

Humanitarian logistics network design for emergency temporary shelters: a Brown-Gibson and p-median optimization approach

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<https://doi.org/10.22306/al.v13i3.800>**Humanitarian logistics network design for emergency temporary shelters:
a Brown-Gibson and p-median optimization approach****Erika Barojas-Payán**Faculty of Engineering-UV, Km 1.0 Sumidero Dos Highway, Ixtaczoquitlán, Veracruz, 94450, Mexico,
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Abstract: The effects of climate change have impacted the whole planet, and although it is certain that losses in infrastructure have cost millions of dollars, what is most worrying is the millions of lives lost; specially in countries such as Mexico. In Mexico, the municipalities of the capital region of the state of Veracruz have been strongly affected by extreme meteorological phenomena, which on several occasions have led to temporary relocation of those affected. Unfortunately, no contingency plan that considers the location of temporary shelters has been proposed. For this reason, the objective of this study is to design of a Network for Temporary Shelters with four nodes by combining a technique with various criteria and an optimization model that not only allows for locating the municipality that would form part of the network through a minimum distance travelled, but also have the characteristics that would allow for safe quality accommodations for those affected in the capital region of Veracruz. The results show that the municipalities of Teocelo, Jalcomulco, Las Vigas Ramírez and Xico have the best conditions to form this network.

1 Introduction

Climate change is the modification of the temperature and the rest of the climate variables. Its effects have been felt worldwide and constitute the largest environmental threat that humanity faces. The North and South poles are melting, which is provoking a rise in the sea level worldwide. The impacts of climate change are unequivocal, it is the largest threat for world health, its effects are direct (heat waves, floods, droughts, etc.) and indirect (respiratory diseases, food insecurity, water, etc.). The socially marginalized are one of the most vulnerable groups affected by these risks. The occurrence of an extreme event or multiple extreme events can cause a catastrophic disaster. In some zones, weather phenomena are increasingly frequent, and in others, intense heat waves and droughts are registered [1-4]. According to [5], the four natural disasters that marked the last 100 years were: **1.** The flooding of the Yangtze River, China, in 1931; **2.** The Indian Ocean tsunami of 2004, which affected India, Indonesia, the Maldives, Sri Lanka, and Thailand, among other countries; **3.** Hurricane Katrina in 2005 devastated the southeastern United States, and **4.** The 2010 earthquake in Haiti, which practically destroyed the country. In this sense, logistic activity has become more relevant worldwide, not just in business and industrial areas, but socially as well. It can be said that *logistics* is the tool through which an effective and efficient resource and information flow can be achieved, integrated with activities along the supply chain with the objective of strengthening and increasing levels of customer service. The logistics field has the denomination of *humanitarian logistics* (HL), which is derived from the concern of looking for solutions for diverse problems, such as those related to *climate change* and its presence, impact, and the frequency of extreme natural phenomena, which has been of interest to governments, organizations, and researchers worldwide [6].

In this area, a shelter is understood as a synonym for an asylum designated for reception or support. When a person is given or assigned one, it not only provides a roof for protection against the elements, minimize the risk of illness or even death, but it is also a place where an individual recovers his or her dignity. In general there are three types of shelter: *a)* emergency, designed for emergency situations, which tend to be tents or prefabricated buildings; *b)* transition, made with more resistant materials for rain or cold, used for refugee camps; *c)* durable, more independent, solid, and better equipped than the first two, which are given to refugees that have been in the host country for many years [7]. In Mexico, the

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General Law of Civil Protection [LGPC] (2023) mentions that a temporary shelter is the physical installation authorized to give temporary protection and well-being to people without immediate possibilities of access to a safe room in case of imminent risk, emergency, catastrophe, or danger [8].

1.1 Mexico facing climate change

Climate change will generate larger impacts on human beings, mainly in the areas of extreme poverty and where there are high risks of extreme weather phenomena such as prolonged droughts or torrential rains. Mexico is situated in the southern part of North America and is adjoined to the United States in the north, the Gulf of Mexico in the east, Belize and Guatemala in the south, and the Pacific Ocean to the west. It has a surface of 1,972,550 km², divided into 32 federal entities, and has a population of 129 million people according to the National Institute of Statistics and Geography [INEGI] 2023 [9].

