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Humanitarian Storage and Safeguard Network in the southwestern part of Mexico
Red de almacenamiento y resguardo humanitario en la zona suroeste de México

Victorino Juárez-Rivera[1], 0000-0003-4243-0415
Erika Barojas-Payán[1], 0000-0002-3087-4046
Dulce-Rocío Mota-López[1] 0000-0001-9521-392X

[1] Faculty of Engineering, Universidad Veracruzana, Ixtaczoquitlán, Veracruz, Mexico

vijuarez@uv.mx, ebarojas@uv.mx, dumota@uv.mx

Abstract. One of the big threats that human beings confront at present is the risk of extreme weather phenomena caused by climate change. The state of Guerrero is one of the eight states that is most vulnerable to climate change in Mexico. Extreme events due to weather have brought death, destruction, and shortages to the state. With the objective of safeguarding and maintaining quality of life to victims, we present the creation of the Humanitarian Safeguard and Storage Network, or Red de Almacenamiento y Resguardo Humanitario (RARH) in Spanish. Every network node corresponds to a municipality in Guerrero and is evaluated according to its location and level of marginalization. Through the p-median problem, networks of 1, 3, and 12 Humanitarian Safeguard and Storage Nodes, or Nodos de Almacenamiento y Resguardo Humanitario (NARH) in Spanish, were obtained. During the first instance, the minimum distance traveled to the city governments that were not considered as possible sites were evaluated, and during a second evaluation a level of marginalization was added as an additional variable to consider. Feasible solutions were obtained in 67% of the RARH evaluated.

Keywords: Climate disasters, humanitarian logistics, humanitarian safeguards and storage nodes, p-median, victims.

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1 Introduction

Climate change is a grave and growing threat to the well-being of humanity and the health of the planet (World Meteorological Organization, 2022). The climate change produced worldwide aggravates and intensifies the risk of extreme meteorological phenomena, the increase of air and water temperature, which causes an increase in sea level, potent storms, strong winds, droughts, and more severe and prolonged fires, as well as intense precipitation that causes floods (OXFAM International, 2023). When many of these phenomena happen at the same time, it becomes more difficult to deal with the consequences, and millions of people are exposed to serious food and water insecurity (World Meteorological Organization, 2022).

Over the last few decades, catastrophic weather disasters have occurred in various parts of the planet, bringing death, illness, unemployment, and destruction as a consequence, among others. An example is hurricane Otis, which struck the port of Acapulco, Mexico (2023), the heat wave in Europe, floods in Chad, Gambia, Pakistan, and northeastern Bangladesh (the last 30 years), as well as heavy rains in Germany, Belgium, Switzerland, and the Netherlands (2021), forest fires in Australia (2020), cyclone Idai, which struck southeastern Africa (2019), Hurricane Maria in Puerto Rico and the Caribbean (2017), landslides in the Serrana region of the state of Rio de Janeiro in Brazil (2011), and a tsunami in Chile (2010) (United Nations, 2023, 2022, 2021, United Nations and the Government of Mexico, 2019, World Wildlife Fund, 2020, OXFAM International, 2020). As can be observed, Mexico is not unaffected by these events, according to the Municipal Strategic Weather Guide of Comprehensive Management of

Risks and Disasters (2019), the eight states most vulnerable to climate change are Veracruz, Oaxaca, Chiapas, Tabasco, Yucatán, Puebla, Guerrero, and Nayarit.

Several researchers worldwide have carried out studies that allow for minimizing the effects of high-impact weather phenomena, particularly within humanitarian logistics (HL), defined as "planning, implementation, and efficient control process with effective cash flow and storage of goods and materials, as well as related information, from the point of origin to consumption, with the goal of alleviating suffering of vulnerable people" (Thomas & Kopczack, 2005, p. 2). Various strategies have been designed that allow for *a)* identifying optimal and feasible locations to store and safeguard food provisions, hygiene products, water, coats, etc., shelters for victims, collection centers, health centers, etc.; *b)* establishing supply routes for products, moving personnel, affected individuals, and *c)* information flow between groups of interest. Each of the phases caused by the weather pattern is applied before, during, and after the event.

