Atmósfera 35(1), 179-196 (2022)
https://doi.org/10.20937/ATM.52895

REVIEW ARTICLE

Vulnerability assessment studies on climate change: A review of the research in Mexico

Areli NÁJERA-GONZÁLEZ[1] and Fátima Maciel CARRILLO-GONZÁLEZ[2]*

[1]*Centro Universitario de la Costa, Av. Universidad de Guadalajara 203, Ixtapa, Los Tamarindos, 48280 Puerto Vallarta, Jalisco, México.*
[2]*Departamento de Ciencias Exactas, Centro Universitario de la Costa, Av. Universidad de Guadalajara 203, Ixtapa, Los Tamarindos, 48280 Puerto Vallarta, Jalisco, México.*
*Corresponding author; email: fatima.carrillo@academicos.udg.mx

Received: April 28, 2020; accepted: September 21, 2020

RESUMEN

Los estudios para valorar la vulnerabilidad al cambio climático son una herramienta esencial para la adopción de estrategias de adaptación que permitan saber cuáles son las amenazas que enfrentan los sistemas y sus componentes (especies, recursos naturales, poblaciones y territorios, entre otros) en condiciones de cambio climático, qué acciones incrementan su vulnerabilidad y qué estrategias se han implementado para reducirla. La popularidad de este tipo de estudios a nivel internacional ha suscitado debates acerca de sus métodos, componentes y variables. ¿Cómo se ha valorado la vulnerabilidad al cambio climático en México? El objetivo de este estudio es presentar una revisión de los estudios en este ámbito, con especial atención a los sujetos de estudio, conceptos, componentes, metodologías, herramientas y aplicaciones. La metodología del estudio consistió en una búsqueda y revisión sistemáticas de artículos publicados en bases de datos internacionales (Scopus, Web of Science, Science Direct y Scielo). Se revisó un total de 57 artículos. Como resultado se identificaron lagunas de conocimiento en la investigación sobre este tema. Los resultados obtenidos pueden utilizarse como guía para entender el marco teórico y conceptual de la vulnerabilidad y en el futuro realizar investigaciones sobre los sujetos y áreas menos estudiados en México.

ABSTRACT

Vulnerability assessment studies on climate change are a substantial tool for the implementation of adaptation strategies that allow us to know what threats systems and their components (species, natural resources, populations, territories, among others) do face on climate change conditions, what actions are caused by them that increase their own vulnerability, and what strategies are implemented to reduce this vulnerability. The popularity of this research at the international level has caused different discussions about methods, components, and variables. How does the vulnerability to climate change have been assessed in Mexico? The objective of this article is to present a review of vulnerability assessment studies on climate change in Mexico, paying particular attention to study subjects, concepts, components, methodologies, tools, and applications. The method consisted of a systematic search and review of articles published on international databases (Scopus, Web of Science, Science Direct, and Scielo). A total of 57 articles were reviewed. The results identify knowledge gaps in research of vulnerability on climate change in Mexico. The conclusions can be used as a guide to understand the theoretical-conceptual framework of vulnerability and to conduct future research on subjects and areas which are less studied in Mexico.

Keywords: adaptive capacity, global warming, vulnerability indicators, vulnerability evaluation.

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), climate change is the term used to refer to changes in climate that persist for an extended period. It is the result of climatic variability at different scales in conjunction with anthropogenic actions that directly alter the climate, such as emissions of gases to the atmosphere and deforestation (IPCC, 2007, 2014).

These changes in climate cause an endless number of transformations in natural systems, such as intensification of hydrometeorological phenomena, variations in the water and carbon cycle, and changes in species' behavior. These, in turn impact the socioeconomic system causing floods, freshwater shortages, food insecurity, diseases, poverty, and violence. Currently, the phenomena derived from climate change are considered as one of the main threats to human populations (IPCC, 2014).

One way to understand the effects of climate change is through vulnerability assessment studies. Vulnerability is defined as the propensity of a system and its components (such as species, natural resources, cities, territories) to be damaged by a threat (e.g., processes, phenomena, or events) based on the system's ability to overcome the damage (Moss et al., 2001; Füssel and Klein, 2006). These studies focus on analyzing the threats faced by the systems and the characteristics that help these systems to deal with them, intending to propose strategies that reduce the system's vulnerability (Füssel, 2007).

As explained by Gallopín (2006), vulnerability is analyzed in three components: exposure (exposed elements of the system), sensitivity (processes or events that cause damage to the system), and a response capacity component called adaptive capacity which consists of actions and habits of the system to overcome the damage (these are physical and socioeconomic characteristics that help to reduce the system's vulnerability).

To assess vulnerability, its components are integrated into a mathematical formula (exposure + sensitivity – adaptive capacity), and the result is interpreted as a vulnerability index (Gallopín, 2006). The function of vulnerability studies is to provide a sufficient context of information to guide adaptation strategies, which are designed to respond to damage at local level caused by climate change phenomena (Kelly and Adger, 2000; Gallopín, 2006; Füssel, 2007) (Fig. 1).

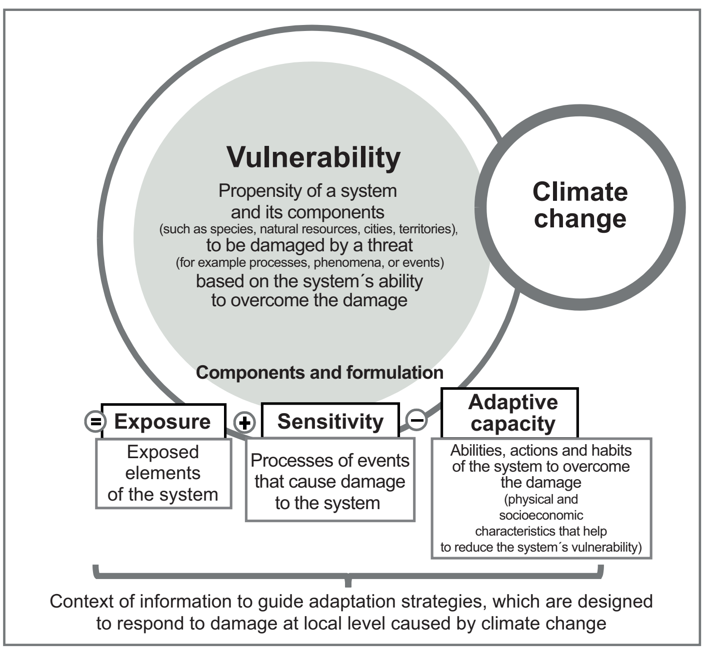

Fig. 1. Concepts and components of vulnerability assessment studies on climate change.

The influence of theoretical origins plays a determining role in vulnerability assessment studies on climate change (Füssel and Klein, 2006). As stated by Coy (2010), in natural sciences and engineering the concept of vulnerability arises from risk theory, the concept is understood as the physical predisposition of a human community to be damaged by some external entity such as natural disasters (whether derived from climate change or not). Therefore, vulnerability assessment studies provide information to propose adaptation strategies that minimize the damage that might be caused by a specific natural disaster (Coy, 2010).

On the other hand, in social sciences, it is considered that vulnerability does not depend only on physical conditions or location, but also depends on social, economic, and cultural factors. Therefore, vulnerability assessment studies provide information to propose adaptation strategies that reduce the vulnerability of human communities by strengthening certain socioeconomic characteristics (Coy, 2010).

As an integrative point of view, the multidisciplinary perspective, as a characteristic of geographical sciences, states that human communities cohabit in socio-environmental systems immersed in conditions of climate change. Thus, vulnerability assessment studies are composed of a balance between physical predisposition and the socioeconomic and environmental characteristics of systems that increase or reduce their vulnerability, which leads to propose complex adaptation strategies (Füssel and Klein, 2006; Gallopín, 2006).

Since 1995, different international organizations have declared that vulnerability assessment studies are a useful tool for decision-making and are essential to face future challenges in terms of climate change (IPCC, 1995; Kelly and Adger, 2000). This has increased the academic popularity of this research topic, causing a diversity of discussions, methods, components, and variables, according to the scientific areas and the challenges of each country (Füssel and Klein, 2006; Gallopín, 2006). What has been done in Mexico about it? How has the vulnerability to climate change been assessed in Mexico?

The objective of this article is to present the results of a literature review about the research conducted on vulnerability assessment studies on climate change in Mexico, paying particular attention to study subjects, concepts, components, methodologies, tools, and applications, in order to identify knowledge gaps.