The geographical and social characteristics of Mexico make it one of the most vulnerable countries to climate change in the world. Due to its location between two oceans as well as its latitude and slopes, it is exposed to different weather phenomena. A determining factor of its social vulnerability is poverty, and the social and environmental impact generated by extreme weather phenomena also affects the economy [10]. Among the natural phenomena over the last ten years are the events mentioned below in Table 1.

Table 1 Natural phenomena in Mexico [11-20]

Date	Phenomenon	States affected
2015	Hurricane Patricia	Michoacán, Colima, Jalisco and Nayarit
2016	Tropical Storm Earl	Veracruz, Hidalgo and Puebla
2017	Earthquake magnitude 7.1	Puebla, Ciudad de México, Morelos, Estado de México, Guerrero, Oaxaca and Tlaxcala
2018	Earthquake 7.2	Oaxaca, Ciudad de México, Estado de México, Guerrero and Morelos
2019	Earthquake 6.7	Chiapas and Hidalgo
2020	Inundaciones en el sureste	Campeche, Tabasco, Veracruz,
2021	Inundaciones del Río Tula	Hidalgo
2022	Hurricane Agatha	Veracruz, Oaxaca, Chiapas and Tabasco
2023	Hurricane Otis	Suroeste de México, Guerrero
2024	Hurricane John	Colima, Michoacán, Oaxaca and Guerrero

1.1.1 Explanation of the problem

The state of Veracruz (of Ignacio de la Llave) is one of the 32 states that makes up the country of Mexico (31 free and sovereign states and Mexico City), located in the eastern part of the country, it is adjoined to Tamaulipas and the Gulf of Mexico in the north, Chiapas and Tabasco to the south, and Puebla, Hidalgo, and San Luis Potosí to the west. It represents 3.7% of the total national surface area. Figure 1 shows the location of Veracruz inside of Mexico.



Figure 1 The state of Veracruz (of Ignacio de la Llave) [21]

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Veracruz is made up of 212 municipalities that are inside ten regions [22,23]. In Figure 2, we can observe these regions.



Figure 2 Regions of the state of Veracruz (of Ignacio de la Llave) [24]

The Capital region is located in the central part of Veracruz. It extends over a surface of 5,568.55 km² and is integrated into 33 municipalities, Acajete, Acatlán, Actopan, Alto Lucero de Gutiérrez Barrios, Altotonga, Apazapan, Ayahualulco, Banderilla, Coacoatzintla, Coatepec, Cosautlán de Carvajal, Chiconquiaco, Emiliano Zapata, Ixhuacán de los Reyes, Jalancingo, Jalcomulco, Jilotepec, Landero y Coss, Miahuatlán, Las Minas, Nolinco, Perote, Rafael Lucio, Tatatila, Teocelo, Tepetlán, Tlacolulan, Tlalnelhuayocan, Tonayán, Las Vigas de Ramírez, Villa Aldama, Xalapa and Xico. There is a high degree of marginalization in 48.48% of its municipalities, low marginalization in 6.06%; medium marginalization in 36.36%; very high marginalization in 3.03%, and very low marginalization in 6.06%, according to the National Council for the Evaluation of Social Development Policy (2015) [25].

In the last ten years, the Capital region has declared disasters by means of the National Center for the Prevention of Disasters [CENAPRED] [26], since it has been significantly affected by weather phenomena. 75% of its municipalities have declared at least one disaster. Despite this, there is no contingency plan to help the government effectively determine the best location of temporary shelters to provide protection and relief to those affected by emergencies or disasters [27]. Thus, the objective of this work is to propose the creation of an Emergency Temporary Shelter Network (ETSN) made up of four nodes, to accommodate people affected by weather events in the region. For this, we use the Brown & Gibson model for multi-attribute decision making. From the results, an adjustment factor is used with the application of the p-median problem, with which we have created an ETSN with four nodes that are found at minimum traveled distances and with appropriate characteristics to shelter people affected by a weather event.