One of the studies regarding HL that we can observe is the article from Barojas-Payán et al. (2019) in which the researchers propose a model that combines the problem of facility locations with the calculation of inventory for an uncertain demand, as well as evaluating the state of Veracruz in Mexico, getting the location for the installation of a humanitarian warehouse and its levels of inventory. Oro & Loza-Hernández (2020) also apply the quantitative center of gravity method to determine the best location for shelters in Mexico. Moreover, Taouktsis & Zikopoulos (2024) have developed a tool that combines a classic heuristic algorithm, and predictive models based on a binary classification problem with the support of a deep neuronal network that allows for the selection of a network node for the installation of a distribution center during the beginning of a humanitarian crisis. The article written by Vahdani et al. (2018) also proposes a two-phase mathematical model to locate distribution centers and warehouses with different storage centers by using two metaheuristic algorithms, NSGAII and MOPSO.

Also of note is research from Pineda-Figueiras et al. (2022), in which the authors look for the best locations in the state of Chiapas, Mexico for the installation of a distribution center for humanitarian response by means of a *p*-median model. In this same area, researchers Loree & Aros-Vera (2018) developed a mathematical model to determine the location of the distribution points and the assignment of HL inventory. Stienen et al. (2021) developed a method to determine locations through historical data, which minimizes transport costs as well as response time, studying the Depository of Humanitarian Response of the United Nations. In this sense, a non-linear programming model uses the inventory level equation (*q.R.*) to locate municipalities as pre-positioning warehouse sites in the state of Veracruz, Mexico. In the case of weather disasters caused by water, it is developed by Barojas-Payán et al. (2022), minimizing logistics costs through its application.

The present document has been developed beginning discoveries from the aforementioned studies. Its objective is to establish a Network of Humanitarian Warehouses and Safeguards (RARH) in the state of Guerrero, Mexico. The investigation shows in the second section the problems in Guerrero in terms of weather, and the methodology to follow to execute this technique. The third section presents the results obtained and the ensuing discussion. Subsequently, the conclusions can be found, finalized with bibliographical sources for this article, cataloged as a study case.

2 Methodology

Located in southwestern Mexico, adjacent in the north to Michoacán, the state of Mexico, Morelos and Puebla, east to Puebla and Oaxaca, and south to Oaxaca and the Pacific Ocean, and west to the Pacific Ocean and Michoacán de Ocampo, the state of Guerrero in size is the 14^{th} largest at 63,596 km^2, which occupies 3.2% of Mexico's national territory (Secretaría de Economía, 2016; Instituto Nacional de Estadística y Geografía, 2016). Chilpancingo de los Bravo is the state capital, and the main economic activities are agriculture and tourism. In Fig. 1 Mexico can be observed in terms of the federal entities that are subject to our study. Guerrero is home to 85 municipalities that are in 7 regions: 1. Región de Acapulco; 2. Región Centro; 3. Región Costa Chica; 4. Región Costa Grande; 5. Región de La Montaña; 6. Región Norte, and 7. Región Tierra Caliente. The biggest cities are Chilpancingo de Bravo and Acapulco in terms of inhabitants, however the largest municipality in terms of area is Coahuayutla (Instituto Nacional de Estadística y Geografía, 2022; Martínez-Rescalvo & Díaz Vásquez, 2017).

Fig. 1. State of Guerrero (Instituto Nacional de Estadística y Geografía, 2023; INEGI, Instituto Nacional de Estadística y Geografía, 2022).

According to the Municipal Strategic Weather Guide of Comprehensive Management of Risks and Disasters (2019), the state of Guerrero is among the most vulnerable eight states to climate change in Mexico. The National Institute of Ecology and Climate Change (2022) mentions that during the period of 1970-2021, Guerrero was affected by 44 tropical storms, of which 12 made direct landfall. One example is Hurricane Max in 2017 which struck the region of Costa Chica, causing negative environmental, economic, and social effects (Bedolla, Solano et al. 2021). In 2013 Tropical Storms Ingrid and Manuel considerably affected the state, especially the region of La Montaña, which suffered from deaths, material loss, the isolation of small communities that had no potable water, food, medicine, or fuel for several weeks (Toscana-Aparicio & Villaseñor-Franco, 2013). In 1997, another event of high ecological impact was Hurricane Paulina (Villegas Romero et al. 2009). Removed from statistics is Hurricane Otis which struck the coast of Guerrero as a Category 5 hurricane and was reported to have cyclonic swells, cause flooding and landslides, as well as cause damage to infrastructure and the Acapulco International Airport (The National Aeronautics and Space Administration, 2023).

