Index of Coastal Urban Resilience (ICURHF) When Coping with Hurricanes and Floods in the City of Chetumal, in the South East of Mexico

José Manuel Camacho-Sanabria[1](✉), Rosalía Chávez-Alvarado[1](✉), Juan Antonio Álvarez-Trinidad[2], and David Velázquez-Torres[2]

[1] Chetumal Academic Unit, Conacyt, Quintana Roo University, Mexico, Mexico
jmanuelcs@live.com.mx, rosaliadf@gmail.com
[2] Chetumal Academic Unit, Quintana Roo University, Mexico, Mexico
jaatalvarez@gmail.com, davvelaz@gmail.com

Abstract. The topic of resilience is essential in the natural disaster risk public management, which influences the quality of life of the people nowadays, specifically in the coastal cities that are the ones that in a near future will be more affected by hurricanes, and atypical rainfall, derived from the climatic change. There are various initiatives or agreements that contributed with evidence to commence the works focused on the increase of resilience in the cities, the most recent one is the Framework of Sendai 2015–2030, which promoted from public policies to global ones, such as the guide to determine resilience. This work proposes the introduction of an Index of Coastal Urban Resilience when coping with Hurricanes and Floods (ICURHF) of an urban location situated in the south east of Mexico (Chetumal). The Index is integrated by three components: Menace, Vulnerability and Capacity of Adaptation, each of them has a determined number of simple indicators which were classified, standardized, and assessed based on the technique known as judgment of experts. The results show that 60% of the city has a high resilience on the account of the indicators originated from the knowledge of the population about the risk of disasters - they are exposed to – when coping with the impact of hurricanes and floods. The remaining 40% registers a medium resilience corresponding to the Basic Geostatistical Areas (BGA's) where the Menace is very high, and the Vulnerability is high. The principal contribution of this Index is the inclusion of qualitative indicators which strengthen the definition of resilience as a social construct.

Keywords: Flood · Hurricane · Resilience · Vulnerability

We would like to thank Gerardo Quiroz Almaraz for his support in the translation.
Project financiad by Conacyt 248375, called: Resiliencia en ciudades costeras del Caribe Mexicano ante desastres por huracanes: Chetumal, Tulum y Playa del Carmen.

M. F. Mata-Rivera et al. (Eds.): GIS LATAM 2020, CCIS 1276, pp. 136–150, 2020.
https://doi.org/10.1007/978-3-030-59872-3_10

1 Introduction

One of the objectives in the world agenda is to deal with the resilience when coping with Hydrometeorological phenomena, based on the reports of the Intergovernmental Panel of Climatic Change (IPCC) which indicate that the menaces of natural origin will occur with higher intensity and magnitude.

Resilience as a connected concept to the risk of disaster is framed in the definitions of social vulnerability, adaptation capacity, and menace. Vulnerability was defined as a direct relation with resilience, some time ago. According to Holling, in 1973, and Gallopin, in 2006, there is a change in time in the relation between the human being and the nature, from the vision of the socioecological systems, where domains of attraction exist, that is to say what is usually known as indicators which explain the results and consequences of such relation human being and the nature [1, 2].

One of the most relevant events related with the risk of disasters was the flood of the Mississippi river in 1927, which provoked the evacuations of 600 000 people, approximately [3]. The first international conference against national calamities was held in Paris in 1937, and the theory of extreme values by Gumbel for the estimate of areas and degrees of the risk of flood was formulated in 1941 [4].

The first studies that included the perception, and the human behavior in the analysis of risks were developed in the 1970s, the fundaments of a theory of catastrophe were, as well, established, then [5, 6]. The works of the 1980s were focused on the correlation between natural danger, and underdevelopment, the improvement of the studies of man-generated risks, and the multidisciplinary recognition, which is required for the study of the risks [7].

The Latin-American Council of Social Sciences (LACSC) allowed its position to be glimpsed when it came to the relation between the condition of the population and the present difficulties in a situation of risk in 1985 [8]. The International Decade for the reduction of natural disasters was declared in the 1990s; its principal objective was to diminish disasters through a higher surveillance, and knowledge of the natural menaces from the scientific and technical point of view [9]. This initiative contributed to the establishment of the Network of social studies for the prevention of natural disasters in Latin America (La RED).

The measures that the scientific community, national governments, and regional organisms, and international organizations elaborated at the beginning of the decade, to prevent and mitigate the disasters, were examined by regional, national, and international groups from 155 countries and territories during the World Conference on the Reduction of National Disasters in the middle of the decade. This analysis, as well as the orientations for the future were recapitulated in the Message, Strategy, and Plan of Action of Yokohama for a Safer World [10]. The latter was the reference so that more concrete actions related to the diminishment of risk could be promoted as well as stated during the Framework of action of Yogo 2005–2015 [11]. The world campaign "Developing Resilient Cities; My City is getting Ready", whose objective was to promote and boost the commitment of local governments so that the diminishment of risk and the resilience of disasters could be a priority of their policies, was instrumented by the office of the United Nations for the reduction of disaster risk (UNISDR) in 2010, taking advantage of the Framework of Action of Hyogo in order to address more closely the local necessities [12].