This study is divided from this paragraph into *a)* the state of art, which carries out a literature review regarding the location of emergency facilities, as well as literature regarding the Brown & Gibson model for multi-attribute decision making and the application of the p-median problem, *b)* methodology, made up of three phases, in this section we carry out data collection and the application of location methods and the results obtained through each one of these, and *c)* results and discussion, which gives a comparison of the obtained results to locate facilities in the state of Veracruz, *d)* conclusions, which presents the discoveries found by the authors, and *e)* references that show the bibliographical sources used as a resource for answers for this explanation.

1.2 Literature review

In this section, we show the revision of the literature of the methods, techniques, and methodologies used by different researchers to give answers to the location problem regarding humanitarian logistics, as well as literature about the methods used for creating the ETSN.

1.2.1 Methodologies, methods, and techniques of the problem of facility location

In the following paragraphs, we present research regarding the subject of humanitarian logistics, specifically installing temporary shelters worldwide.

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Researchers [28] presented a Mixed Integer Linear Programming model to solve the problem of shelter location in the midst of uncertainty in Turkey, and the results showed that with different combinations, the factors of rate of shelter use, service level of demand, and demand pattern lead to completely different solutions. In the same way, the research document [29] proposes the design of shelter networks through a methodology based on risk (population, shelter, and evacuation). In Haiti, the results guaranteed the efficiency of the model in a real context. Likewise, the researchers [30] developed a multi-objective shelter location and relocation model in the midst of uncertainty in case of an earthquake evaluated in different scenarios. It is worth mentioning the work of [31], where researchers carried out a study regarding shelter location and assigning the affected population shelters with a mixed-integer stochastic programming model in three stages to simulate the real environment of an earthquake.

Continuing with this analysis, it is worth mentioning the work of [32], in which the authors developed a multi-objective multi-period with multi-sourcing model, which determines the location of logistics centers in a disaster, implements a fuzzy factor evaluation system under the condition of making decisions in groups in order to determine weights, the results provided great managerial perspectives for the decision makers. Likewise, the work of [33] presents a fuzzy additive weighting system to resolve facility location problems through subjective and objective attributes, under the condition of making group decisions, and it numerically gives examples of the procedure. The researchers [34] propose a multi-objective optimization model to determine the location in response to the logistics of humanitarian help using the Epsilon-Delta limit method and programming objectives for its resolution. The validation of the model is carried out using a case study in Thailand.

Some researchers have been reviewing the literature regarding the location of humanitarian logistics facilities by means of techniques, methodologies, and tools used to give a solution to specific problems as well as global problems. In some studies elements are proposed that should be considered to minimize risks and guarantee quality of life for people affected, such as in the case of researchers [35], who carried out a literature review about the location of humanitarian facilities for a period of three years, signaling that the revised studies are normally adjusted to the following realities; 1. Capacity limit; 2. Stochastic models; 3. Locations that are not pre-defined; 4. Deprivation and multi-objective functions. They recommend that in future investigations aspects such as facility temporality, robust models, routing with restrictions, etc. should be included. The work of [27] gives a temporary shelter network evaluation framework through critical indicators of coverage performance and relevant services. The results of the evaluation show the need to take measures to alleviate shelters that, due to their location, can be overfilled.

It should be noted that the literature review did not find any articles proposing the design of an ETSN in the capital region of Veracruz that combines the Brown-Gibson and P-median or any other location methods. This gap constitutes the main contribution of this research.

1.2.2 Literature review of facility location methods Brown-Gibson and p-median

The following describes the literature relevant to methods used for the creation of ETSN.

Brown-Gibson method

The Brown-Gibson location model is a location model of one site with multiple attributes, it deals with the disadvantages associated with qualitative and quantitative methods and considers types of factors or criteria, objective and subjective. The first ones determine if a location is considered for an additional evaluation, the objective factors are the translation in monetary terms, while the subjective ones are qualitative measures. The model that integrates the three categories in this way is presented in equation (1) [36]:

$$LM_i = CFM_i [\alpha \times OFM_i + (1 - \alpha) \times SFM_i], \quad i = 1, 2, \dots, m, \quad (1)$$

Where:

CFI_{ij} : critical factor index for location i regarding the critical factor CF_j , takes value 1 if location i fulfills the requirement of critical factor CF_j , and 0 in the opposite case.

