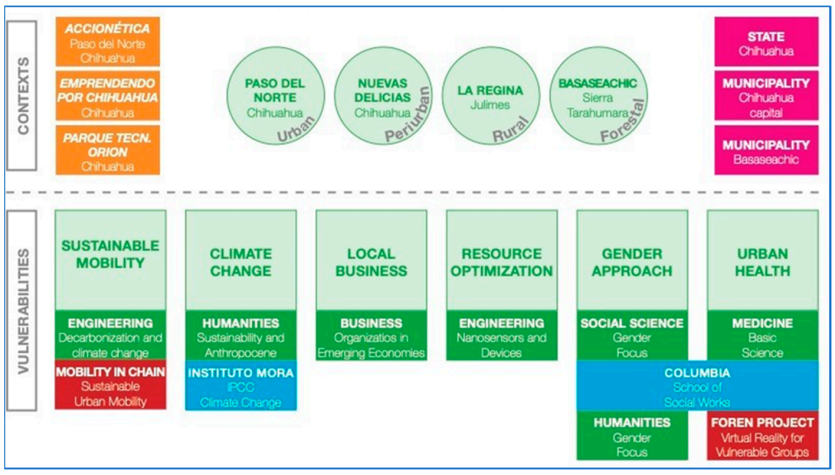

Figure 5. The challenge project, Design for Vulnerable.

2.1.3. Stage 3: Weighting (78 Indicators)

The third stage was intended to weigh the social and ecological indicators selected in the previous step, using both technical expertise and community weighting. The scale of choice was a three-point Likert scale (0—not at all important; 1—somewhat important; and 2—very important) to gauge expert opinions from the four localities on the importance of the chosen indicators. Such a scale could test the different indicators for each category upon matching expert views with those of community leaders. Such a procedure generated a set of indicators focusing on the contextual differences in the vulnerability of communities, both at the socioeconomic and ecological levels [57]. The results were analyzed with descriptive statistics to define the dimensions and indicators of the explanatory framework of vulnerability.

2.1.4. Stage 4: Final Set—Community Participatory Approach (50 Indicators)

The fourth stage assembled the final indicators from the literature review and a stakeholder's analysis of the communities involved. To collect data from the residents in the four vulnerable communities, the research group organized a list of the 78 indicators and results of the previous stage and asked the residents to evaluate each indicator with the values "0" (not relevant), "1" (maybe relevant), or "2" (relevant). The researchers asked the residents to evaluate each indicator according to the relevance of this specific topic in their life in the community. To do so, they organized one workshop in each district, where an assigned researcher could explain the meaning of every indicator with easy words to each group of residents. This exercise helped the research group to create a list of indicators elaborated with the participation of the communities.

3. Results

3.1. Identification of Indicators

From the literature review, 218 indicators emerged, grouped into ecological and social components (Table S1). The ecological part includes 116 indicators related to natural supply, livestock care, natural disasters, climate, ecological connectivity, and agricultural and livestock production. The social component comprises 102 indicators linked to the local and family economy, culture, ecological and social protection figures, employment, social exposure to natural disasters, urban equipment, demography and gender, and access to public services and infrastructure. The final set of indicators may help assess sustainability and vulnerability in specific socio-ecosystems. Likewise, this set of indicators allows for a vulnerability assessment from a socio-ecological perspective [55].

3.2. Screening by Eligibility Criteria

When applying the selection code of congruence with geographical contexts, the rural setting of La Regina fits all the indicators (102 social and 116 ecological). On the contrary, a much smaller number of indicators could be used in the urban area of Paso del Norte (78 ecological and 87 social). Figure 6 presents a comparison among the four territories under study.

Tables 2 and S2 show the comparative scores of the six dimensions of vulnerability using the alignment criterion. Resource optimization is the highest-scoring dimension (ROP/76%), followed by local businesses (L.B./58%), climate change (CC/55%), urban health (U.H./48%), gender approach (GA/47%), and sustainable mobility (S.M./24%).