The Framework of Sendai for the Reduction of disaster risk 2015–2030, successor instrument of the Framework of Action of Hyogo – which continues recognizing the objective of reducing every type of loss provoked by disasters – was approved in 2015; conducting the international efforts related to the topic until 2030 as well as sharing strategies of action with the purpose of achieving better results than in the first ten years [13]. This initiative has demonstrated that some countries take advantage of the information and allow databases which permit the planning of prevention, mitigation, response, recovery, and reconstruction.

Other initiatives, orientated to raise awareness and get the cities ready for the construction of resilience when coping with social, economic and physical challenges that they will have to face in an even more urbanized world, have been developed in recent years. Out of those initiatives, the challenge 100 Resilient cities of Rockefeller Foundation, Resilient Cities Profile Program (CRPP) of the United Nations, Habitat, and New Urban Agenda stand out among them [14, 15].

Actions to deal with the international commitments related to the diminishment of the environmental risks in urban areas were commenced by Mexico after the latter initiatives were developed.

Some of the principal actions were consultation, revision, and modification of some of the national laws related to the environment, territorial ordering and risks which were disassociated from international agreements as well as from the reality of the country. In some cases, the decree of new laws was indispensable.

In 2012, the General Law of Climatic Change, which foresees two indispensable instruments to orient and instrument the public policy in the subject: The National Strategy of Climatic Change and the Special Program of Climatic Change 2013–2018 [16], was published. The General Law of Human Settlements, currently known as General Law of Human Settlements, Territorial Ordering, and Urban Development) that strengthens the bases of the public management in human settlements, was modified.

Together with the latter, there are recent domestic initiatives and works that have been developed with the objective of diminishing the vulnerability and increase the resilience when coping with the impact of diverse menaces such as the Network of Resilient Cities for Mexico and the Guide of Resilience which was developed with the goal of strengthening and orienting local governments to prevent, cope with, and respond to disasters immediately. Nowadays, there are profiles of resilience principally in the following cities of these Mexican states: Playa del Carmen and Cozumel (Quintana Roo), La Paz (Baja California Sur), Tijuana (Baja California Norte), Ciudad Juárez (Chihuahua) Manzanillo (Colima), Allende (Nuevo León).

On the other hand, it must be considered that Mexico is one of the most vulnerable countries to the effects of climatic change, especially due to its location set in a continuously exposed region – which is frequently hit by the impact of hurricanes and affected by floods. Chetumal is a coastal city located in the south east of Mexico, and ever since it was founded (previously known as Payo Obispo back in 1904) until nowadays different hydro-meteorogical phenomena of this kind have been registered, which have caused

Table 1. Hurricanes that have caused damages to the city of Chetumal

Name/Date	Damages
Hurricane/1910	650 people were affected by this natural menace amidst the absence of basic services
Hurricane/10–1916	It destroyed houses, provoked floods, and caused collateral damage (Death toll: 84 malaria victims)
Hurricane/09–1931	No record of damages known
Hurricane/08–1934	It generated floods, as a result of a cyclonic disturbance that affected Belize and the coasts of Campeche
Santa Mónica/08–1942	It generated a few damages in dwellings and public spaces facilities as well as the decrease of lands of crop
Hurricane/11–1942	It destroyed parks, docks, public buildings, and houses, impacted the forest activity apart from causing insalubrity problems
Janet/09 –1955	Death toll: 84 people as well as a large number of missing people, 80% of the infrastructure was destroyed, and the cover of the jungle was lost
Carmen/09–1974	It generated floods particularly near the harbor area and damages to the public infrastructure and dwellings; electricity and water supplies were interrupted, and the surrounding jungle was gravely affected
Gert/09–1993	It generated enormous puddles and floods in the lower area of the city (evacuation of the inhabitants)
Opal y Roxanne/09 y 10–1995	Payo Obispo, the water supply was also suspended in 60% of the city
Mitch/10–1998	There were floods that affected approximately 70 families in Fidel Velázquez and Proterritorio neighborhoods (The flood level reached 50 cm); Nueva Reforma and 5 de Abril neighborhoods were also affected by the floods
Dean/08–2007	It affected nine hundred thousand hectares of forest vegetation and generated severe floods in low-leveled areas of the city
Karl/09–2010	157 mm of rainfall were recorded in approximately three hours, generating floods in 40 neighborhoods

(*continued*)

Table 1. (*continued*)