α : is the weight of the objective factor decision, it should be between 0 and 1.

OFM_i : relative value of the objective factors for location i , it is based on the cost.

SFM_i : relative value of the subjective factors for location i , it is found in the 0-1 scale.

LM_i : the best location for the plant is the one which has the highest location measurement.

P-median method

The facility location problem arises when deciding where the facilities should go, guaranteeing client satisfaction [37]. In the same way, the p-median model looks to locate “p” facilities in a way that minimizes the distance between the nodes that have a demand and the designated facilities. The model is described in the following paragraphs.

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Parameters:

$J = \{1, \dots, n\}$ index group for clients

$N = \{1, \dots, m\}$ index group for the location of the averages

$J = N$ for each $(j, i), j \in N, i \in J$

Variables

W_j = total demand to cover the node j ;

C_{ij} = distance from the node j to the node i ;

P = number of facilities to locate;

Y_i = takes the value one if an installation is located at i y 0 otherwise.

X_{ji} = takes the value one if an installation is located at i y 0 otherwise.

Mathematical Formulation

The mathematical formulation of the problem is presented in the following way:

$$\text{Min} = \sum_{i \in J} \sum_{j \in N} W_j C_{ji} X_{ji} \quad (2)$$

Subject to

$$\sum_{i \in J} X_{ji} = 1 \quad \forall j \in N \quad (3)$$

$$\sum_{i \in J} Y_i = P \quad (4)$$

$$X_{ij} \leq Y_i \quad \forall j \in N, i \in J \quad (5)$$

$$X_{ji} \in \{0,1\}, Y_i \in \{0,1\} \quad \forall j \in N, i \in J \quad (6)$$

Equation (2) represents the objective function, minimizing the sum considered for distances associated with the nodes of the client municipalities assigned to the nodes of the candidate municipalities. Equation (3) guarantees that all the client municipalities have a precise location. Equation (4) establishes the number of facilities in P . Equation (5) prohibits assigning a site without facilities, which means only nodes with facilities will supply the product. Equation (6) reinforces the binary nature of the decisions for installing a node and assigning a node a facility for a client municipality [38].

2 Methodology

Figure 3 shows the methodology used for the implementation of an emergency temporary shelter network in the state of Veracruz, especially in the Capital region. The methodology starts with the collection, analysis, and selection of the information to make way for the application of the first facility location method called Brown & Gibson, or Synergetic. With this, the priority load that has the municipalities contained in the region to be able to form part of the humanitarian shelter network will be obtained. Once the Synergetic method is applied, it makes way for the programming and application of the classic p -median problem with Lingo 21.0® software and the results will be shown on graphs.

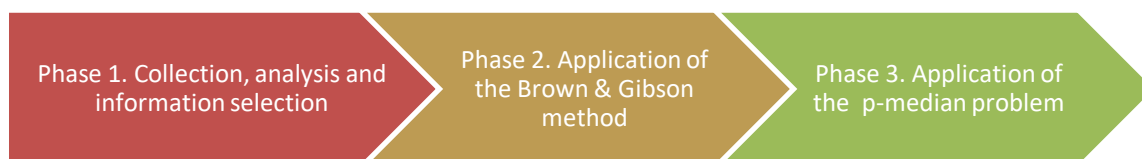


Figure 3 Methodology to solve the facility location problem

2.1 Phase 1 - collection, analysis and information selection

To carry out the application of the proposed methods, different databases with information from each one should be developed, the information used and the reference source is below.

2.1.1 Synergetic method

1. *Critical factors* are those elements considered essential for an organization to function, in this case the functioning of a humanitarian shelter, one determining critical factor is:
 1. *Municipalities that have declared a hydrometeorological weather phenomena disaster in the last 10 years.* The information will be used as a probability factor for a municipality with a high impact factor to be

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disregarded in forming a humanitarian shelter network. For this step, we can refer to the National Center of the Prevention of Natural Disasters website (CENAPRED).