2. Materials and methods

The method used for this work was a systematic search and review. As explained by Grant and Booth (2009), this type of review combines the strengths of a critical review with a comprehensive and systematic search process to result in the best synthesis of evidence on a topic. It is characterized by answering broad questions previously defined, presenting a clear and systematic scheme for the selection of papers, showing the obtained results according to each question in narrative with tabular accompaniment, and discussing knowledge, recommendations for practice, and limitations.

For the development of the review, we followed the three stages of the guide described by Pullin and Stewart (2006): questions formulation, selection of data, and report of results.

2.1 Questions formulation

We defined four topics to answer seven specific questions (Fig. 2):

1. Timeline, institutional origin, and associated words. Since when the vulnerability to climate change in Mexico is assessed (timeline), who makes the assessment (institutions), and what are the main words associated with this research topic?
2. Study subject and spatial location. What are the study subjects on vulnerability assessment studies on climate change (for example biological species, towns, cities, natural resources), and where are they located in Mexico (spatial location)?
3. Scientific area, theories, methods, variables, indicators, measurement units, and tools. What scientific areas and theories predominate, and what methods and formulas are used to assess vulnerability to climate change? How are the components of vulnerability (exposure, sensitivity, and adaptive capacity) conceptualized, and what variables are used for each one? What are the methods used to normalize and estimate the weight of indicators in each variable? What are the measurement units used to express the level of vulnerability, and what are the most used tools?

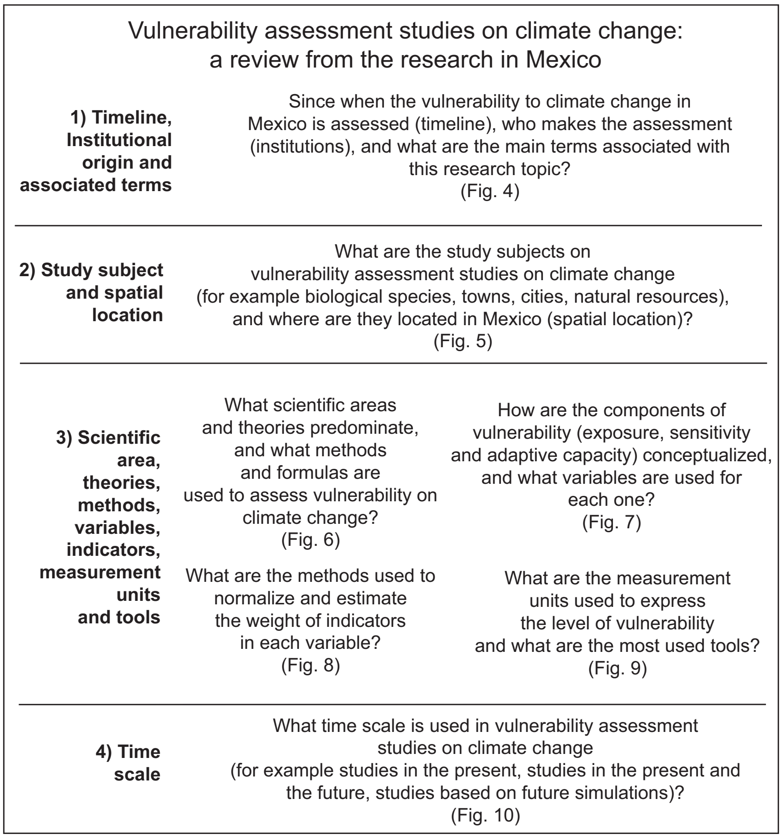

Fig. 2. Development of the review (specific questions and distribution of figures in results).

4. Time scale. What time scale is used in vulnerability assessment studies on climate change? (e.g., studies in the present, studies in the present and future, studies based on future simulations).

2.2 Selection of data

The databases used for this work were Scopus, Web of Science (WOS), Science Direct, and Scielo. Only articles published until the day of the search (March 8, 2019) were selected. Book chapters, reviews, conference articles, books, editorial material, or letters were excluded. The search details are described in Figure 3.

The first search was carried out with the terms "climate change" AND "vulnerability" located in keywords, abstract, or title. As suggested by Tonmoy et al. (2014), in order to capture as much of the relevant literature as possible, in the second search we added terms related to climate change and vulnerability such as ("climate change" OR "global warming" OR "climate variability") AND ("vulnerability" OR "resilience").

The term "global warming" refers to the prevalence of warmer temperatures as a consequence of the excessive concentration of greenhouse gases that affects the Earth's radiative balance. On the other hand, the term "climate variability" refers to fluctuations in the mean state of different climate variables on spatial and temporal scales beyond individual weather events (it may be due to natural processes or anthropogenic forcing) (IPCC, 2014).

The term "resilience" refers to the ability of socio-environmental systems to cope with a dangerous event while maintaining their adaptive capacity (IPCC, 2014). Thus, resilience, as well as adaptive capacity, are part of the response capacity component in the theoretical framework of vulnerability (Gallopín, 2006). Janssen and Ostrom (2006) state that both terms, resilience and vulnerability/adapt-

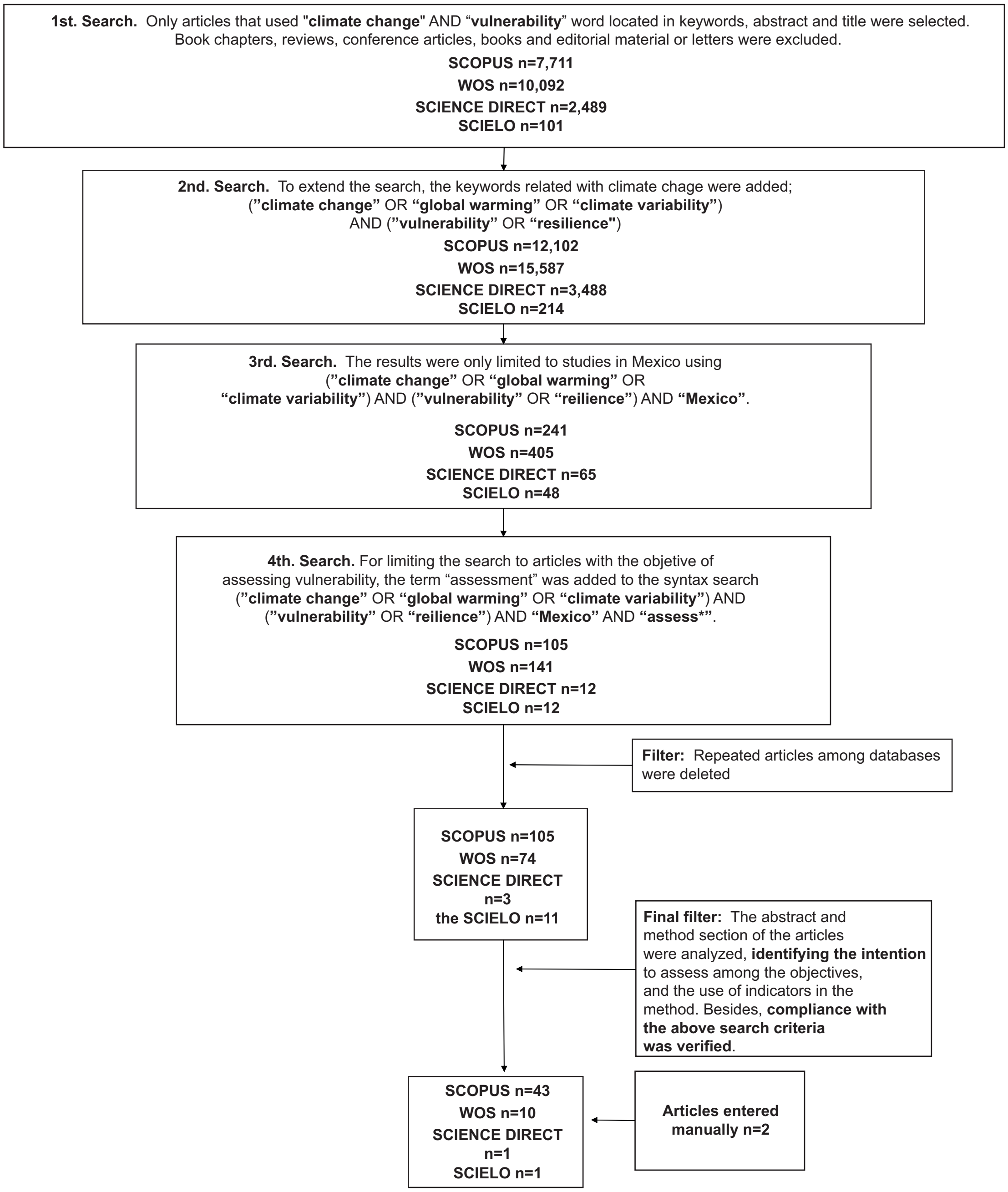

Fig. 3. Search process diagram and article selection.

ability, answer similar research questions, but remain on different research currents due to two different epistemologies. The concept of resilience arises from ecology analyzing human-environment interactions (specifically how humans affect ecosystems resilience); on the other hand, vulnerability arises from geography analyzing how natural disasters affect humans.