The ROP dimension has the highest number of linkages (106) within the ecological component. Of those, 61 indicators cover two dimensions, 34 are related to three, while the main contributions for the social part are 28 indicators aligned with four dimensions, and 18 are aligned with five. However, U.H. and G.A. have the highest number of alignments with indicators of the social component: 88 and 85, respectively. In addition, 36 indicators of the social element of U.H. and 35 social indicators of G.A. are associated with four dimensions.

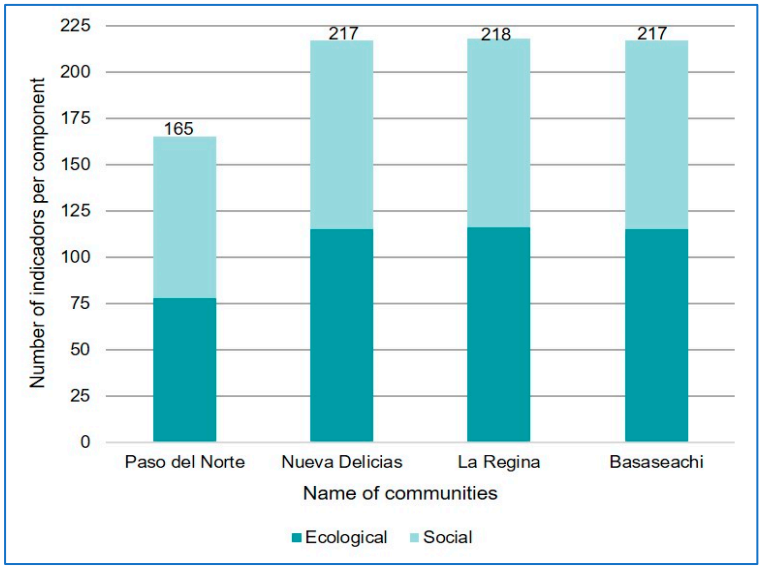

Figure 6. Distribution of indicators according to geographic contexts.

Table 2. Alignment of indicators with vulnerability dimensions.

Number of Dimensions	Component	CC Climate Change	ROP Resource Optimization	L.B. Local Businesses	GA Gender Approach	U.H. Urban Health	S.M. Sustainable Mobility
1	Ecological	2	0	1	0	0	1
	Social	0	0	0	0	0	0
2	Ecological	42	61	19	1	1	0
	Social	0	4	4	6	9	3
3	Ecological	39	34	34	5	5	0
	Social	2	7	23	23	22	7
4	Ecological	6	6	0	6	6	0
	Social	9	28	30	35	36	22
5	Ecological	5	5	5	5	5	0
	Social	13	18	9	19	19	17
6	Ecological	0	0	0	0	0	0
	Social	2	2	2	2	2	2
Subtotal	Ecological	94	106	59	17	17	1
	Social	26	59	68	85	88	51
Total		120	165	127	102	105	52

Figure 7 and Table S2 show a more detailed view of the results, with 34% of the indicators linked to two dimensions and only 1% aligned with six. In the latter case, they are indicators of the social component, the household proportion with a person aged 65 and older, and population density.

In addition, of the ecological component, 53% of the indicators have links with two dimensions. In comparison, 34% of the ecological indicators are aligned with three dimensions, 5% of the indicators are associated with four, and 4% are related to five dimensions. Finally, 3% are aligned with a single dimension (Distance–SM; Biodiversity Intactness Index–CC; Percentage of protected area–CC; and tourism to GDP-LB). Of the social indicators, 2% are aligned with six dimensions of vulnerability. In contrast, 40% of the indicators are related to four dimensions, 27% are associated with three dimensions, 19% of the social indicators are aligned with five dimensions, and 13% are linked to two dimensions. The ecological component had no indicators grouping all six dimensions, nor did the social part.