2. *Objective factors*, the objective factors allude to measurable and quantifiable criteria, in the case of the temporary shelter study, the factors considered are:
 1. *Provisioning*, two sites of shops of social interest were considered as suppliers for people affected in temporary shelters, located in the municipalities of Puente Nacional and Villa Aldama and the cost of fuel to move the supplies to the temporary shelters was calculated, the cost estimated was \$1 MXP per km. The data were obtained through the Google Maps® application.
 2. *Attention to health*, with the objective of providing the medical attention necessary to people affected by weather phenomena, the cost of taking medical equipment to screen, vaccinate, and evaluate affected people was considered, the cost of fuel to move the supplies to the temporary shelters was calculated, the cost estimated was \$1 MXP per km. The attention points considered were the Speciality Regional Hospital of Veracruz and the Regional Hospital of Xalapa. The data were obtained through the Google Maps® application.
 3. *Active shelters for the state government*, the Civil Protection Department shows a series of temporary shelters located in different municipalities, this factor was considered since the cost of reusing a shelter would be reduced, as it would already have the conditions necessary, as opposed to opening a new shelter. The more shelters a municipality has, the higher the capacity could potentially be. The information is taken from [39].
3. *Subjective factors* are qualitative elements based on perception and evaluated with a scale. The factors considered are listed below:
 1. *Degree of marginalization (60%)*, marginalization is a multi-dimensional and structural phenomenon which originates from the economic production model expressed in the unequal distribution of progress, in the productive structure, and in the exclusion of diverse social groups, in the process as well as the benefits of development [40]. The higher the marginalization, the higher the costs would be for a municipality to form part of the ETSN.
 2. *Insecurity (40%)*, the perception of security looks to measure the perception of public security that the population and homes have where they reside, as well as crime rate [41]. Gleaned from information obtained on page [37], rubrics such as damage to property, breach of trust, threats, dispossession, extortion, domestic violence, gender violence, home invasion, robbery, and other more unusual crimes, the increase in reports in 2024-2025 of property damage was considered for this evaluation.

2.2 Phase 2 - application of the Brown-Gibson method

1. Critical factors from the information obtained in Phase 1 was included in Table 2, which shows an extract from the evaluation table that determines which municipalities continue to be evaluated and which will be disregarded.

Table 2 Critical factors

Critical factor / Municipality	Acajete	Banderilla	Emiliano Zapata	Jalancingo	Las Vigas Ramírez	Villa Aldama	Xico
Disaster declared in the last 10 years	0	0	1	0	1	1	0
Remove (R) Keep (K)	R	R	K	R	K	K	R

The municipalities which will continue to be evaluated with the Synergetic method will be eight:

- a) Emiliano Zapata; b) Ixhuacán de los Reyes; c) Jalcomulco; d) Las Minas;
e) Las Vigas Ramírez; f) Teocelo; g) Villa Aldama, and h) Xico.

2. To give continuity to the synergetic method, Table 3 shows the objective factors used.

Table 3 Objective factors

Objective Factor / Municipality	Emiliano Zapata	Ixhuacán de los Reyes	Jalcomulco	Las Minas	Las Vigas Ramírez	Teocelo	Villa Aldama	Xico
Provisioning 1	23.70	107.00	39.90	110.00	92.00	78.20	101.00	74.60
Provisioning 2	87.90	54.90	86.90	22.60	16.20	73.30	0.00	69.70
Health Services 1	75.20	158.00	95.00	161.00	143.00	131.00	153.00	128.00

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Health Services 2	42.70	54.50	39.20	58.80	39.60	25.80	50.50	22.10
Active shelters	16	02	03	12	03	02	00	04

The results show that the municipality of Emiliano Zapata would incur the lowest installation costs, followed by Jalcomulco and Xico.

- To validate the subjective factors (Table 4), the marginalization factor and the perception of insecurity in the area are considered.