From this vulnerability and with the objective of helping victims of disasters to safeguard and to maintain their quality of life, a RARH was designed in the state of Guerrero, in which the nodes should not only be established in municipalities with basic qualities (mediated through levels of marginalization), but also with a minimum distance from the affected area. A methodology was established which is expressed in Fig 2, in which as a first step information is obtained, such as *a)* municipalities that have been affected by weather phenomena; *b)* distances between affected and unaffected municipalities; *c)* marginalization index of the eighty-five municipalities in the state, and *d)* statistics of the families affected by weather phenomena from 2015 to 2022; in the second step the *p*-median problem is expressed, which is used to generate the RARH, in step three, the application of the model in diverse scenarios is presented.

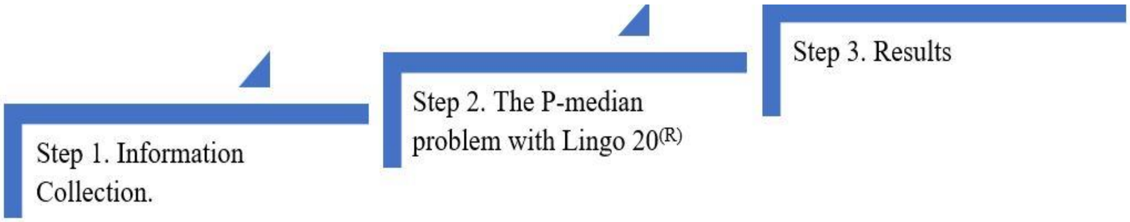


Fig. 2. Methodology.

Step 1. Information Collection.

a) Municipality vector

A municipality vector was designed that makes up the federal entity of Guerrero, obtained from the Instituto Nacional de Estadística y Geografía website (2020), part of the vector can be observed in Table 1, first column.

b) Distance matrix.

Distance in kilometers to and from municipalities that make up the state of Guerrero was obtained through the Google Maps® application and which forms a symmetrical distance matrix that feeds the model used for the network of humanitarian storage and safeguarding. Table 1 shows part of this matrix.

Table 1. Distance matrixes.

Municipalities	Acapulco de Juárez	Acatepec	Ahuacuotzingo	Ajuchitlán del Progreso
Acapulco de Juárez	0	196	216	389
Acatepec	196	0	270	542
Ahuacuotzingo	216	270	0	380
Ajuchitlán del Progreso	389	542	380	0
Alcozauca de Guerrero	330	167	146	442

c) Victims.

Starting from the government transparency databases: National Coordination for Civil Protection, the National Center for Disaster Prevention, CENAPRED (2022), and the National Fund for Natural Disasters, FONDEN (2016), the number of victims for the period of 2015-2022 was obtained for the state of Guerrero, with which the average the NARH number that makes up the RARH was calculated, obtaining a total of 12 nodes.

d) Levels of marginalization

According to the Consejo Nacional de Población (CONAPO) (2010), "marginalization is conceived as a structural societal problem, in which certain development opportunities are not present, nor the ability to acquire them." CONAPO (2006) also defines the marginalization index as "a summary of nine socioeconomic indicators that allow for the measurement of forms of social exclusion and are variables of backwardness or deficit."

Among the socioeconomic dimensions involved within the marginalization index are education, housing, income, and population distribution. The design of the index allows for the classification of federal entities in Mexico into five levels (very low, low, medium, high, and very high marginalization) in correlation with the nine forms of social exclusion in the cited aspects (Consejo Nacional de Población, 2006). The variable level of marginalization indicates the intensity of the exclusion. It is one of the factors for the municipalities to have a node in the humanitarian storage and safeguarding network, in that each node should have electricity, drainage, and plumbing, so that the lower in the index a municipality is, the higher probability it has to be selected. Table 2 shows part of the information, while in Fig. 3, the 85 municipalities are shown that make up Guerrero and are shown with pin icons with different colors, depending on their level of marginalization.

Table 2. Level of marginalization matrix.

Municipality	**Level of Marginalization**
Acapulco de Juárez	Low
Ajuchitlán del Progreso	Very High
Arcelia	Medium
Coyuca de Catalán	High
Cutzamala de Pinzón	High
Pungarabato	Low

Secretaria del Medio Ambiente y Recursos Naruales, 2021.