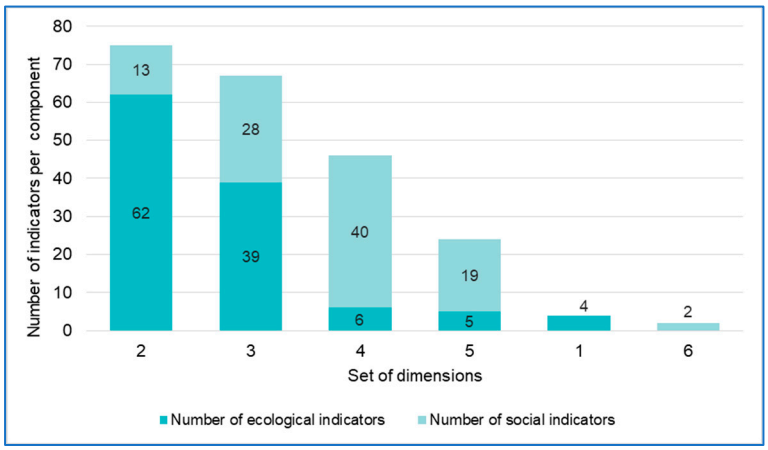

Figure 7. Links between indicators and the dimensions.

3.3. Weighting Indicators by Experts and Community

A total of 43 people participated in the community weighting process, with 31 women, 10 men, and two individuals who did not state their gender. The average age in the whole group was 42 years, 43 for women and 40 for males. Everyone was over 18 years old. In the first instance, the weighting of the 218 indicators was based on experts' technical judgment (Figure 8 and Table S3). In ascending order, 6% of the indicators had a zero average rating, 15% had only one, 22% had two, 25% had three, and 33% had four.

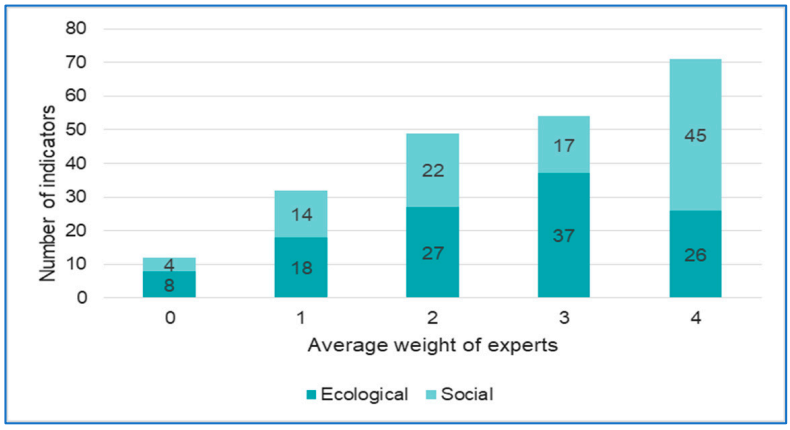

Figure 8. Weighting of experts.

On the other hand, indicators with an average weight of four were assigned one of the categories of environment, social, or territory (Figure 9). In each category, the indicators have the following distribution: environment (nine), social (twenty-eight, with four ecological and twenty-four social), and territory (34 indicators: 13 ecological and 21 social), for a total of 71 indicators (26 ecological 45 social). Table S3 shows the results after the expert application of the Si criterion.

The following results come from the community's weighting of indicators. In the measures of central tendency, the most repeated assessment is 2—very important in the whole data set, by ecological and social components (Table 3). Likewise, the valuation of very important is the one that is most repeated in each of the geographical contexts: in La Regina (64.5%), in Nuevas Delicias (50.5%), in the Paso del Norte colony (44%), and in Basaseachi (39.3%). The information is shown in Table S4.

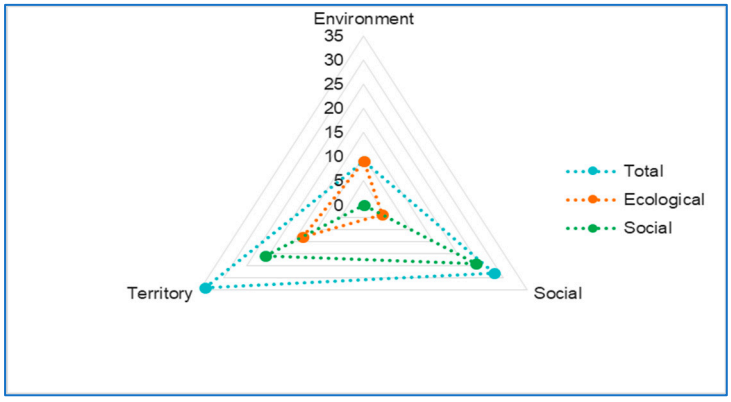

Figure 9. General categories of expert-weighted indicators.