Table 4 Subjective factors

Objective Municipality	Factor	/ Emiliano Zapata	Ixhuacán de Reyes	los Jalcomulco	Las Minas	Las Vigas Ramírez	Teocelo	Villa Aldama	Xico
Marginalization Level		Very low	High	Medium	High	Medium	Low	Medium	Low
Increase in insecurity		9.33	0.00	0.00	0.00	0.00	0.00	0.00	+66.7

The results show that the municipality of Teocelo has the highest possibility of being chosen, followed by the municipalities of Jalcomulco and Las Vegas Ramirez.

- Applying the objective and subjective factors importance levels of 60% and 40% respectively, the formula is applied to obtain the Measurement of Location Preference, obtaining the results of Table 5.

Table 5 Measurement of location preference

Emiliano Zapata	Ixhuacán de los Reyes	Jalcomulco	Las Minas	Las Vigas Ramírez	Teocelo	Villa Aldama	Xico
0.1545	0.1360	0.1373	0.1360	0.1373	0.1386	0.1373	0.049

Figure 4 shows in red the municipalities disregarded during the first stage of the Synergetic process and in blue the municipalities that have the possibility of being the site of a temporary shelter.

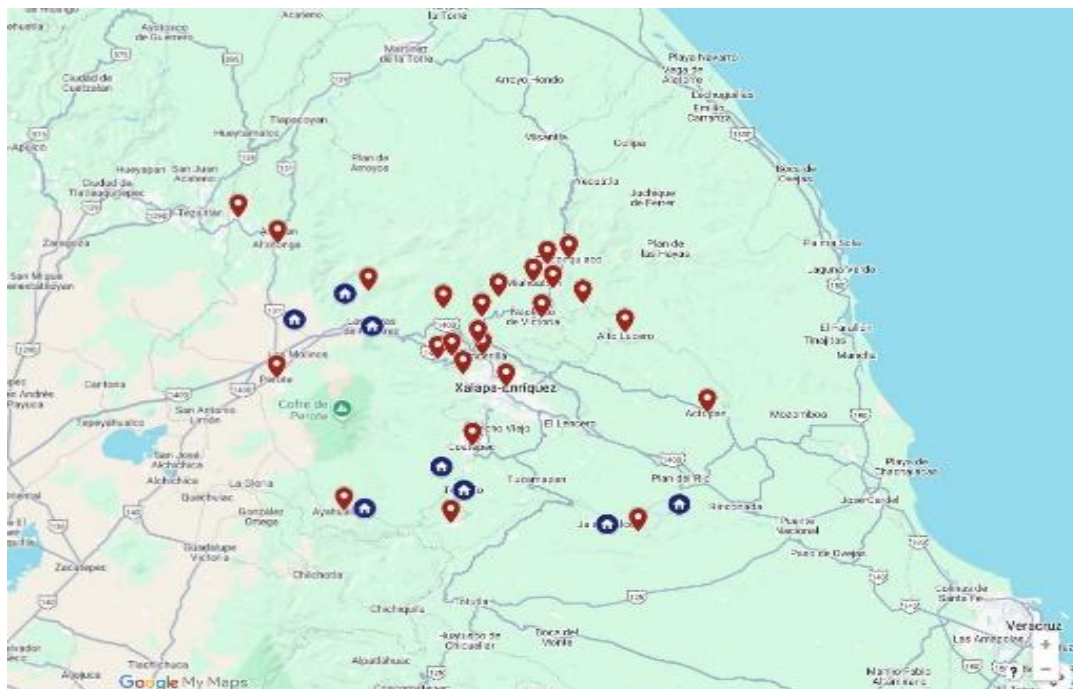


Figure 4 Resulting municipalities of the Brown-Gibson method, extracted through Google My Maps®

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From the above results, the application of the p-median problem was carried out, which will have the importance that not only allows for the minimum distance traveled, but also characterization of the zone in order to form part of the ETSN, using as a base the first term of the mathematical model of the Barojas-Payán et al. investigation [42].