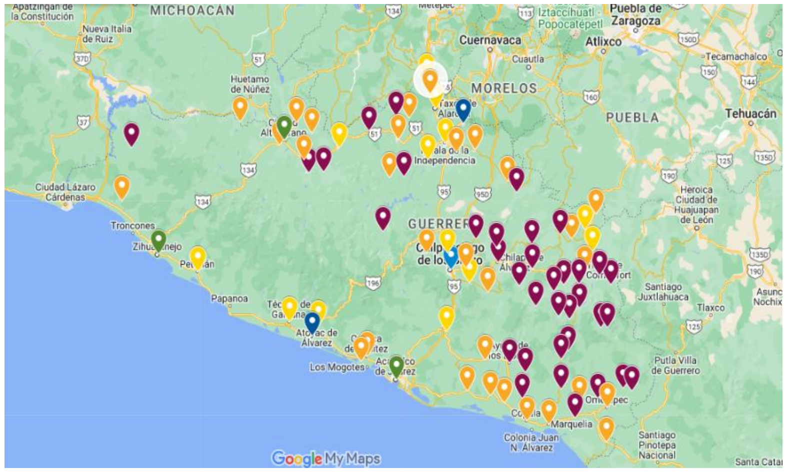


Fig. 3. Municipalities of the state of Guerrero.

Step 2. The P-median problem with Lingo 20®

a) Locating facilities with the p-median problem.

The facility location problem comes from deciding where facilities will be located that allow for customer satisfaction, and maximizing utilities (Flores-Garrido & Oliva-San Martín, 2016). Also, the *p*-median model has the objective of locating "P" facilities, in such a way that the distance between nodes in demand and the designated facilities is minimized (Reza Zanjirani & Hekmatfar, 2009). For the present study, the p-median model will be used to locate the municipalities that could be sites for the installation of a Humanitarian Storage and Safeguarding Node (NAEH) for the RAGH, minimizing the distance traveled. The formulation of the problem for the p-median application is shown here:

Formula:

$J = \{1,\ldots,n\}$ group of client nodes.
$N = \{1,\ldots,m\}$ group of indexes for potential median locations.
$J = N$ for which (j,i), $j \in N$, $i \in J$.

Variables:
$W_i =$ total demand to cover node *j;*
$C_{ji} =$ distance from node *j* to node *i;*
$P =$ number of locations to locate;
$X_{ji} =$ take the value of 1 if the node *j* is assigned to facility *i* and 0 in the opposite case;
$Y_i =$ take the value of 1 if a facility is located in *i* and 0 in the opposite case.

The mathematical formulation of the problem is presented with the following:

$$Min = \sum_{i \in J} \sum_{j \in N} W_j C_{ji} X_{ji} \quad (1)$$

Subject to

$$\sum_{i \in J} X_{ji} = 1 \;\; \forall \; j \in N \quad (2)$$

$$\sum_{i \in J} Y_i = P \quad (3)$$

$$X_{ij} \leq Y_i \quad \forall \; j \in N, \; i \in J \quad (4)$$

$$X_{ji} \in \{0,1\}, Y_i \in \{0,1\} \quad \forall \; j \in N, \; i \in J \quad (5)$$

Equation 1 represents the objective function, minimizing the sum contemplated for the distances that are associated with the nodes of the client municipalities assigned to the nodes of the candidate municipalities. *Equation 2* guarantees that all the client municipalities are assigned a precise location. *Equation 3* establishes the number of facilities in P. *Equation 4* bans any assigning of a site that does not have a facility, that is, just the nodes with a facility will supply the product. *Equation 5* reinforces the binary nature of the decisions of locating a facility of a node and assigning a node of a client municipality to a facility (Pineda-Figueiras et al. 2022).

b) LINGO.

LINGO software allows for the creation and the resolution of linear, non-linear, quadratic, stochastic, and complete optimization models, among others (LINGO SYSTEMS INC, 2024).