On the third search, the results were limited to studies in Mexico only, using ("climate change" OR "global warming" OR "climate variability") AND ("vulnerability" OR "resilience") AND "Mexico".

On the fourth search, the word "assess*" was added to obtain articles that resulted from an evaluation.

Once the search process was finished, two filters were applied. The first filter deleted items that repeated among databases (67 articles from WOS were removed because they appeared on Scopus results, nine from Science Direct, and one from Scielo that appeared on WOS results). In the final filter, the abstract and methods section of the articles were analyzed, identifying the intention of assessing among the objectives and the use of indicators in the method. Besides, compliance with the above search criteria was verified.

A total of 55 articles were obtained from the database search (43 from Scopus, 10 from WOS, one from Science Direct, and one from Scielo). Additionally, two articles were added manually. The selected articles were compiled in a database. Subsequently, each of these was carefully read paying particular attention to answering the specific questions previously defined.

2.3 Reporting the results

The results were organized according to the four topics described above and displayed in composite figures (Figs. 4-10). RStudio software was used to perform the cloud of word frequency in title, abstract, and keywords.

3. Results and discussion

3.1 Timeline, institutional origin, and associated terms

The total number of reviewed articles on studies evaluating vulnerability to climate change in Mexico was 57; 50 of them were in English and seven of them in Spanish. The oldest article is from 1990 (Fig. 4a), in which climate change is called climatic extremes, and it identifies drought as a threat (Liverman, 1990). Few and sporadic articles were registered between 1990 and 2006. It was observed that the frequency begins to reverse from 2007, and the increase becomes exponential from 2014 (Fig. 4a). The same is true internationally; according to the review by Tonmoy et al. (2014), it could be due to the increase in public policies on climate change since the publication of the 2007 IPCC report (IPCC, 2007). In this report, the vulnerability study is incorporated as a transverse axis, specifying its concept and components. This was reaffirmed later, in the 2014 IPCC report (IPCC, 2014).

A total of 177 different authors from 65 institutions were found: 27 from Mexico, six from Latin America (Colombia, Chile, Ecuador, Brazil, and two from Argentina), 18 from the United States, two from Canada, 10 from Europe (Germany, Greece, six from the United Kingdom, and two from Spain), and two from Australia. Figure 4b shows the 10 institutions of origin with the highest percentage of authors; most of the authors are affiliated to the National Autonomous University of Mexico (20%). The participation of international institutions is due to their collaboration in the research on territories on the United States-Mexico border (Browning-Aiken et al., 2007; Eakin and Bojórquez-Tapia, 2008; Collins et al., 2013), water vulnerability (Martínez et al., 2015; Stathatou et al., 2015; Lerner et al., 2018), and species vulnerability such as birds (Culp et al., 2017), bats (Zamora-Gutiérrez et al., 2017), and crabs (Hossain et al., 2018).

Figure 4c shows the 50 most mentioned terms in the title and abstract of the reviewed articles. The associated terms with higher frequency ("vulnerability", "climate", "change", and "Mexico") are displayed in the center of the cloud. In the second group of frequencies, the term "water" represents a high number of studies on this topic (Navarrete et al., 2013; Martínez et al., 2015). The same happens for the term "risk", which is a concept linked to the theoretical origins of vulnerability. Less frequently, terms associated with vulnerability components were observed, such as "exposure", "sensitivity" and "adaptive capacity". Also, some of the most used variables are "use" and "soil" (Galloza et al., 2017; Carranza-Ortiz et al., 2018), "economy" (Eakin and Bojórquez-Tapia, 2008) and "social" (Stathatou et al., 2015). The term "index" was also understood to be the way to quantify vulnerability, and the term "resilience" as a concept linked to vulnerability (Hernández-Montilla et al., 2016).

3.2 Study subject and spatial location

Study subjects refer to systems that are vulnerable or exposed to a threat associated with climate change. Due to the complexity of the vulnerability concept, there are no limitations for the definition of study subjects (Füssel and Klein, 2006). We found 16

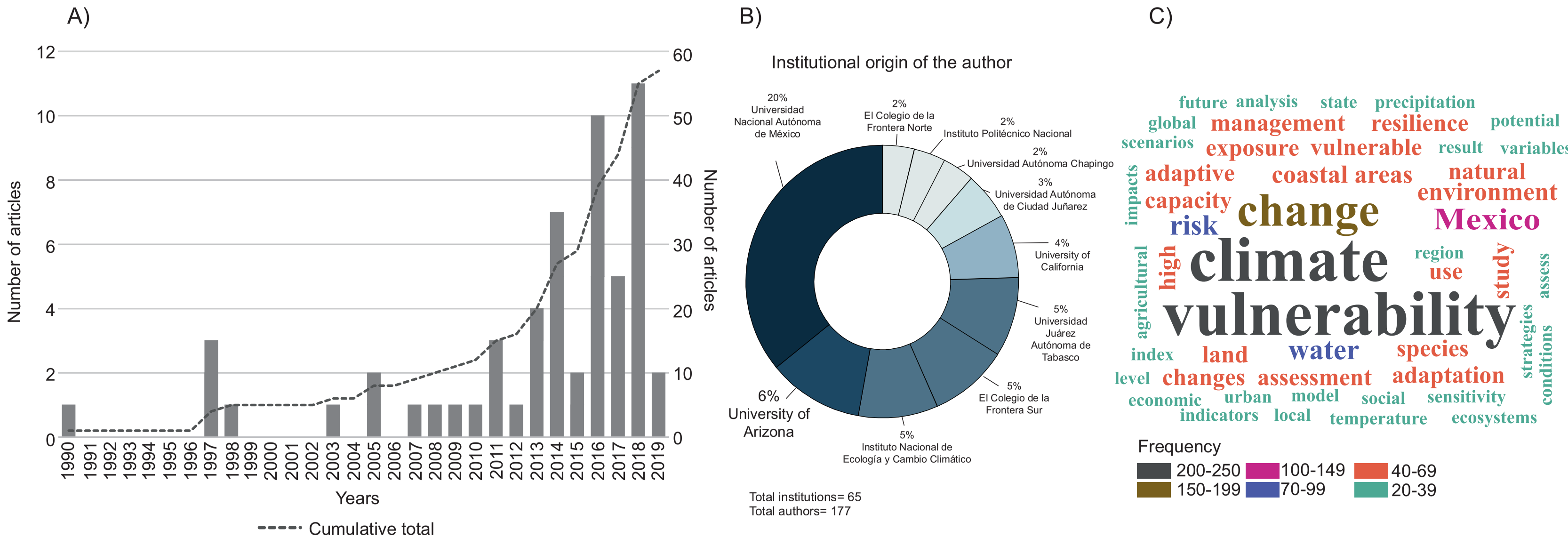

Fig. 4. (a) Number of articles per year; (b) principal institutional origin of the authors; (c) cloud of the 50 most frequent terms used in articles' title, abstract, and keywords considered in the review.

different types of study subjects. These were grouped into four categories: biological (species, ecosystems), socioeconomic (economic and cultural activities), territory (land area delimited under jurisdiction), and natural resources (water, soil) (Fig. 5a).