2.3 Phase 3 - application of the p-median problem, with weight

Before carrying out the p-median problem with load, a trip with no load was carried out obtaining the 4 municipalities required as sites for temporary shelters to form the ETSN: *a)* Banderilla, *b)* Naolinco, *c)* Tatatila, and *d)* Teocelo. As can be observed, due to the restriction established in the present study case, the only municipality that can form part of the ETSN would be that of Teocelo, Figure 5 shows the municipalities mentioned in yellow, in blue, those obtained with the Synergetic method, in red, the municipalities that have resisted a disaster in the last 10 years, as well as Teocelo with a yellow pin with a protection symbol.

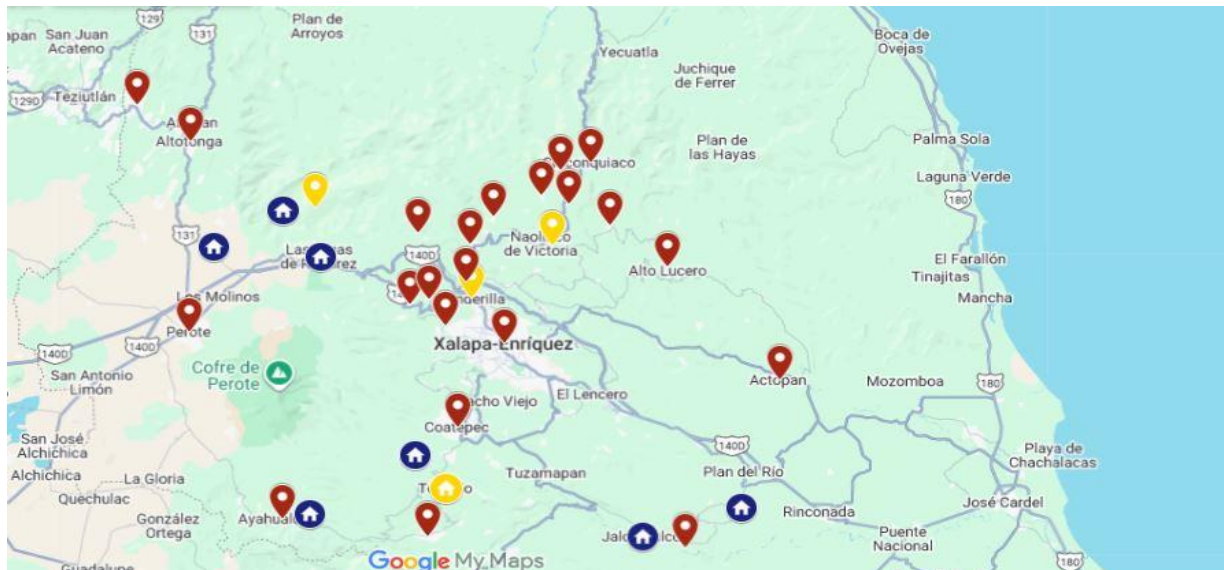


Figure 5 P-median with no load, extracted from Google My Maps®

During the application of the p-median model with a load, four municipalities were disregarded from the system, Acatlán, Banderilla, Altotonga, and Actopan, due to declaration of disasters. Figure 6 shows the colors 1. Red, municipalities disregarded in the first synergy stage and that also have been affected by natural phenomena in the last ten years; 2. Yellow, municipalities disregarded during the p-median application process due to their characteristics; 3. Blue, municipalities obtained with the Brown-Gibson method and that do not form part of the ETSN, and 4. Green, the municipalities that will form part of the ETSN, *a)* Jalcomulco; *b)* Las Vigas Ramírez; *c)* Teocelo, and *d)* Xico.