3 Results and discussion

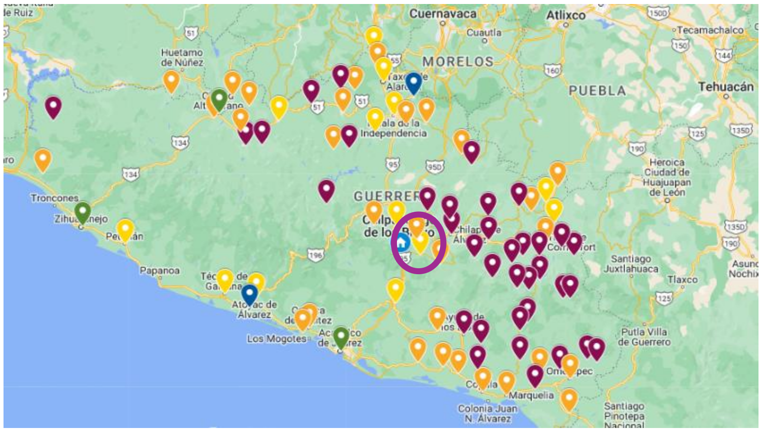
The RARH is built through the *p*-median problem under different scenarios, among which 1. Minimum distance and 2. Minimum distance traveled vs level of marginalization is found.

3.1 Minimum distance travelled

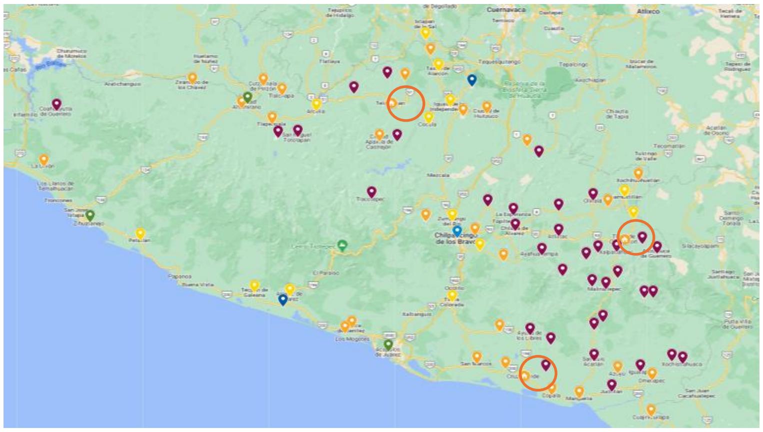
The RARH is built through the p-median problem under different scenarios, among which 1. Only node, evaluating distance traveled, result: Chilpancingo de los Bravo; 2. Three nodes, evaluating only distance traveled, results: Florencio Villarreal - Teloloapan - Tlapa de Comonfort; 3. 12 nodes, evaluating only distance traveled, result: Benito Juárez – Chilapa de Álvarez – Chilpancingo de los Bravo – Florencio Villarreal – Iguala de Independencia – La Unión Isodoro de Montes de Oca – Malinaltepec – Ometepec – Pungarabato – Teloloapan – Tetipac – Tlapa de Comonfort. Table 3 shows the results of one, three, and twelve network nodes, using the Google Maps® application.

Table 3. Results for minimum distance traveled.

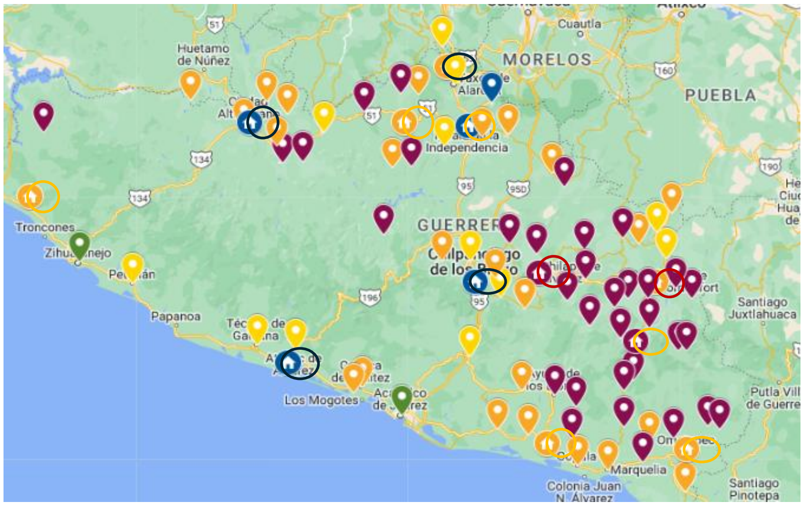
No.	Objective	Result	Level de Marginalization
1	Minimum distance traveled	Chilpancingo de los Bravo	Low



No.	Objective	Result	Level de Marginalization
2	Minimum distance 3 RARH nodes	Florencio Villarreal, Teloloapan, Tlapa de Comonfort	High