The territory category was the most frequent (between eight and 10 articles); this could mean that the theory of vulnerability on climate change is more suitable for assessing territories, and this is possibly associated with the ease of obtaining information and reference studies. This coincides with the fact that the objective of assessing vulnerability is to design adaptation strategies, and the execution of these strategies in terms of decision-makers is facilitated when the study subject is a political-territorial construction (Coy, 2010). It should be noted that although it is not possible to assess the vulnerability of the territory itself, it is possible to assess the different

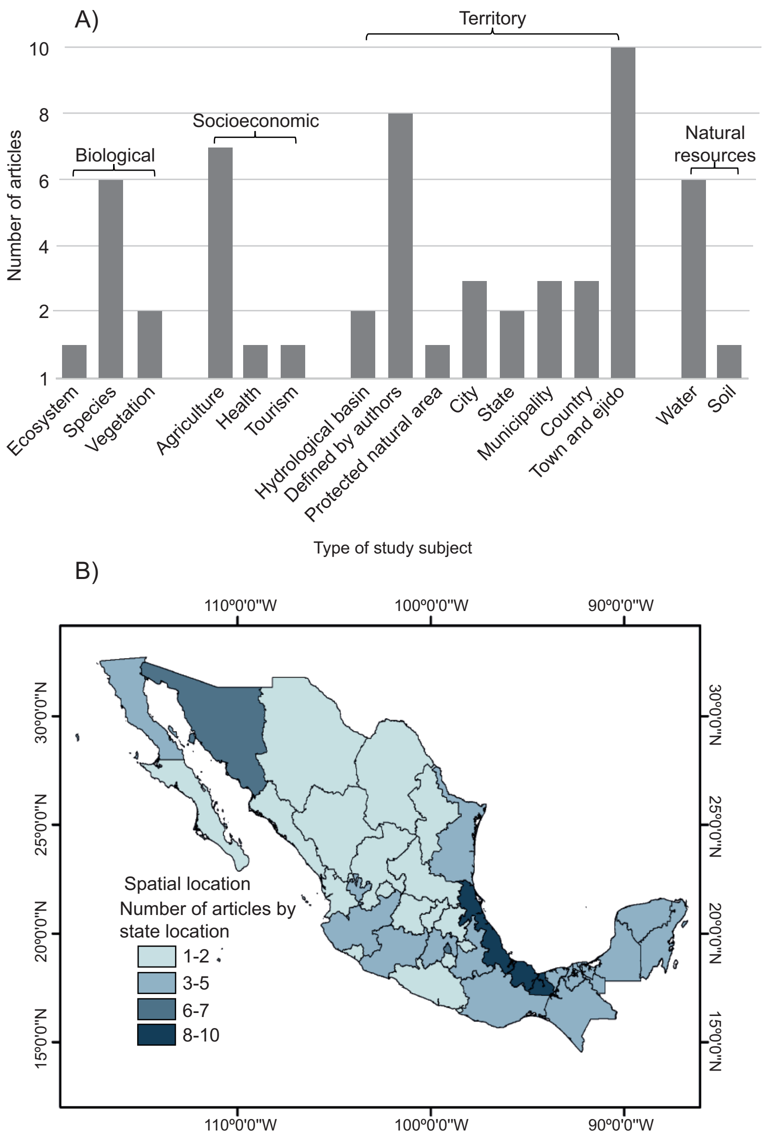

Fig. 5. (a) Number of articles by subject study, and (b) number of vulnerability assessment studies on climate change in Mexico by spatial location according to the states of the country.

factors that interact in it (physical, biotic, human, and cultural factors) from a territorial perspective (Rodríguez, 2010).

Vulnerability studies in which the territory is the study subject evaluate the vulnerability of the different territory factors as a whole, unlike the studies that assess the vulnerability of other study subjects which are located in a particular territory. In this category, towns and ejidos (a type of tenancy system that only exists in Mexico and refers to land farmed communally) were the ones that registered the highest number of articles, followed by research on territories defined by the author. With a lower frequency we found studies on cities (Sánchez and Morales, 2018; Soto-Montes-de-Oca and Alfie-Cohen, 2018), municipalities (Monterroso and Conde, 2017; Pérez-Maqueo et al., 2018) and at country level (Calil et al., 2017; Zúñiga and Magaña, 2018).

With a notable frequency (between six and seven articles) we found study subjects in the socio-economic category (e.g., agricultural vulnerability) (Groot et al., 2016; Monterroso et al., 2018). A similar frequency was shown by the biological category, with bats (Zamora-Gutiérrez et al., 2017), migratory birds (Culp et al., 2017), and trees (Esperón-Rodríguez and Barradas, 2015). The least frequent were the natural resources category with studies of water and hydrological vulnerability (Navarrete et al., 2013; Martínez et al., 2015; Stathatou et al., 2015).

Regarding spatial location, at least one vulnerability study was found in each state of Mexico (Fig. 5b). For example, the study presented by Monterroso and Conde (2017) includes each state of the country in their analysis. The state of Veracruz registered the majority of articles, followed by Sonora and Mexico City. Other regions with notable frequency were the Baja Californian peninsula (González-Baheza and Arizpe, 2017) and the Gulf and Caribbean regions of Mexico (Rosete et al., 2013; Baca et al., 2014; Núñez et al., 2016).

3.3 Scientific areas, theories, methods, variables, indicators, measurement units, and tools

The predominant scientific area was the multidisciplinary perspective (45%), followed by the natural sciences and engineering (38%), and in the lowest percentage the social sciences (17%). Most of the articles were based on the vulnerability theory (53%), followed by the risk theory (32%), and in a lower percentage, other theories such as resilience (15%) (Hernández-Montilla et al., 2016).

The results showed 21 different methods used to assess vulnerability to climate change (Fig. 6). The vulnerability formula method described by Gallopín (2006), which is represented by exposure + sensitivity – adaptive capacity, was the most used (21%), followed by the qualitative method based on the literature and social opinion (14%), the risk method (10%), the analysis of exposure to climate (9%), and the coastal vulnerability index (CVI) (5%). The rest of the percentage was determined by methods with a

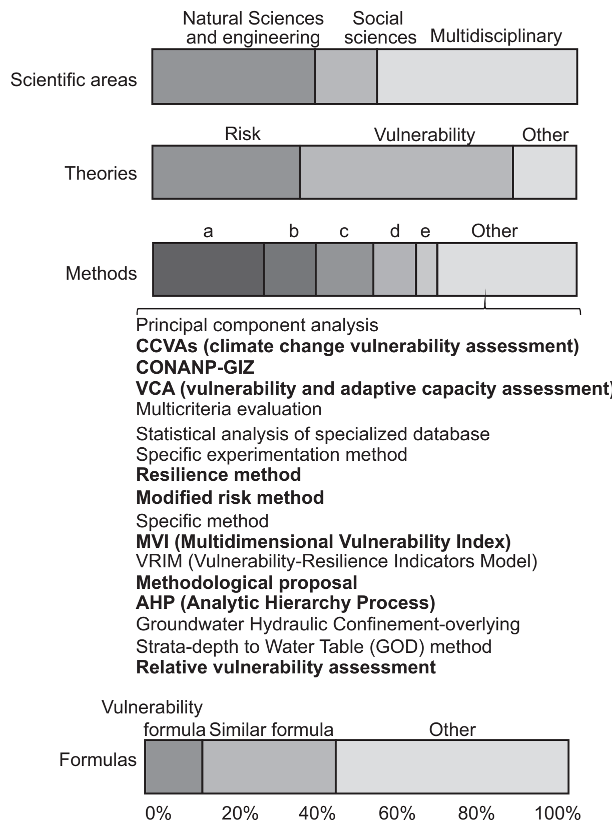

Fig. 6. Scientific areas, theories, methods and formulas used on vulnerability assessment studies on climate change in Mexico: (a) for vulnerability formula; (b) for risk method; (c) based on observation, literature and social opinion; (d) for analysis of exposure to climate, and (e) for coastal vulnerability index. In bold, the methods that use formulas similar to the vulnerability formula, where the three components are indicated: exposure, sensitivity, and adaptive capacity.

frequency of one. In general, the results showed that less than half (45%) of the methods implemented to assess vulnerability to climate change use the vulnerability formula described by Gallopín (2006) or a similar one considering the vulnerability components. However, the majority of methods use their own formulas or do not use formulas (as qualitative studies).

While analyzing articles that used the vulnerability formula or similar, we discovered that there are differences in the way of conceptualizing the components of vulnerability (exposure, sensitivity, and adaptive capacity) (Fig. 7). The conceptualization of the components is related to the choice of variables and indicators, and these are related to the study subject. To show these differences and connections, the articles were grouped into two groups named A (16 articles) and B (nine articles).