Name/Date	Damages
Ernesto and Tropical Wave No.11/08–2012	They caused several enormous puddles and floods (210 mm of rainfall were recorded in 12 h)
Tropical Wave No. 11/08–2015.	There were floods in several neighborhoods, roads, contiguous zones to the harbor (200 mm of rainfall were recorded in 12 h)
Earl /08–2016	Floods in critical areas in the city
Tropical Wave No. 3/06–2018	There were floods in Comité Proterritorio neighborhood, the emergency program "Operativo Tormenta" was activated with the purpose of helping the affected population
Tropical Wave No. 29/06–2019	It generated floods in the Proterritorio neighborhood, automobiles were stuck in the flooded streets
Tropical storm Amada Tropical storm Cristóbal/06–2020	Accumulated water exceeded 50 cm of height. In some neighborhoods, the Monument of the Fisher, located near the bay, was also affected by the flood because of the storm tide effect

Source: Chart elaborated by the authors based upon [17–23].

floods turning in human, economic, infrastructural, and environmental damages (see Table 1).

In the presence of this panorama, the present work suggests a proposal of Index of Coastal Urban Resilience (ICURHF) which allows the integration of indicators to evaluate the conditions of menace, vulnerability and capacity of adaptation of the city of Chetumal located in the south east of Mexico.

2 Methodology

2.1 Area of Study

Chetumal, capital city of the Mexican state of Quintana Roo, is a coastal city of the Mexican Caribbean; it is located between the parallels 18°, 33′, 46″ and 18°, 29′, 40″ north latitude, and between the meridians 88°, 21′, 57″ and 88°, 16′, 45″ west longitude. It is adjacent with the Bay of Chetumal, to the east, and the Río Hondo – the natural limit in the borderline with Belize – to the south, the wetlands La Sabana, to the west, and the lagoon system of Bacalar (see Fig. 1).

The criteria of selection of the area of study were established based upon two principal aspects: a) The exponential demographic growth reported by INEGI (Informatic, Geography and Statistical National Institute, in English) during the decade between 2000–2010 (2.2%), which was higher than the annual national growth rate (1.4%) [26], and b) the continuous hurricane menace, as well as the exposure to it; tropical waves or storms that are originated in the Atlantic Ocean and the Pacific Ocean.

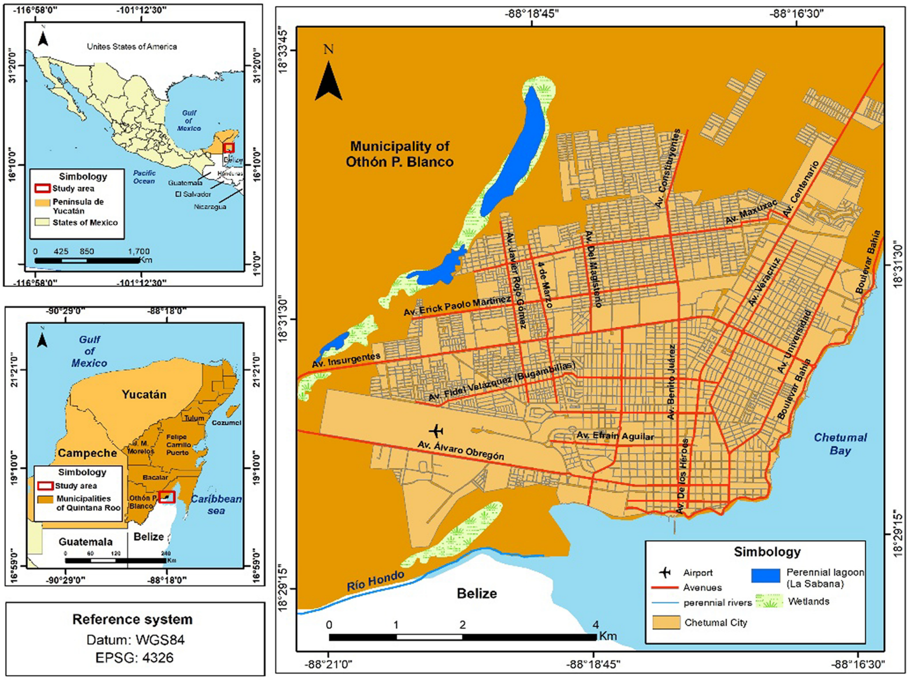

Fig. 1. Geographical location of the area of study in the national, regional, state, and municipality context [24, 25].

2.2 Methods and Materials

In order to demarcate the index of coastal urban resilience (ICURHF), a conceptual model and a system of indicators of coastal urban resilience were previously elaborated, both instruments were sustained in the framework of reference that encompasses (national and international) initiatives, agreements, strategies, actions, and methodologies associated with the prevention and mitigation of disasters, disaster risk public management, and urban resilience. The construction of the conceptual model and the system of indicators was developed based upon participative workshops (between professor-researchers and postgraduate students), semi-structured interviews with key actors and a survey which was applied in 450 private inhabited dwellings [27, 28].