3	Minimum distance 12 RARH nodes, with a capacity for 300 families.	Benito Juárez – Chilpancingo de los Bravo - Iguala de Independencia - Pungarabato	Low
		Florencio Villarreal - La Unión Isodoro de Montes de Oca - Ometepec – Teloloapan – Tetipac – Tlapa de Comonfort	High
		Chilapa de Álvarez — Malinaltepec	Very high

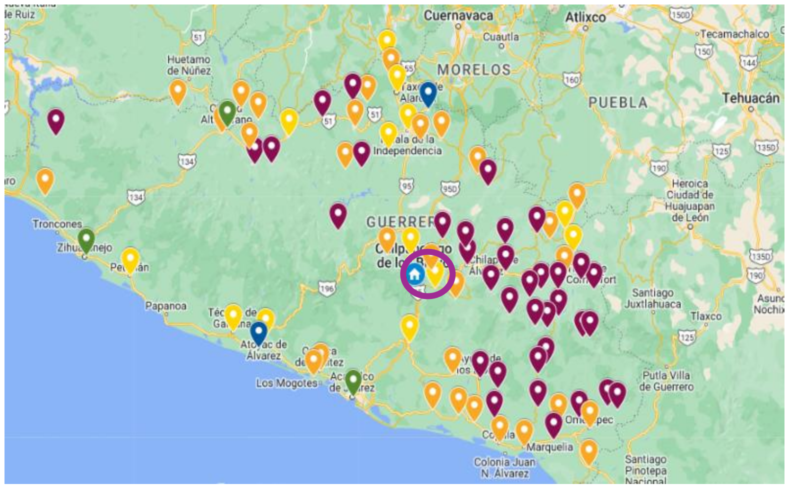


3.2 Minimum distance traveled and level of marginalization.

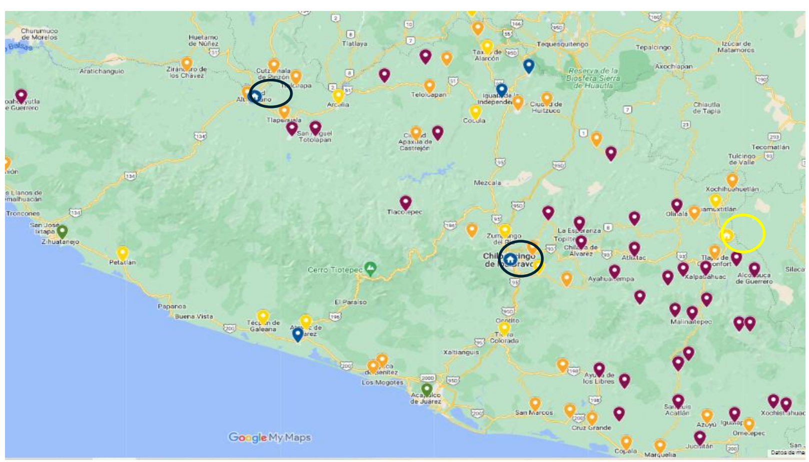
The RARH is built through the *p*-median problem under different scenarios, among which 1. Only Node, evaluating distance traveled and level of marginalization, result: Chilpancingo de los Bravo; 2. Three nodes, evaluating only distance traveled and level of marginalization, result: Alpoyeca, Chilpancingo de los Bravo y Pungarabato; 3. 12 nodes, evaluating only distance traveled and level of marginalization, result: Acapulco de Juárez, Benito Juárez, Pungarabato, Iguala de Independencia, Chilpancingo de Bravo, Alpoyeca, Taxco de Alarcón, Ometepec, Tecoanapa, Malinaltepec, Metlatónoc. Table 4 shows the results of one, three, and twelve network nodes, using the Google Maps® application.