In the articles of group A (Fig. 7a) the exposure component was defined as the threat that can cause damage to the system (considering that the threat is an entity external to the system); therefore, the variables were mostly natural disasters associated with climate change (floods, droughts, tropical cyclones, and hurricanes), and future consequences (climate change scenarios, sea-level rise). The sensitivity component was defined as the processes, phenomena, events, or conditions of the system that increase or decrease its vulnerability to the threat. The variables of the sensitivity component depend on the particular threat that is being analyzed. The most frequent variables were population, health, public services, and economy as socioeconomic characteristics, and topographic slope, hydrology, erosion, and land use and cover change as physical characteristics. The adaptive capacity component was defined as the system's ability, actions, and habits to overcome the damage, also considering the physical and socioeconomic characteristics of the system which help to address the vulnerability. The most used variables were a set of indicators called capital and its components were natural capital, financial capital, physical capital, social capital, and human capital. These variables arise from the sustainable livelihood methodology (Krantz, 2001). Other mentioned variables were technologies, institutional capacities, environmental sustainability, and social perception.

In the articles of group B (Fig. 7b), the exposure component was defined as the exposed system (it refers to exposed elements of the system), so the variables are related to the study subject. The most mentioned variables were water, agriculture, and ecosystems. The sensitivity component was defined as the processes, phenomena, events, or conditions of the system that cause damage. This group of articles does not consider an external threat but, instead, it assimilates that certain conditions, characteristics, and phenomena that occur inside the system compose its own vulnerability (they consider climate change as part of the system). The most used variables were climate variability, land use, land cover change, hydrology, and climate change scenarios. These same variables are among the most mentioned in the exposure component of group A. The definition of the adaptive capacity component was the same as in group A. It considers abilities, actions, and habits of the system to overcome the damage and includes characteristics of physical and socio-economic aspects. The most frequent variables were also the capitals from sustainable livelihood methodology (financial, human, and natural) (Krantz, 2001) and other variables as legal capital, institutional capacities, social perception, information, and governance.

These differences in the conceptualization of vulnerability components are a constant discussion between different authors because there is no defined agreement. According to Gallopín (2006), the exposure component is an attribute of the relationship between the system and the threat, therefore it can be interpreted from two approaches:

1. The system is vulnerable only when it is exposed to a threat, considering the threat as external to the system. If the threat does not exist, or the system is not exposed to the threat, then the system is not vulnerable. In this sense, the exposure component analyzes the frequency and intensity with which the threat can impact the system. The sensitivity component analyzes the existence of conditions in the system that may aggravate or reduce the impacts of the threat, and the adaptive capacity component is the response variable.
2. The system is always vulnerable (to a greater or lesser extent) because threats are perceived as part of the system. Threats may or may not appear in specific periods, but they will always exist in the system. In this sense, the exposure component is

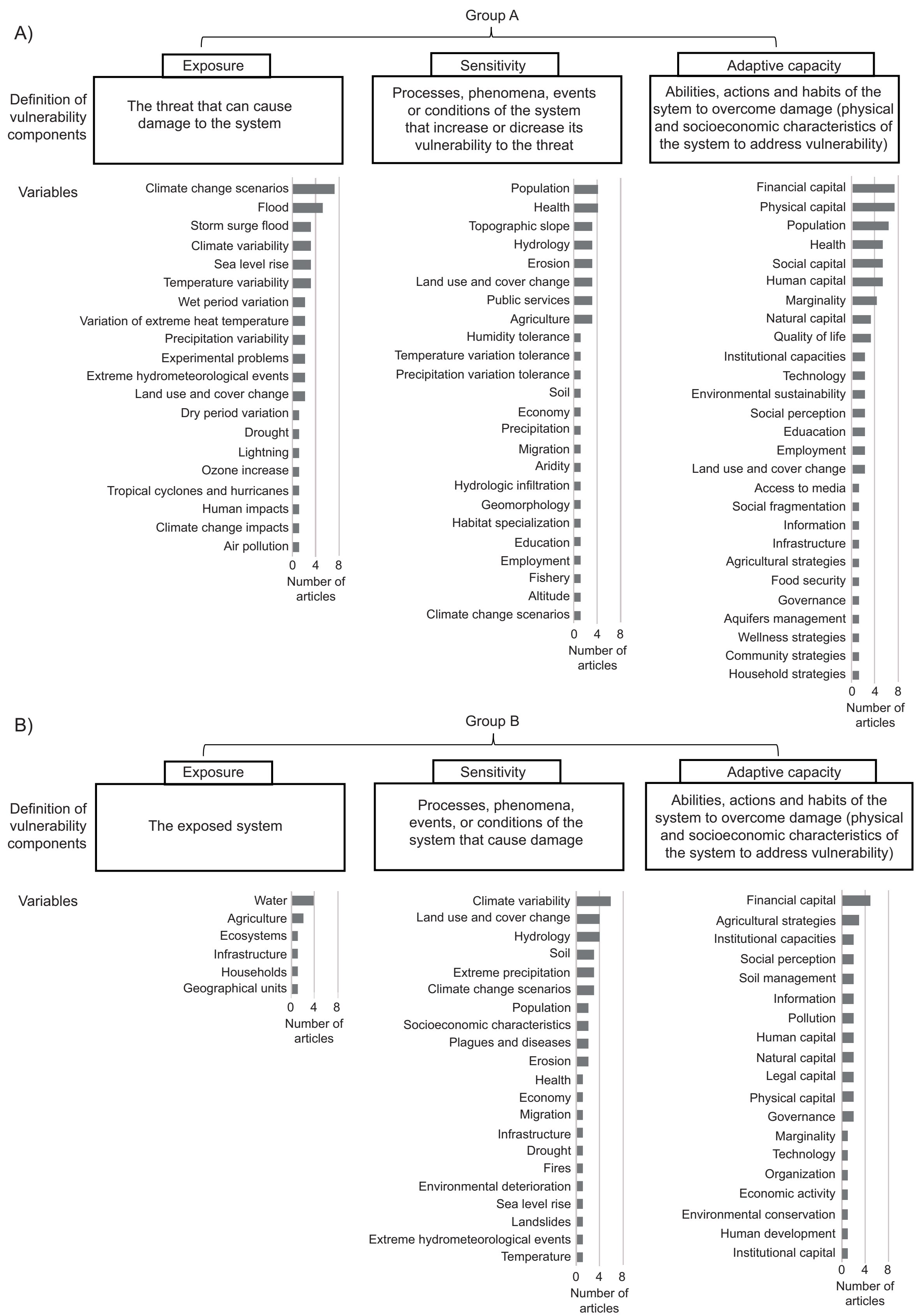

Fig. 7. Definition of vulnerability components and variables.

externalized from the equation in the vulnerability formula, but it is taken as a basis, because it analyzes the elements of the system under study. Therefore, the vulnerability is evaluated with the sensitivity component, which analyzes the existing threats in the system (historically, including frequency and intensity), and the adaptive capacity component as a response variable.

The first approach is the case of the articles of group A, and the second approach is the case of the articles of group B.

The choice between one approach or another has consequences (Gallopín, 2006). From the observations of Cárdenas and Tobón (2016), it can be distinguished that the choice of one approach or another can lead to different types of vulnerability assessment studies and, consequently, different adaptation strategies. The first approach considers studies focused on assessing the impacts of threats that lead to adaptation strategies to minimize the effects. And the second approach makes studies focused on assessing the system's interactions that lead to comprehensive adaptation strategies.

This discussion seems to be related to the objective of the vulnerability assessment study; it aims at determining if the objective is to design adaptation strategies to mitigate the impacts of climate change or to adapt and coexist with them. Cárdenas and Tobón (2016) point out that certain adaptation strategies designed to mitigate the impacts of climate change in the short-term cause new long-term threats, particularly when territories are studied without taking into account human-nature interactions.

To integrate the indicators in each variable, the variables in each vulnerability component, and each vulnerability component in a vulnerability index, it is necessary to follow a process of indicator treatment that consists of two steps which are indicator weight estimation and normalization. Estimating the indicators' weights is a way to display the importance of each indicator as an individual concerning the set of indicators. After establishing weights, the indicators must be normalized to the same scale and, after that, they can be added. This process is decisive to obtain the final value of the vulnerability index; for that reason, it must be clearly described in the methodologies of vulnerability assessment studies on climate change (Tonmoy et al., 2014).

Following the categories described in the review by Tonmoy et al. (2014), we found seven different methods to estimate indicators' weights (Fig. 8a), and eight methods to normalize (Fig. 8b).