Table 3. Measures of central tendency of community weighting.

	All Data	Ecological Component	Social Component
Mode	2.00	2.00	2.00
Mean	1.36	1.44	1.31
Median	2.00	2.00	1.00
Standard deviation	0.73	0.70	0.75
Mean deviation	0.66	0.63	0.67
Variance	0.54	0.49	0.56
Coefficient of variation	0.54	0.49	0.57
Maximum limit	2.09	2.14	2.05
Minimum limit	1.34	1.37	0.33

Of the total indicators, 11 have a value of one. In the ecological component, two indicators score lowest: animal seasonal cash flow compared to family food and health expenses and rate of afforestation area. In the social element, nine indicators have a low weighting (value = 1). Those indicators are the emigration rate; the percentage of the population living in informal settlements; the percentage of households without official land titles; the percentage of the illiterate population; the percentage of the population with disabilities; the percentage of households without gross savings, and the number of people with higher education. The indicators with a zero value are the percentage of the population without electricity access and households without bank loans/(micro-)credits.

Table 4 shows the measures of central tendency according to each geographical context. However, in each locality, the set of indicators has different preferences.

Table 4. Measures of central tendency in each geographical context.

	Paso del Norte	Nueva Delicias	La Regina	Basaseachi
Mode	2.00	2.00	2.00	2.00
Mean	1.00	2.00	1.58	1.00
Median	0.77	0.72	2.00	0.76
Standard deviation	0.68	0.64	0.63	0.65
Mean deviation	0.59	0.52	0.55	0.58
Variance	0.59	0.52	0.40	0.58
Coefficient of variation	0.68	0.32	0.40	0.65
Maximum limit	1.68	1.36	2.22	1.65
Minimum limit	0.32	1.24	2.55	0.18

In Basaseachi (forest), the community assessment indicates that 56% of the proposed indicators score nothing important (seven) and something important (21). In Paso del Norte (urban), 46% of the indicators weigh low (seven are not critical, and sixteen are somewhat important). Then, in Nueva Delicias (peri-urban), 36% of the indicators are weighted as unimportant (three indicators as not essential and fifteen as somewhat necessary). Finally, in the town of La Regina (rural), 16% of the indicators are unimportant for the community. Six indicators weigh one, while two have a rating of zero (Table S4).

3.4. Final Set of Indicators

Tables 5 and 6 show the selected indicators according to the three-point rating scale, with those with a mode of two integrating a general and local set. Table 5 includes data for the ecological context, while Table 6 includes data for the social one.

Table 5. Vulnerability indicators for ecological contexts.

Ecological Component	General Set	Paso del Norte	Nueva Delicias	La Regina	Basaseachi
Indicator	**Mode**	**Mode**	**Mode**	**Mode**	**Mode**
Groundwater quality	2.0	2.0	2.0	2.0	1.0
Animal seasonal cash flow compared to family food and health expenses.	1.0	2.0	1.0	1.0	2.0
Proximity index (distance)	2.0	2.0	2.0	1.0	2.0
Species richness and diversity	2.0	2.0	1.0	2.0	2.0
Soil and water quality and availability	2.0	2.0	2.0	2.0	2.0
% of protected area	2.0	2.0	0.0	2.0	2.0
Standard deviation of annual rainfall	2.0	2.0	2.0	2.0	2.0
Biodiversity of landscapes	2.0	2.0	2.0	2.0	2.0
Ecosystem exposed to flooding	2.0	2.0	1.0	2.0	0.0
% of vegetation loss	2.0	2.0	2.0	2.0	2.0
% of deforested area	2.0	2.0	2.0	2.0	2.0
% of the area covered by "problem soils"	2.0	2.0	2.0	2.0	2.0
Increased use of chemicals and fertilizers	2.0	2.0	2.0	2.0	1.0
Forest connectivity	2.0	2.0	2.0	2.0	2.0
River connectivity	2.0	2.0	2.0	2.0	2.0
% of change in land use (agriculture, vegetation, settlement)	2.0	2.0	2.0	2.0	1.0
% of forest area restored	2.0	2.0	1.0	2.0	2.0
Rate of afforestation area	1.0	2.0	1.0	2.0	2.0
Ecosystem exposed to drought	2.0	1.0	2.0	2.0	2.0

Table 6. Vulnerability indicators for social context.