Table 4. *Results for minimum distance traveled + level of marginalization.*

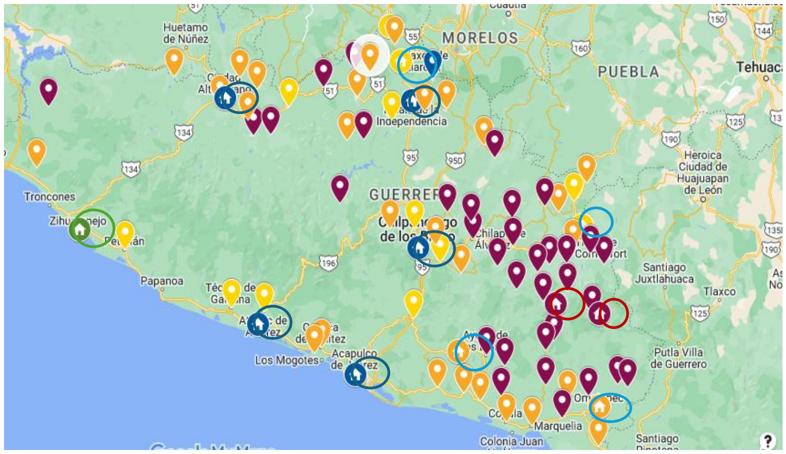
No.	Objective	Result	Level of marginalization
1	1 node, minimum distance traveled + lowest level of marginalization	Chilpancingo de los Bravo	Low



2	3 nodes, minimum distance traveled + lowest level of marginalization	Alpoyeca Chilpancingo de los Bravo - Pungarabato	Medium Low



3	12 nodes, minimum distance + lowest level of marginalization with a capacity for 300 families.	Zihuatanejo de Azueta Acapulco de Juárez – Benito Juárez – Pungarabato – Iguala de Independencia - Chilpancingo de Bravo Alpoyeca – Taxco de Alarcón Ometepec – Tecoanapa Malinaltepec - Metlatónoc	Very low Low Medium High Very Low



3.3 Discussion

Starting from the previously obtained results, we observed that by establishing just one node (1 p) the municipality of Chilpancingo de los Bravo due to its geographical location can become the site of a NARH, also, this selection is reinforced considering the level of marginalization, Chilpancingo de los Bravo being at a low level, it is considered a feasible city. A second validation is that it goes through three NARHs, where the municipalities obtained just by considering the minimum distance traveled, are Florencio Villarreal, Teloloapan, and Tlapa de Comonfort. However, considering the level of marginalization, the municipalities of Alpoyeca, Chilpancingo de los Bravo and Pungarabato make up the solution, this last solution has higher feasibility, since the three first cities have a high level of marginalization, while the three last cities have medium to low levels of marginalization, which is the reason the second obtained solution is considered feasible.

A third validation was carried out by calculating the number of site municipalities for a NARH from the average number of victimized families in catastrophes in the state from 2015 to 2022, which were obtained from the municipalities of Benito Juárez, Chilpancingo de los Bravo, Iguala de Independencia, - Pungarabato, Florencio Villarreal, La Unión Isodoro de Montes de Oca, Ometepec, Teloloapan, Tetipac, Tlapa de Comonfort, Chilapa de Álvarez, and Malinaltepec. However, through considering the level of marginalization, 1. Municipio de Zihuatanejo de Azueta (very low level of marginalization); 2. Acapulco de Juárez, Benito Juárez, Pungarabato, Iguala de Independencia y Chilpancingo de Bravo (low level of marginalization); 3. Cities of Alpoyeca y Taxco de Alarcón (medium level of marginalization); 4. Ometepec y Tecoanapa (high level of marginalization), y 5. Malinaltepec – Metlatónoc (very high level of marginalization) were obtained. Within the first solution, only 33% of the municipalities were considered feasible for the installation of a NARH, while in the second solution, 33% were considered unfeasible due to their level of marginalization, however, they had an adequate geographical location for a NARH.

4 Conclusions

Guerrero is one of the eight most vulnerable states to climate change in Mexico, which also leads to stronger and more severe weather phenomena, which not only affects the population but also the infrastructure. This is the reason that it is imperative to establish strategies that allow for the safeguarding of human life. The establishment of warehouses for products, and shelters for victims in locations that allow for faster access to affected areas and that also have characteristics that allow for adequate operation is fundamental for humanitarian assistance. The developed study looks at the design of a Humanitarian Storage and Safeguarding Network (RARH), in which each network node corresponds to a state municipality and is evaluated in accordance with its location and level of marginalization. With the p-median problem, 1, 3, and 12 humanitarian storage and safeguarding nodes (NARH) are evaluated. During a first instance, only the minimum distance traveled to the cities not considered as possible sites is evaluated, and in a second evaluation a level of marginalization is added as a variable to take into consideration. The solutions have a feasibility characteristic that establishes that although a location does not have a low to medium level of marginalization, it can still allow for a faster response time in a disaster.

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