The conceptual model and the system of indicators was structured in three components: menace, vulnerability, and capacity of adaptation. The system of indicators was integrated by a simple indicator ensemble which were selected by the following criteria: a) availability of sources (access to sources of data) b) pertinence (To contribute to decision taking), c) comprehension (to promote credibility and reliability of the users), d) comparability (local, municipal, state, regional, and national analysis) e) prediction capacity (to warn problems, risks and significant changes).

A total of 28 simple indicators were established, which were classified as positive (contributing to the resilience, and negative ones influencing the stability and/or the decrease of the resilience). A standardization by rank was applied with the purpose of homogenizing the scale of obtained results considering the parameters from 0 to 1 as well as the following formulas [29, 30]:

$$Positive = \frac{x - VMin}{VMax - VMin} \tag{1}$$

$$Negative = \frac{VMax - x}{VMax - VMin} \tag{2}$$

Where:

X = Brute value of the simple indicator j in the component i.
$VMin$ = Minimal value of the simple indicator j in the component i.
$VMax$ = Maximum value of the simple indicator j in the component i.

Regarding the ponderation (P_i) of the indicators, equi-proportional values were selected and utilized for the components menace and vulnerability (2.5) while for the capacity of adaptation an ponderation of 0.5 was assigned due to the fact that this component was considered to be part of one of the key properties of the resilience from the moment it assists in the construction of the capacity of attenuation (reduction of the vulnerability) permitting the system to learn and adapt itself to the change based upon reorganization, ponderation, and the process of existing knowledge [31, 32]. It is important to emphasize that the standardization and assessment of the indicators were established based on the technique judgment of experts (see Tables 2, 3, and 4).

Table 2. Simple indicators for menace components of ICURHF

Context	Indicator	Ponderation
Natural	% of rainfall flooding area	−0.4
	% of storm tide flooding area	−0.6
		$\sum -1.0$

Source: Table elaborated by the authors based upon [25].

The calculation of ICURHF and its components, it was necessary to use the ponderation, that is to say, numeric ponderation or percentages which were associated according to the relevance of the component [29, 34–36]. The Index of coastal urban resilience was determined based upon the following formula:

$$ICURHF = C_1 * P_1 + C_2 * P_2 + C_3 * P_3; \forall P_i \neq 0 \tag{3}$$

Where:

$ICURHF$ = Index of coastal urban resilience
C_i = Component i in the Index of coastal urban resilience

Table 3. Simple indicators for vulnerability components of ICURHF

Context	Indicator	Ponderation
Natural	Population Density	−0.09
	% of infantile population (0–14)	−0.07
	% of 65-year-old or older population	−0.07
Social	% of non-rightful claimant to healthcare service population	−0.07
	% of handicapped population	−0.07
	% of 15-year-old, or older, and illiterate population	−0.07
Economic	% of non-economically active	−0.07
	Population % of censual homes with female leadership	−0.07
	% of inhabited private dwellings with earth floor	−0.07
	% of inhabited private one-room dwellings	−0.07
Constructed	% of inhabited private dwellings without services	−0.07
	% of inhabited private dwellings	−0.07
	% threatened by flood risk	−0.07
Cultural	% of the population who ignores their location is hurricane-prone	−0.07
	% of the population who has not experienced a hurricane yet	−0.07
		∑−1.0

Source: Table elaborated by the authors based upon [25, 27, 28, 33].

P_i= Ponderation of the component in the calculation of the Index of coastal urban resilience

$$\sum_{i=1}^{3} P_i = P_1 + P_2 + P_3 = 1 \quad (4)$$

Where:

In the same way, the result of every component is obtained through the ponderation mean of the simple indicators considered in each one of them.

$$C_i = \sum_{i=1}^{ni} I_{i,j} * P_{i,j} = I_{I,1} * P_{I,1} + I_{I,2} * P_{I,2} + \ldots + I_{i,ni} * P_{i,ni}; \forall P_{i,j} \neq 0 \quad (5)$$

Where:

$I_{i,j}$ = Simple indicator j which is used for the calculation of ICURHF in the component i.
$P_{i,j}$ = Assigned ponderation to the simple indicator j in the calculation of ICURHF in the component i.

Table 4. Simple indicators for capacity of adaptation components of ICURHF

Context	Indicator	Ponderation
Social	% of the population who has dwelled in the city for over 5 years	0.03
Economic	% of inhabited private dwellings where 2, or more, [family members] work	0.03
Natural	% of green areas	0.02
Constructed	% of inhabited private dwellings with insurance	0.04
Cultural	% of inhabited private dwellings which count on an emergency plan	0.2
	Risk atlas	0.15
	Plan of urban development	0.1
	% of inhabited private dwellings where, at least, a family member has been trained to know what to do in case a hurricane hits or in the event of floods	0.2
	% of inhabited private dwellings where, at least, a family member has received information about what to do in the event of a hurricane, or flood	0.04
Institutional	% of the population who knows government, and non-government programs that promote the prevention of risks in the event of a hurricane or a flood	0.04
	% of the population who knows the location of the closest temporary shelter	0.1
	% of the population who knows the routes of evacuation in the event of a flood or a hurricane	0.05
		$\sum$1.0

Source: Table elaborated by the authors based upon [25, 27, 28, 33].

$$\sum_{j=1}^{ni} P_{i,j} = P_{i,1} + P_{i,2} + \ldots + P_{i,ni} = 1 \tag{6}$$

With the goal of spatially representing on a BGA (Basic Geostatistical Area) scale, the obtained results from every component and, consequently, from ICURHF, the following ordinal scale was established (See Table 5).