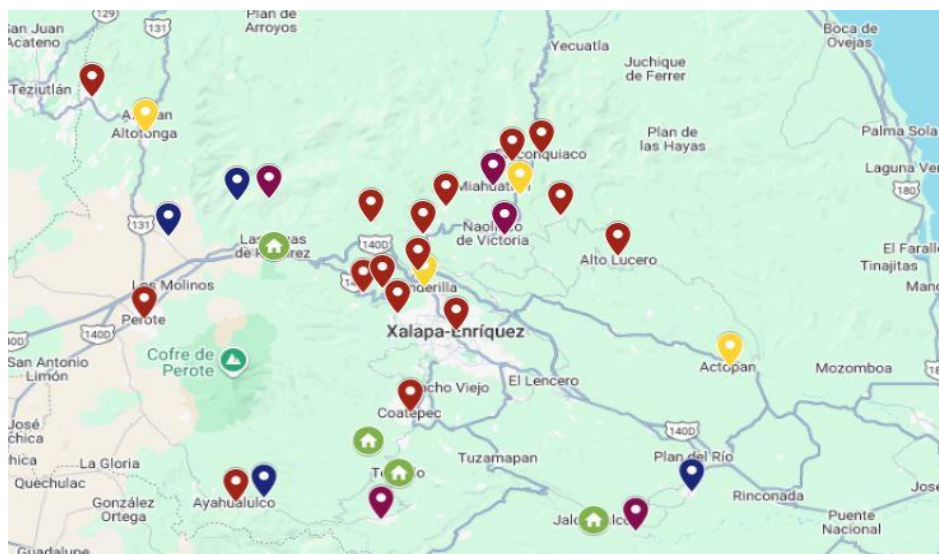


Figure 6 P-median with load, extracted from Google My Maps®

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3 Results and discussion

Table 6 presents the results through each one of the employed methods. The Synergetic method gives 8 municipalities with characteristics that allow for temporary shelters, however, the costs to provide supplies and services to those affected would be disproportionate. With the p-median method, the municipalities with the minimum distance traveled to the impacted municipalities is obtained, however, 75% of them do not fulfill the criteria of not having declared an emergency in the last ten years. Finally, the p-median method with a load allows us to have the four municipalities that will form part of the ETSN. It is worth mentioning that the municipality of Teocelo is the only one that fulfills the characteristics that each one of the methods looks for in a location.

Table 6 Location results

Method	Brown-Gibson	p-median	p-median with load
Resulting Municipalities	Emiliano Zapata		
	Teocelo	Teocelo	Teocelo
	Jalcomulco		Jalcomulco
	Las Vigas Ramírez		Las Vigas Ramírez
	Villa Aldama		
	Las Minas		
	Ixhuacán de los Reyes		
	Xico		Xico
Disregarded Municipalities		Banderilla	Banderilla
		Naolinco	
		Tatatila	
			Acatlán
			Altotonga
			Actopan

The facility location problem considers not only the costs of the establishment, but also the service; these two elements are fundamental to making decisions about the location of the facilities and who will provide the services. Regarding natural disasters, the uncertainty of the optimal location increases due to the level and area of impact of the phenomenon. After going through the literature, the temporary shelter network proposal for the Capital region of the state of Veracruz has not been found, however, in the work of [43], the p-median problem was used to establish three shelters in the municipality of La Perla Veracruz. What differentiates both investigations is the additional characterization carried out in this document, that although it is not the minimum distance traveled, it does have considerable municipal conditions for a temporary shelter.

4 Conclusions

The increase in temperatures has brought with it the presence of more frequent and impactful weather phenomena. Climate change is the biggest threat to world health and socially marginalized people are one of the most vulnerable sectors to its risks. The state of Veracruz is one of the Mexican states with the largest amount of weather phenomena, the Capital region specifically has been strongly affected by these events on many occasions and had temporary relocation of people affected. The document presents the design of an Emergency Temporary Shelter Network with four nodes with the combination of the Brown & Gibson Method and the p-median problem, which not only allows for the location of the municipalities that will form part of the network by means of a minimum traveled distance, but also has the characteristics that allow for quality accommodations for people affected in the capital region of the state of Veracruz. The results indicate that the municipalities of Teocelo, Jalcomulco, Las Vigas Ramírez, and Xico are the components of the ETSN. Future research will look to geographically extend the radius of the study and include more elements that allow for the formation of a complete humanitarian logistic network with stockpile centers, pre-positioned warehouses, levels of inventory, and vehicle routing.

Acknowledgement

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