The most popular methods to estimate indicators' weights were estimation according to references (24.5%), assigning the same weight for all variables (9%), and determination by statistical models (9%). In 44% of the articles, the method was not specified. According to Tonmoy et al. (2014), it is a general recurrent practice in assessment vulnerability studies, possibly related to the diversity of methods and the lack of strict parameters.

The most popular methods to normalize were normalizing to 1 and percentage (21%), a couple of formulas that include maximums, minimums, and standard division (16%), and two methodological proposals. However, articles continue to predominate without a specific standardization method (44%), or without any standardization (16%) (Hossain et al., 2018). Compared with the results of the Tonmoy et al. (2014) the trend is similar, which indicates that it is possibly caused by the large number of qualitative vulnerability assessments which do not group the indicators or use the vulnerability formula.

For measurement units, an index was used in most of the articles (53%) to show the final result of the vulnerability assessment. The indices with ranges from 1 to 5 and from 0 to 100 were the most frequent (Fig. 9a). In most of these articles, a traffic light signal was used to express the level of the vulnerability index; green or light colors correspond to low vulnerability and red or dark colors to the highest levels (Villers-Ruiz and Trejo-Vázquez, 1998; Ahumada-Cervantes et al., 2015). However, in 23% of the articles, the range was not specified, and the information was presented in a graphical form (Sisto et al., 2015), or the articles did not use an index (24%) and the results were presented as a described explanation (Browning-Aiken et al., 2007; Santos-Lacueva and Saldié, 2016). The existence of different ranges in the vulnerability indexes can cause difficulties to make comparisons between studies (Tonmoy et al., 2014).

The most used tools in the articles (56%) were geographic information systems (GIS), which are useful for the cartographic representation of vulnerability in the territories (Ramos et al., 2016; Monterroso et al., 2018). With less frequency, 17.5% of

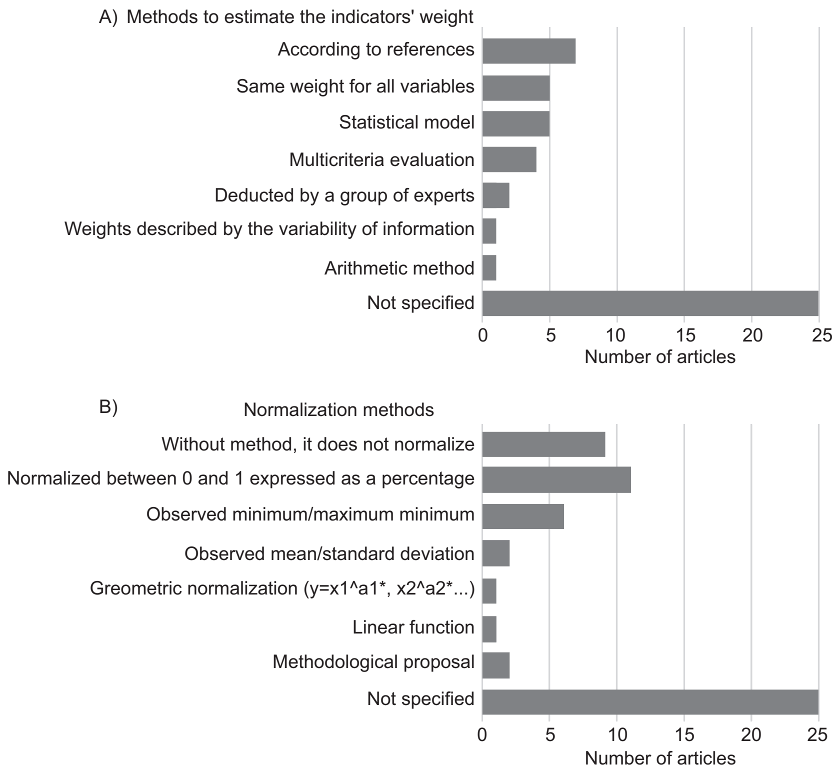

Fig. 8. (a) Number of articles by methods to estimate indicators' weight. (b) Number of articles by methods to normalize indicators and variables.

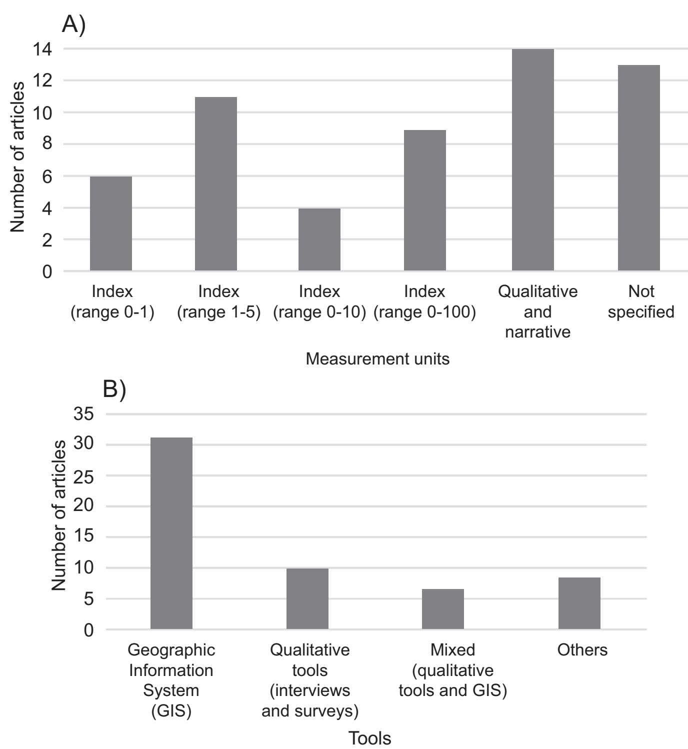

Fig. 9. (a) Number of articles grouped by range of measure. (b) Number of articles grouped by the use of tools.

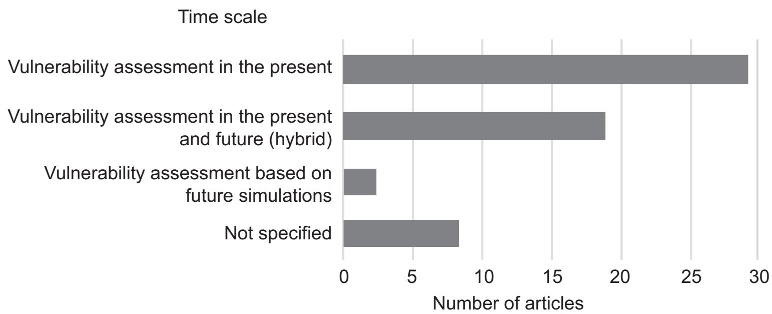

Fig. 10. Number of articles by time scale.

the articles were identified by the use of survey and interview instruments to obtain information about the adaptive capacity component (Eakin, 2005; Lerner et al., 2018), and only six articles (12 %) used both GIS and surveys or interviews (Sánchez and Morales, 2018) (Fig. 9b). We found other types of tools including specialized databases on climate and birds (Culp et al., 2017), statistical software (Sisto et al., 2015; Stathatou et al., 2015), participatory GIS (Krishnamurthy et al., 2011), and specialized software such as FarmDesign (Groot et al., 2016).

3.4 Time scale

Four types of time scales were identified in the review (Fig. 10). Vulnerability assessment in the present refers to studies carried out with information in the present, taking information from preceding periods as a reference to compare the level of vulnerability. Vulnerability assessment in the present and future (hybrid) refers to studies that are similar to the previous ones, which additionally make a future projection based on the reference information in the present and preceding periods. Vulnerability assessment based on future simulations refers to studies that assess vulnerability considering only future climate scenarios.

Most of the articles were assessments of vulnerability in the present (51%) (Pérez-Maqueo et al., 2018; Gran and Ramos, 2019); the vulnerability assessments in the present and future (hybrid) were less frequent (29%) (Rivas and Montero, 2014; Galloza et al., 2017). Regarding vulnerability assessments based on future simulations, only two articles were identified (Villers-Ruiz and Trejo-Vázquez, 1998; Ahmed et al., 2009). In general, vulnerability assessments in the present prevail, which differs from what has been reported internationally. As Tonmoy et al. (2014) explain, vulnerability assessment in the present and future (hybrid) predominate in international research because climate change is an observable phenomenon over time. Therefore, it is necessary to have a present parameter and future scenarios to compare and control the efficiency of adaptation strategies.