Table 5. Nominal scale to spatially represent ICURHF

Interval	Scale
0%–39.9%	Low
40%–59.9%	Medium
60%–79.9%	High
80%–100%	Very High

Source: Adapted by the authors based upon [29, 34, 35].

3 Results and Discussion

In the Fig. 2a, the spatial distribution of the indicators of the menace component can be observed, the very high values correspond to the BGA's with a surface flooded by storm tide higher or equal to 80% (Del Bosque, 5 de Abril, Nueva Reforma, Plutarco Elías Calles, Centro and Aarón Medino neighborhoods are principally located in these areas), the BGA's with high values in zones that are flooded by a 60 to 79.9% of rainfall or storm tide (Proterritorio, Primera Legislatura, Andrés Quintana Roo, Solidaridad, Nuevo Progreso, Fidel Velázquez, and Adolfo López Mateos neighborhoods are located there). Both menaces (coastal flood and pluvial flood) cause damages in the dwellings, as well as in the road infrastructure and, at the same time, deteriorate the quality of life of its inhabitants. The Comission of Drinking Water and Sewerage of Chetumal has located 124 locations that have problems of flood and enormous puddles in the city [17].

Regarding the vulnerability, Fig. 2b shows that 67% of the GBA's that compound the city, registered high vulnerability while 22% correspond to medium vulnerability, 7% to the low one, 2% to the high one, and 2% is non-applicable (regarding the airport and residential areas which are not included in this study due to lack of access to the information). The areas with very high and high vulnerability are associated to: 1) dwellings at risk of floods (48%), principally the ones located in the nearby area of the harbor and the wetlands called La Sabana, as well as the neighborhoods previously listed, and 2) the population that has never experienced a hurricane hitting (54%). Regarding this [20], states the affectations that have caused the different hurricanes in the city of Chetumal, from its foundation until hurricane Earl hit in 2016. He mentions that most [of the damages] are floods in the nearby area of the bay, as well as in some neighborhoods referred in the previous paragraph.

Additionally, 58% of the BGA's reported high capacity of adaptation, 33% very high, 4% low, 3% medium, and 2% non-applicable (see Fig. 2c). The high values of this component are principally related with the updated Plan of Urban Development (100% corresponds to the year 2018) the dwelling where inhabitants have received information about what to do in case of the event of a hurricane or a flood (93%), the population that knows the location of the nearest temporary anticyclonic shelter (68%), and the population who is familiar with programs that promote prevention of risks as a result of a hurricane or a flood (56%).

According to Rodriguez [20], during the last decades there has been an intense media bombing in Chetumal regarding what to do before, during, and after the event of a hurricane. Notwithstanding the difficulties, state authorities have been exclusively concerned in the preparation and recovery of the population, emphasizing that the institutional decisions are still centered in an emergency nevertheless, they are not actions centered in the processes of mitigation of risks.

The presence of indicators, whose values are low, and have an effect on the capacity of adaptation is also emphasized, for instance: The Atlas of Risks to scale of the city (50%), it is not updated, solely the 1.8% of the surveyed dwellings have a Plan of Familial Emergency, 7% of the dwellings have insurance, 29% of the inhabitants of the dwellings have been trained in relation to what to do in the event of a hurricane, or a flood, and 31% of the population knows the routes of evacuation when coping with a hurricane or a flood. Vis-à-vis the Atlas of Risks, this planning instrument was elaborated for the city of Chetumal in 2005, and it was the first approximation to the study of risk in this territory and locations within the Plan of Urban Development of the Suburban Area. This instrument was updated in 2011 with the purpose of identifying, in addition to locating, the type and grade of risk for geological and hydrometeorological phenomena, as well as their vulnerability [25]. In the last years, in the presence of the demographic growth of this city, together with the effects of the climatic change, it is compelling to bring the Atlas of Risks of Chetumal up to date based on methodologies that take into consideration the urban hydrographic analysis with the purpose of obtaining the identification and zoning of the areas at risk of floods [37].