Social Component	General Set	Paso del Norte	Nueva Delicias	La Regina	Basaseachi
Indicator	**Mode**	**Mode**	**Mode**	**Mode**	**Mode**
Surface area of sites of community importance	2.0	2.0	2.0	2.0	2.0
Employment in tourism and other aesthetic activities	2.0	2.0	2.0	2.0	2.0
% of houses with poor facilities that are more fragile to climate change and hazards	2.0	2.0	1.0	2.0	1.0
% of population exposed to drought/flooding	2.0	1.0	2.0	2.0	1.0
Emigration rate	1.0	1.0	0.0	2.0	1.0
% of population without access to electricity	0.0	1.0	2.0	0.0	0.0
% of households without access to irrigation	2.0	1.0	1.0	2.0	0.0
% of population without access to clean water	2.0	2.0	2.0	2.0	2.0
% of population living in informal settlements	1.0	2.0	1.0	1.0	0.0
Household proportion with persons aged 65 and older	2.0	1.0	1.0	2.0	1.0
% of households without official land title	1.0	1.0	1.0	1.0	1.0
% of population living in poorly constructed houses	2.0	2.0	1.0	2.0	1.0
% of illiterate population	1.0	1.0	2.0	1.0	1.0
% of primary industry to GDP	2.0	2.0	2.0	2.0	1.0
% female-headed households	2.0	1.0	2.0	2.0	1.0
% of the population with disabilities	1.0	1.0	1.0	2.0	1.0
% malnourished population	2.0	1.0	2.0	2.0	1.0
% of families below poverty line in total households	2.0	1.0	2.0	2.0	1.0
% of households without individual means of transportation	2.0	1.0	1.0	2.0	0.0
% of households without gross savings	1.0	1.0	1.0	2.0	1.0
% of households without access to bank loans	0.0	0.0	0.0	0.0	0.0
% of households without any insurance—excl. health insurance	2.0	0.0	2.0	2.0	1.0
Equipment: telephone, internet, road, electricity, etc.	2.0	0.0	2.0	1.0	2.0
Number of people with higher education	1.0	2.0	2.0	2.0	1.0

Table 6. *Cont.*

Social Component	General Set	Paso del Norte	Nueva Delicias	La Regina	Basaseachi
Indicator	**Mode**	**Mode**	**Mode**	**Mode**	**Mode**
Volume of water storage in a safe reservoir/container	2.0	0.0	2.0	2.0	1.0
% of households without access to waste/water treatment	2.0	2.0	2.0	2.0	2.0
Access to emergency places (density of hospitals, fire bridges, police stations)	2.0	1.0	2.0	2.0	2.0
Density of transportation network	2.0	1.0	2.0	2.0	1.0
% of population who have experienced hazard(s) in the past 10 years	2.0	0.0	1.0	2.0	0.0
Number of income-generating activities per household	2.0	0.0	2.0	2.0	2.0
Existence of adaptation policies/strategies	2.0	0.0	2.0	2.0	1.0

In La Regina, the group includes 42 indicators, 17 ecological and 25 social ones. In Basaseachi, vulnerability can be measured with twenty-two indicators: fifteen ecological and seven social components. In Nueva Delicias, 32 indicators were identified, grouping 13 ecological and 19 social indicators. In Paso del Norte, the set of indicators consists of twenty-seven: eighteen ecological, and nine social indicators (Table S4).

Each community's proposed set of indicators of the descriptive vulnerability framework is heterogeneous. It will allow measuring social and ecological vulnerability from a multidisciplinary perspective through the six dimensions and according to the local context.