4. Conclusions

Research on vulnerability to climate change in Mexico continues to be developed. The first investigations date back to 1990 and it was until 2007 that the popularity of this research topic increased. The years 2014, 2016, and 2018 registered the highest number of articles. Regarding the academic origin of the authors, we found the collaboration of 27 Mexican institutions and 34 international institutions. The National Autonomous University of Mexico was the institution with the greatest contribution. In addition to the terms "vulnerability", "climate" and "change", the most frequently mentioned terms in the selected articles were "water", "risk" and the vulnerability components "exposure", "sensitivity" and "adaptive capacity".

In Mexico, 16 types of study subjects have been studied; the category territory registered the highest number of articles, specifically towns and ejidos, and territories defined by the author, followed by studies of agriculture vulnerability and water vulnerability. We found at least one vulnerability assessment study in each state of the country. The states of Veracruz, Sonora, and Mexico City presented the highest frequency (between six and 10 articles).

The predominant scientific area in the research on vulnerability to climate change in Mexico is the multidisciplinary perspective, through vulnerability theory. This indicates that most of the research in the country is complex and integrates different analyses of the physical, socioeconomic, and environmental characteristics of the study subjects.

For the assessment of vulnerability, we found 21 different methods including methodological proposals, multi-criteria evaluation, risk theory method, coastal vulnerability index, and qualitative methods based on observation, literature, and social opinion. However, the most used method was the vulnerability formula (exposure + sensitivity – adaptive capacity) or similar with respect to vulnerability components.

While analyzing the articles that use the vulnerability formula or similar, some differences were identified in the conceptualization of the exposure and sensitivity component. In the first group of articles, the exposure component refers to the threat concept as an entity that is external to the system (climate change is a threat external to the studied system), and the sensitivity component refers to the conditions of the system that increase or decrease its vulnerability to the threat. On the other hand, in the second group of articles, the exposure component refers to the study subjects (exposed system), and the sensitivity component refers to the threats that are recognized as part of the system to which the study subjects belong (climate change is part of the studied system).

This discussion about the conceptualization of the exposure component is recurrent in the academic community and has been presented by different authors. Some of them point out that it is important to pay attention to this for future research because choosing one conceptualization or another can lead to different results of the vulnerability assessment and, therefore, to different adaptation strategies.

In the case of the first group, it can lead to design immediate adaptation strategies focused on minimizing the impacts of the external threat, ignoring that these may become repercussions or create new threats in the long term (especially in those studies in which the subject maintains clear human-nature relationships such as ecosystems, natural resources, and some territories). In the case of the second group, by recognizing that the threat is not going to disappear, it can lead to the design of comprehensive and articulated adaptation strategies, which may not stop the impacts of the threat immediately, but might be functional in the long term, leading to sustainable development.

The choice depends on the objective of the vulnerability assessment and the study subject. To contribute to the discussion, we suggest conducting a literature review to analyze the relationship between vulnerability assessment studies and the adaptation strategies derived from these.

The methods to estimate indicators' weights and the methods to normalize are not specified in most of the articles; this may be related to the number of qualitative vulnerability assessment articles where the vulnerability formula is not used. For measurement units, a vulnerability index accompanied by traffic light signage was used in most of the articles (53%) to express the vulnerability level obtained as a result of the assessment. GIS tools were the most popular.

Finally, regarding the time scale, we found that vulnerability assessment studies in the present and vulnerability assessment studies in the present and future (hybrid) were those with the highest number of articles (51 and 32%, respectively).

Considering the reduced number of articles that we found, some areas of opportunity for future research in Mexico are study subjects in some categories like natural resources (e.g., soil), socioeconomic activities (e.g., tourism and the health sector), biological (e.g., ecosystems and vegetation), and territory (e.g., protected natural areas).

References

Ahmed SA, Diffenbaugh NS, Hertel TW. 2009. Climate volatility deepens poverty vulnerability in developing countries. Environmental Research Letters 4: 1-9. https://doi.org/10.1088/1748-9326/4/3/034004

Ahumada-Cervantes R, Velázquez-Angulo G, Rodríguez-Gallegos HB, Flores-Tavizón E, Félix-Gastélum R, Romero-González J, Granados-Olivas A. 2015. An indicator tool for assessing local vulnerability to climate change in the Mexican agricultural sector. Mitigation and Adaptation Strategies for Global Change 22: 137-152. https://doi.org/10.1007/s11027-015-9670-z

Baca M, Läderach P, Haggar J, Schroth G, Ovalle O. 2014. An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in Mesoamerica. Plos One 9: 1-11. https://doi.org/10.1371/journal.pone.0088463

Browning-Aiken A, Morehouse B, Davis A, Wilder M, Varady R, Goodrich D, Carter R, Moreno D, Dellinger E. 2007. Climate, water management, and policy in the San Pedro Basin: Results of a survey of Mexican stakeholders near the U. S. Mexico border. Climatic Change 85: 323-341. https://doi.org/10.1007/s10584-007-9302-z

Calil J, Reguero BG, Zamora AR, Losada IJ, Méndez FJ. 2017. Comparative Coastal Risk Index (CCRI): A multidisciplinary risk index for Latin America and the Caribbean. Plos One 12: 1-24. https://doi.org/10.1371/journal.pone.0187011

Cárdenas MF, Tobón C. 2016. Evaluación de la vulnerabilidad biofísica de los servicios ecosistémicos ante el cambio climático: una aproximación conceptual y metodológica. Gestión y Ambiente 19: 163-178.

Carranza-Ortiz G, Gómez-Mendoza L, Caetano E, Infante Mata D. 2018. Vulnerability of human communities in Mexican mangrove ecosystems: An ecosystem-based adaptation approach. Investigaciones Geográficas (95): 1-18. https://doi.org/10.14350/rig.59502

Collins TW, Grineski SE, Ford P, Aldouri R, Romo Aguilar ML, Velázquez-Angulo G, Fitzgerald R, Lu D. 2013. Mapping vulnerability to climate change-related hazards: Children at risk in a US-Mexico border metropolis. Population and Environment 34: 313-337. https://doi.org/10.1007/s11111-012-0170-8

Coy M. 2010. Los estudios de riesgo y de la vulnerabilidad desde la geografía humana. Su relevancia para América Latina. Población & Sociedad (17): 9-28.

Culp LA, Cohen EB, Scarpignato AL, Thogmartin WE, Marra PP. 2017. Full annual cycle climate change vulnerability assessment for migratory birds. Ecosphere 8: 1-22. https://doi.org/10.1002/ecs2.1565

Eakin H. 2005. Institutional change, climate risk, and rural vulnerability: Cases from central Mexico. World Development 33: 1923-1938. https://doi.org/10.1016/j.worlddev.2005.06.005

Eakin H, Bojórquez-Tapia LA. 2008. Insights into the composition of household vulnerability from multicriteria decision analysis. Global Environmental Change 18: 112-127. https://doi.org/10.1016/j.gloenvcha.2007.09.001

Esperón-Rodríguez M, Barradas VL. 2015. Ecophysiological vulnerability to climate change: Water stress responses in four tree species from the central mountain region of Veracruz, Mexico. Regional Environmental Change 15: 93-108. https://doi.org/10.1007/s10113-014-0624-x

Füssel HM, Klein RJT. 2006. Climate change vulnerability assessments an evolution of conceptual thinking. Climatic Change 75: 301-329. https://doi.org/10.1007/s10584-006-0329-3

Füssel HM. 2007. Vulnerability: A generally applicable conceptual framework for climate change research. Global Environmental Change 17: 155-167. https://doi.org/10.1016/j.gloenvcha.2006.05.002

Gallopín GC. 2006. Linkages between vulnerability, resilience, and adaptive capacity. Global Environmental Change 16: 293-303. https://doi.org/10.1016/j.gloenvcha.2006.02.004

Galloza MS, López-Santos A, Martínez-Santiago S. 2017. Predicting land at risk from wind erosion using an index-based framework under a climate change scenario in Durango, Mexico. Environmental Earth Sciences 76: 1-14. https://doi.org/10.1007/s12665-017-6751-1

González-Baheza A, Arizpe O. 2017. Vulnerability assessment for supporting sustainable coastal city development: A case study of La Paz, Mexico. Climate and Development 10: 552-565. https://doi.org/10.1080/17565529.2017.1291406

Gran JA, Ramos SL. 2019. Climate change and flood risk: Vulnerability assessment in an urban poor community in Mexico. Environment & Urbanization 31: 75-92. https://doi.org/10.1177/0956247819827850

Grant MJ, Booth A. 2009. A typology of reviews: An analysis of 14 review types and associated methodologies. Health Information & Libraries Journal 26: 91-108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Groot JCJ, Cortez-Arriola J, Rossing WAH, Amédola Massiotti RD, Tittonell P. 2016. Capturing agroecosystem vulnerability and resilience. Sustainability 8: 1-12. https://doi.org/10.3390/su8111206

Hernández-Montilla MC, Martínez-Morales MA, Posada Venegas G, de Jong BHJ. 2016. Assessment of Hammocks (Petenes) Resilience to sea level rise due to climate change in Mexico. Plos One 11: 1-20. https://doi.org/10.1371/journal.pone.0162637

Hossain MA, Lahoz-Monfort JJ, Burgman MA, Böhm M, Kujala H, Bland LM. 2018. Assessing the vulnerability of freshwater crayfish to climate change. Biodiversity Research 24: 1-14. https://doi.org/10.1111/ddi.12831

IPCC. 1995. SAR Climate Change 1995: Synthesis report. Intergovernmental Panel on Climate Change. Available at: https://www.ipcc.ch/report/ar2/syr/ (accessed on January 18, 2020).