The ICURHF of the city of Chetumal, on a BGA scale, showed that 60% of it has a high resilience, in the meantime the rest of the area (40%) registered a medium resilience. The latter corresponds to the BGA's where the menace was very high, and the vulnerability high. The ICURHF of Chetumal, at a city level, was of 63% (see Fig. 2d). This datum is approximated to the Index of hurricane risk in Chetumal (69%) corresponding to the impact of hurricane Dean in 2007 [38]. At the other end of the spectrum, Martínez et al., in 2018, got the Index of resilience in the infrastructure of drinking water of the city of Chetumal when coping with hurricanes: which was of 69% [39]. Frausto et al., in 2018, reported a medium level of resilience for the island of Cozumel (situated in the south east of Mexico) that was determined based on the integration of simple indicators and derived composed by the conduction of a representative survey. Participative methods, for the assignation of the ponderations, were utilized, as well [40].

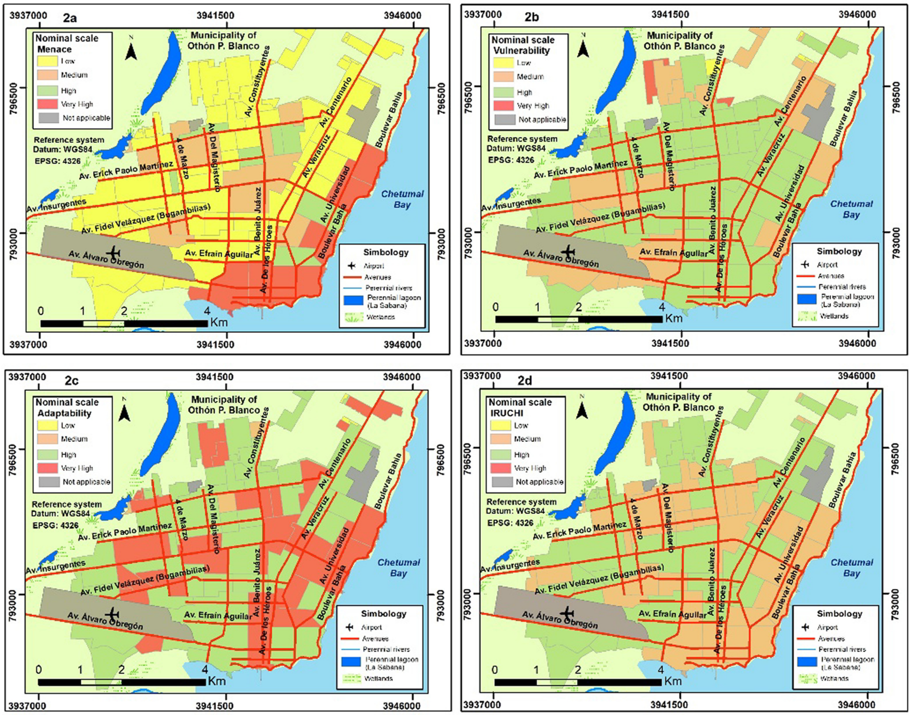

Fig. 2. Index of menace, vulnerability and capacity of adaptation and resilience Chetumal [24, 25, 27, 28, 33].

4 Conclusion

The studies of resilience when coping with disaster risks are still scarce. Furthermore, it is observed that the concept of resilience in diverse work as an adjective for communities, and people, which is correct in the face of the study of phenomena that involve the population, Nevertheless, in the Guide of Resilient Cities it can be observed that these are tangible elements, and not people, which are evaluated for the resilience; that is the reason why in this work an exercise is done which considers the inhabitants of the city of Chetumal, and their knowledge regarding the risk of hurricanes and floods that they have acquired through life experience, as well as via different mass media. This aspect was decisive in the process of assignation of weights of each one of the components that integrated the index, since the indicators of Menace and Vulnerability depend on the (physical, natural, and social) characteristics of the city – to a greater extent- and not on the knowledge of the population about the risk, that is the reason why a higher ponderation of the indicators of the component Capacity of Adaptation was assigned.

The Index of Coastal Urban Resilience when coping with hurricanes and floods (ICURHF) of Chetumal combines a series of simple indicators associated to the natural, social, economic, cultural, institutional, as well as the dwelling, conditions that characterize this coastal city.

Even though the ICURHF turned out to be high, it is compelling to train, from the approach of the Disaster Risk Public Management, (the state and municipal) authorities as well as the population regarding hydrometeorological phenomena they are continuously living together with, because both parts reaffirm having a culture before the impact of hurricanes and floods, when they have actually been focused on the preparation and recovery when these menaces hit, without emphasizing on the measures or actions of mitigation of risks that contribute to the prevention of future risks.

The proposed Index, in this work, can be replicated, adapted, and improved for the development of future studies associated with resilience in the light of risks of disasters in coastal cities, or in other urban spaces. Its main contribution is the inclusion of qualitative indicators that strengthen the definition of resilience as a social construct. Nevertheless, the spatial interpretation and representation of the obtained data are presented on a BGA scale; it would be convenient to have information on a block scale, in order to design with the purpose of establishing strategies of local solution on a community or neighborhood scale.