This investigation has generated a descriptive vulnerability framework approximation, and the results are two-fold. On the one hand, there is a conceptual understanding of the link between vulnerable communities and ecosystems in different geographical and ecological contexts. On the other hand, there is an illustration of 50 social and ecological indicators weighted by stakeholders, aligning with the six vulnerability dimensions.

Vulnerability is a complex, multidimensional, multiscale, multitemporal, and heterogeneous phenomenon [58,59] that requires intersectional approaches [24] and disciplinary overlap to be analyzed with a multi-, inter-, or transdisciplinary approach [60,61]. Vulnerability research integrates multiple fields of knowledge, such as climate change. It is often associated with ecological degradation, inadequate policies or unfavorable commercial conditions [62], development and poverty studies, anthropology, land management, disaster management, public health, and sustainability [11]. Thus, the proposed dimensions explore vulnerability in four different contexts under a multidisciplinary approach targeting (1) sustainable mobility; (2) climate change; (3) gender approach; (4) resource optimization; (5) local businesses; and (6) urban health.

4. Discussion

The comprehensive measurement of vulnerability should consider social and ecological or biophysical vulnerability separately and in the interaction between both units [63,64]. Thus, systemic and integrated approaches [65] should look at socio-ecological vulnerability [63,66], including ecological or social indicators with a participatory perspective or those focused on transformation processes [54,67,68]. Facchini et al. [62] point out that vulnerabilities are individual, collective, socioeconomic, demographic, or ecological processes

that are not correlated but are always interrelated with feedback effects. Similar results are shown by their studies on the implications of feedback processes in rural development in Spain and the sustainability of livestock systems in drylands. Therefore, the proposed descriptive framework and indicators may allow the identification of the future effects of vulnerability feedback on the four communities in the north of Mexico.

From the perspective of social vulnerability, this relationship compromises well-being in several ways because multiple threats can coincide, affecting the individual or population group that may be vulnerable in more than one dimension (e.g., migration, conflicts, health problems, and food insecurity), increasing the likelihood of being vulnerable to other threats as well [69]. Likewise, as a multidimensional concept, social vulnerability allows identifying the community's attributes to respond to ecological hazards [63]. However, Beroya-Eitner [66] points out that such a type of vulnerability is a recent concept that must be developed at small scales and in specific contexts due to the nonlinearity, complexity, and dynamics of natural systems.

The results from this study show the proportion of ecological and social indicators of the proposed indicators, where the 19 ecological indicators are in smaller numbers than the 31 social indicators. At the local level, ecological indicators predominate in the forest and urban contexts, while social indicators stand out in the peri-urban and rural areas. The latter contradicts the results of Facchini et al. [62], who point out that in studies of rural vulnerability in Spain, ecological factors prevail over social ones. Therefore, the social and ecological history and the processes of landscape transformation could determine the perception of which components of vulnerability stay in the study context.

From an overview of the descriptive framework, the indicators of the ecological component (116) are the most numerous within the total set of indicators (218). Regarding the dimensions of vulnerability, the dimensions of resource optimization and climate change are the ones that incorporate the most indicators from the ecological component. On the other hand, urban health and gender approach are the dimensions most integrated by indicators of the social element. Likewise, the six dimensions of vulnerability are proposed to allow an alignment with the aspects and frameworks of the global vulnerability assessment based on indicators [70,71].

At the local scale, ecological indicators predominate in the forest and urban contexts, while social indicators stand out in the peri-urban and rural areas. To further contextualize the descriptive framework, further steps should define which of the proposed ecological and social indicators allow the diagnosing and assessing of vulnerability in terms of exposition, sensitivity, and threat and the deepening of the intersectionality approach to better understand the effect of social stratification and the various dimensions of vulnerability in the four communities [24].

In recent years, several studies have been conducted to develop vulnerability indicators that are integrative, robust, and replicable to understand the complex interaction of vulnerability components at different scales to focus interventions and decision making against the factors that threaten community sustainability [41,64,66]. The proposed indicators for this investigation cover essential aspects such as the economy, access to basic services, literacy rate, and social protection. These are used in global vulnerability assessment frameworks based on indicators such as the World Risk Index and the INFORM Index [70]. Additionally, the indicators help to identify who is at risk. Causal analysis indicates why they are at risk and guides what actions should be taken [72].