IPCC. 2007. Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, Eds.). Cambridge University Press, Cambridge, UK, 976 pp. Available at: https://www.ipcc.ch/report/ar4/wg2/ (accessed on January 18, 2020).

IPCC. 2014. Climate Change 2014: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE et al., Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp. Available at: https://www.ipcc.ch/report/ar5/wg2/ (accessed on January 18, 2020).

Janssen MA, Ostrom E, eds. 2006. Resilience, vulnerability, and adaptation: A cross-cutting theme of the International Human Dimensions Programme on Global Environmental Change. Global Environmental Change 16: 237-239. https://doi.org/10.1016/j.gloenvcha.2006.04.003

Kelly PM, Adger WN. 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Climatic Change 47: 325-352. https://doi.org/10.1023/A:1005627828199

Krantz L. 2001. The sustainable livelihood approach to poverty reduction an introduction. Available at: https://www.sida.se/contentassets/bd474c210163447c9a7963d77c64148a/the-sustainable-livelihood-approach-to-poverty-reduction_2656.pdf (accessed on December 13, 2019).

Krishnamurthy PK, Fisher JB, Johnson C. 2011. Mainstreaming local perceptions of hurricane risk into policymaking: A case study of community GIS in Mexico. Global Environmental Change 21: 143-153. https://doi.org/10.1016/j.gloenvcha.2010.09.007

Lerner AM, Eakin HC, Tellman E, Bausch JC, Hernández Aguilar B. 2018. Governing the gaps in water governance and land-use planning in a megacity: The example of hydrological risk in Mexico City. Cities 83: 61-70. https://doi.org/10.1016/j.cities.2018.06.009

Liverman DM. 1990. Drought impacts in Mexico: Climate, agriculture, technology, and land tenure in Sonora and Puebla. Annals of the Association of American Geographers 80: 49-72. https://doi.org/10.1111/j.1467-8306.1990.tb00003.x

Martínez S, Kralisch S, Escolero O, Perevochtchikova M. 2015. Vulnerability of Mexico City's water supply sources in the context of climate change. Journal of Water and Climate Change 6: 518-533. https://doi.org/10.2166/wcc.2015.083

Monterroso AI, Conde AC. 2017. Adaptive capacity: Identifying the challenges faced by municipalities addressing climate change in Mexico. Climate and Development 10: 729-741. https://doi.org/10.1080/17565529.2017.1372264

Monterroso AI, Conde AC, Pérez JL, López J, Gaytán M, Gómez JD. 2018. Multi-temporal assessment of vulnerability to climate change: Insights from the agricultural sector in Mexico. Climatic Change 147: 457-473. https://doi.org/10.1007/s10584-018-2157-7

Moss R, Brenkert A, Malone E. 2001. Vulnerability to climate change. A quantitative approach. Available at: http://danida.vnu.edu.vn/cpis/files/Papers_on_CC/Vulnerability/VULNERABILITY%20TO%20CLIMATE%20CHANGE%20A%20Quantitative%20Approach.pdf (accessed on December 13, 2019).

Navarrete S, Jiménez B, Navarro I, Domínguez R. 2013. Evaluación del riesgo al acuífero de Xochimilco por lluvias extremas. Tecnología y Ciencias del Agua 4(3): 103-123.

Núñez JC, Ramos R, Barba E, Espinoza A, Gama L. 2016. Coastal vulnerability index for the Tabasco State coast, Mexico. Investigaciones Geográficas (91): 70-85. https://doi.org/10.14350/rig.50172

Pérez-Maqueo O, Martínez ML, Sánchez-Barradas FC, Kolb M. 2018. Assessing nature-based coastal protection against disasters derived from extreme hydrometeorological events in Mexico. Sustainability 10: 1-17. https://doi.org/10.3390/su10051317

Pullin AS, Stewart GB. 2006. Guidelines for systematic review in conservation and environmental management. Conservation Biology 20: 1647-1656. https://doi.org/10.1111/j.1523-1739.2006.00485.x

Ramos R, Zavala-Cruz J, Gama L, Pech D, Ortiz MA. 2016. Indicadores geomorfológicos para evaluar la vulnerabilidad por inundación ante el ascenso del nivel del mar debido al cambio climático en la costa de Tabasco y Campeche, México. Boletín de la Sociedad Geológica Mexicana 68: 581-598.

Rivas I, Montero MJ. 2014. Assessment of surface runoff vulnerability to climate change in the Lerma-Chapala basin, Mexico. Journal of Water Resources Planning

Management 140: 1-13. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000433

Rodríguez D. 2010. Territorio y territorialidad. Nueva categoría de análisis y desarrollo didáctico de la geografía. Uni-pluri/versidad 10: 95-103.

Rosete FA, Enríquez G, Aguirre E. 2013. The risk component in land use planning programs: The case of the regional and marine use planning for the Gulf of Mexico and Caribbean Sea. Investigaciones Geográficas (80): 7-20. https://doi.org/10.14350/rig.36393

Sánchez RA, Morales AE. 2018. Vulnerability assessment to climate variability and climate change in Tijuana, Mexico. Sustainability 10: 1-21. https://doi.org/10.3390/su10072352

Santos-Lacueva R, Saldié Ó. 2016. Acción pública en materia de turismo y cambio climático: las percepciones de los stakeholders en la Riviera Maya (México). Pasos 14: 611-630. https://doi.org/10.25145/j.pasos.2016.14.040

Sisto NP, Ramírez AI, Aguilar-Barajas I, Magaña V. 2015. Climate threats, water supply vulnerability and the risk of a water crisis in the Monterrey Metropolitan Area (northeastern Mexico). Physics and Chemistry of the Earth 91: 2-9. https://doi.org/10.1016/j.pce.2015.08.015

Soto-Montes-de-Oca G, Alfie-Cohen M. 2018. Impact of climate change in Mexican peri-urban areas with risk of drought. Journal of Arid Environments 162: 74-88. https://doi.org/10.1016/j.jaridenv.2018.10.006

Stathatou PM, Kampragou E, Grigoropoulou H, Assimacopoulos D, Karavitis C, Porto MFA, Gironás J, Venegas M, Reyna S. 2015. Vulnerability of water systems: A comprehensive framework for its assessment and identification of adaptation strategies. Desalination and Water Treatment 57: 2243-2255. https://doi.org/10.1080/19443994.2015.1012341

Tonmoy FN, El-Zein A, Hinkel J. 2014. Assessment of vulnerability to climate change using indicators: A meta-analysis of the literature. WIREs Climate Change 5: 775-792. https://doi.org/10.1002/wcc.314

Villers-Ruiz L, Trejo-Vázquez I. 1998. Climate change on Mexican forests and natural protected areas. Global Environmental Change 8: 141-157. https://doi.org/10.1016/S0959-3780(98)00012-0

Zamora-Gutiérrez V, Pearson RG, Green RE, Jones KE. 2017. Forecasting the combined effects of climate and land use change on Mexican bats. Diversity and Distributions 24: 1-12. https://doi.org/10.1111/ddi.12686

Zúñiga A, Magaña V. 2018. Vulnerability and risk to intense rainfall in Mexico: The effect of land use cover change. Investigaciones Geográficas (95): 1-18. https://doi.org/10.14350/rig.59465