References

1. Holling, C.S.: Resilience and stability of ecological systems. Ann. Rev. Ecol. Syst. **4**, 1–23 (1973)
2. Gallopín, G.C.: Linkages between vulnerability, resilience, and adaptive capacity. Glob. Environ. Change **16**(3), 293–303 (2006)
3. Congress of the United States: Ley de control de Inundaciones 70°, Sess, 1. Ch.596, 5 May 1928, Unites States (1928)
4. Vilches, O.R., Reyes, C.M.: Riesgos naturales: evolución y modelos conceptuales. Review Universitaria de Geografía **20**(1), 83–116 (2011)
5. García-Tornel, F.C.: La Geografía de los Riesgos. Review Geocrítica, Cuadernos Críticos de geografía humana **54**, 5–40 (1984)
6. Ayala-Carcedo, F.J., Olcina-Cantos, J.: Riesgos naturales. Editorial Ariel, Barcelona, Spain (2002)
7. de Castro, S.D.A., Riesgos y Peligros: Una visión desde la geografía. Scripta Nova. Electronic Review of Geografía y Ciencias Sociales **4**(60), 55–78 (2000)
8. Lovón-Zavala, G., Caputo, M.G., Hardoy, J.E., Herzer, H.M.: Desastres naturales y sociedad en América Latina. Buenos Aires. Argentina. Grupo Editor Latinoamericano (1985)
9. Lavell, A.: Comunidades urbanas, vulnerabilidad desastres y opciones de prevención y mitigación: Una propuesta de investigación-acción para Centroamérica en: Viviendo en Riesgo. Chapter 2. LA RED: https://www.desenredando.org/public/libros/1994/ver/html/3cap2.htm (1997). Accessed 01 Aug 2020
10. United Nations - EIRD. Conferencia Mundial sobre desastres. Yokohama: ONU. https://eird.org/fulltext/Yokohama-strategy/YokohamaEspa%F1ol.pdf (1994). Accessed 01 Aug 2020
11. United Nations. Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters. International Strategy for Disaster Reduction. World Conference on Disaster Reduction 18–22 January 2005, Kobe, Hyogo, Japan. https://www.unisdr.org/2005/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf. Accessed 01 Aug 2020
12. United Nations. Cómo desarrollar ciudades más resilientes. Un manual para los líderes de los gobiernos locales. Una contribución a la Campaña Mundial 2010–2015 “Desarrollando ciudades resilientes - ¡Mi ciudad se está preparando!”. March 2012, Ginebra. https://www.unisdr.org/files/26462_manualparalideresdelosgobiernosloca.pdf. Accessed 01 Aug 2020

13. ONU. Marco de Sendai para la Reducción del Riesgo de Desastres 2015–2030. https://www.unisdr.org/files/43291_spanishsendaiframeworkfordisasterri.pdf (2015). Accessed 01 Apr 2020
14. Galcerán, M.L.: reducción del riesgo de los desastres Translación de la agenda global de resiliencia al ámbito local. Notas internacionales CIDOB **117**, 1–5 (2015)
15. United Nations. Nueva Agenda Urbana H III. A Conferencia de las Naciones Unidas sobre la Vivienda y el Desarrollo Urbano Sostenible (Hábitat III). Quito, Ecuador, el 20 de octubre de 2016. http://habitat3.org/wp-content/uploads/NUA-Spanish.pdf. Accessed 30 May 2020
16. Natural Resources and Environmental Secretary. Versión de difusión del Programa Especial de Cambio Climático 2014–2018. México: Secretaría de Medio Ambiente y Recursos Naturales. http://www.sectur.gob.mx/wp-content/uploads/2014/09/PECC-2014-2018.pdf (2014). Accessed 27 Jan 2020
17. CAPA-IMTA. Informe del Programa para el Manejo del Agua Pluvial de la Ciudad de Chetumal, Quintana Roo. Comisión de Agua Potable y Alcantarillado (CAPA) and Instituto Mexicano de Tecnología del Agua (IMTA). Cuernavaca, México (2013)
18. Morales, J.J.: Selvas, mares y huracanes. Gobierno del estado de Yucatán y Biblioteca básica de Yucatán. Mérida, México (2012)
19. Morales, J.J.: Quintana Roo, Tierra de Huracanes. En Carlos Macías Richard (Coord.). Quintana Roo: Vitalidad histórica y despliegue contemporáneo. Tomo II, pp. 144–161. Agencia Promotora de Publicaciones, México (2016)
20. Alarcón, M.N.R.: Convivir con la amenaza, vulnerabilidad y riesgo frente a los huracanes en la ciudad de Chetumal, Quintana Roo. Thesis for Master in Social Antropology. Universidad de Quintana Roo, México (2017)
21. Secretaría de Desarrollo Agrario, Territorial y Urbano SEDATU. Programa de Desarrollo Urbano de Chetumal, Calderitas, Subteniente López, Huay-Pix y Xul-há. Municipio de Othón P. Blanco. http://www.opb.gob.mx/portal/wp-content/uploads/transparencia/93/I/f/PDU2018/PDU%20integrado%2019012018-publicacion%20digital.pdf (2018). Accessed 01 Aug 2020
22. Maiza, X., Ángel, J.: Enciclopedia de Quintana Roo. Fascículo Historia, Quintana Roo, México (2004)
23. Maiza, X., Ángel, J.: Enciclopedia de Quintana Roo. Fascículo Chetumal, Quintana Roo México (2005)
24. Instituto Nacional de Estadística y Geografía INEGI. Marco Geoestadístico, Datos Vectoriales, México (2016)
25. Centro de Información Geográfica-Universidad de Quintana Roo CIG-UQROO. Atlas de Riesgo de la ciudad de Chetumal, Municipio de Othón P. Blanco, Quintana Roo. México. http://rmgir.proyectomesoamerica.org/PDFMunicipales/2011/vr_23004_AR_OTHON_P_BLANCO.pdf (2011). Accessed 01 Aug 2020
26. Instituto Nacional de Estadística y Geografía INEGI. *Censo de Población y Vivienda 2010. Perfil sociodemográfico: Estados Unidos Mexicanos*. México. http://internet.contenidos.inegi.org.mx/contenidos/Productos/prod_serv/contenidos/espanol/bvinegi/productos/censos/poblacion/2010/perfil_socio/uem/702825047610_1.pdf (2013). Accessed 27 July 2020
27. Sanabria, J.M.C., Alvarado, R.C., Torres, D.V.:. Propuesta Metodológica para Medir la Resiliencia Urbana ante Huracanes e Inundaciones en el Caribe Mexicano. Rev. REDER **3**(2), 28–43 (2019)
28. Alvarado, R.C., Sanabria, J.M.C., Torres, D.V.: El camino hacia un modelo metodológico para realizar un índice de resiliencia en ciudades costeras (IRCC) del Caribe mexicano ante huracanes e inundaciones. Review Contexto **XIII**(18), 13–29 (2019)
29. Villanueva, L.C., et al.: Modelo de indicadores para la evaluación y monitoreo del desarrollo sustentable en la zona costera de Mahahual. Quintana Roo, México. Perspectiva Geográfica **19**(2), 309–330 (2014)