The proposed descriptive framework of vulnerability is an approach to an indicator model that takes up global conceptual dimensions to measure contextualized vulnerability in four exposed communities. It also facilitates the applicability and its impact on state and local policy while providing adequate information to reduce vulnerability [11,41] and allowing for the identifying and mapping of factors necessary for sustainable development [73]. Likewise, the ecological and social indicators describing a vulnerability in the four heterogeneous communities are conceptually linked to the typical dimensions and

indicators of vulnerability in arid zones, such as poverty, water stress, degradation of natural resources, agro-natural restrictions, and isolation [71].

The impact of the development of a system of indicators, with the participation of the community, is not only the definition of indicators itself, but involves other aspects such as (a) creating and/or strengthening relationships of trust and mutual respect, (b) designing and implementing participatory techniques to acquire technical and socio-environmental knowledge to favor the community, (c) making the residents of the communities aware of some issues that may pass as secondaries, and (d) laying the foundations for the project's next steps to reduce vulnerability through current technology.

The set of indicators developed from the literature, validated by the experts and selected by the residents, is only a first step. Shortly, it will follow the identification of strengths and weaknesses for the implementation and follow-up of technological intervention strategies and the creation of partnerships between community and scientific collaborators to address different vulnerability dimensions. All of that will be contextualized at a local level.

5. Conclusions

Vulnerability analysis at the local scale and in heterogeneous contexts needs a multidisciplinary descriptive framework adaptable to peculiar ecological and social characteristics, such as the one proposed in this study. In addition, this set of dimensions and indicators is the first step to performing the standardization and modeling process. Even if modest, this investigation may offer new insights into addressing different vulnerability types in diverse but interrelated territories. As the field territory expands, it increases the complexity of the phenomena under scrutiny. Thus, other possibilities for future research lay open to those that may provide reliable measures of contextual factors to measure the stated constructs. This research contributes to the broader field of vulnerability studies by demonstrating the significance of a multidisciplinary approach in understanding and addressing the challenges faced by communities in Northern Mexico and similar territories.

The results of this investigation lead to several recommendations. In the first place, dynamics involving populations in need require the shared effort of experts from multiple disciplines. Tackling complex problems in those communities requires a broad approach, with scholars and practitioners willing to leave aside the fundamentals of their fields instead of a joint effort with those from careers with little overlap. It is not only a matter of unifying different areas of knowledge but being willing to learn new tools and work hand in hand with those who may look at differently at a given problem. In the second place, community engagement is fundamental to understanding those scenarios, which is probably easier said than done. During the field study for this investigation, researchers devoted much time to listening and understanding the local voices. It is not only a matter of language but the openness to strangers and the difficulty in understanding traditions and local thinking, which frequently leads to slow learning, consolidating over a long time. In third place, adding voices to speak about a social problem may increase the number of proposals. Still, it is necessary to set some communication rules to benefit from synergies. Finally, many tools proven internationally may require some adaptation to local needs. Still, it may be worth making those small changes and using standards and methodologies already tested.

This project was conducted in Mexico, an economy with many needs. The targeted areas are home to people of different socioeconomic statuses, although there is a prevailing scarcity of the most basic needs. Nevertheless, vulnerability is not inherent to lower income. As illustrated in the literature review, there is no society where all its members may escape from risk or potential hazard. Vulnerability in advanced economies may differ from less affluent nations, but it is a part of life for many individuals in more fortunate countries. New studies could target the importance of the self-perception of vulnerability across societies, perhaps drawing from the experiences of less prosperous nations. When coming across exposure to natural disasters or social inequality, the dividing line between the

haves and the have nots may be thinner than expected. Therefore, all societies should embrace those in need in foreign lands, careful not to neglect their citizens exposed to perils and limitations.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su151713077/s1, Table S1: List of social and ecological indicators; Table S2: Selection of indicators by selection criteria; Table S3: Expert weighting of indicators; Table S4: Analysis of data.

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