30. Miranda, J.P.R., Suazo, Á., Malfanti, I.S.: Análisis por medio de la normalización de variables para un modelo de planificación ambiental hídrica estacional. Obras y proyectos **20**, 76–85 (2016). http://dx.doi.org/10.4067/S0718-28132016000200006
31. Jacobi, J., Schneider, M., Pillco Mariscal, M.I., Huber, S., Weidmann, S., Rist, S.: La contribución de la producción del cacao orgánico a la resiliencia socio-ecológica en el contexto del cambio climático en el Alto Beni - La Paz. Acta Nova **6**(4), 351–383 (2014)
32. Jeans, H., Castillo, G.E. Thomas, S.: L'avenir est un choix. Absorption, adaptation et transformation: Les capacités de résilience. Oxfam International. https://oxfamilibrary.openrepository.com/bitstream/handle/10546/620178/gd-resilience-capacities-absorbadapt-transform-250117-fr.pdf?sequence=6&isAllowed=y (2017). Accessed 04 Aug 2019
33. Instituto Nacional de Estadística y Geografía INEGI. Censo de Población y Vivienda 2010. Principales resultados por AGEB y manzana urbana. México (2010)
34. Leva, G.: Indicadores de calidad de vida urbana. Teoría y metodología. Universidad Nacional de Quilmes, Argentina (2005)
35. Villanueva, L.C.: Urbanización, problemas ambientales y calidad de vida urbana. Plaza y Valdés, Ciudad de México, México (2009)
36. Nieves, A., Domínguez, F.C.: Probabilidad y estadística para ingeniería: Un enfoque moderno, 1a edn. McGraw-Hill, México (2010)
37. Chaparro, M., Carlos, J.: Mapping the Risk of Flood, Mass Movement and Local Subsidence. Springer, Switzerland (2020)
38. Hernández, M.L., Carreño, M.L., Castillo, L.: Methodologies and tolos of risk management: Hurricane risk index (HRi). Int. J. Disaster Risk Reduct. **31**, 926–937 (2018). https://doi.org/10.1016/j.ijdrr.2018.08.006
39. Méndez, A.M., Martínez, O.F., Villanueva, L.C., Sanabria, J.M.C.: Índice de Resiliencia de Infraestructura de agua potable ante huracanes en ciudades costeras **61E**(3), 339–365 (2018). http://dx.doi.org/10.15359/rgac.Esp-3.17
40. Martínez, O.F., et al.: Perfil de resiliencia urbana de la isla de Cozumel, México. Antrópica, Revista de Ciencias Sociales y Humanidades **4**(8), 215–237 (2018). https://antropica.com.mx/ojs2/index.php/AntropicaRCSH/article/view/113/113