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Techniques for Locating Facilities in Emergency Situations, Chiapas, Mexico

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Abstract. Disasters due to natural causes occur more frequently worldwide. In order to provide a solution to the problem of locating facilities for humanitarian aid, this research is based on the application of different models for locating facilities, such as weighted factors, the center of gravity, Break-even point, transport method, and *p*-median; to locate one or several feasible geographical spaces for the installation of a warehouse that allows the protection and supply of essential products to people affected by the impact of a natural phenomenon in the state of Chiapas, Mex. Under different factors and evaluation characteristics derived from the methods used, two municipalities are considered feasible venues. The first is within the municipality of El Parral, followed by the municipality of Emiliano Zapata. Their characterization of proximity to suppliers, level of marginalization, and services, to name a few, make them acceptable for the purpose above.
Keywords: Facilities Location Methods; Storage Warehouse; Natural Phenomenon, Factors and Characteristics of Evaluation.

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1 Introduction

Natural hazards are severe and extreme weather and climate phenomena that occur worldwide, although it should be noted that some regions are more vulnerable to specific hazards than others. These hazards can become disasters when they considerably impact, causing deaths and destruction of livelihoods (OMM, 2022).

Natural disasters are classified according to their origin as *a)* meteorological, caused by climatic changes that exceed the limits contemplated, such as hurricanes, droughts, tornadoes, and snowfall, to name a few; *b)* hydrological, related to the behavior of water masses, among which are tsunamis, tidal waves, and floods; *c)* geophysical, geological phenomena and earth movements are their origins, avalanches, volcanic eruptions, earthquakes, and earthquakes; and *d)* biological, involving bacteria, viruses, and parasites that cause diseases that directly affect the population in the form of plagues, epidemics, and pandemics (Comisión Nacional de Áreas Naturales Protegidas, 2018).

According to the World Meteorological Organization (WMO), every day in the last 50 years, meteorological disasters have caused the death of 115 people and losses of 202 million dollars. 44% of the catastrophes that occur worldwide are associated with floods (fluvial 24% and general 14%) and 17% with tropical cyclones (Naciones Unidas México, 2021). An example is Mexico, which experiences various climatic manifestations that impact its territory yearly, causing human and material losses (Gobierno de México, 2022). The situation has brought about agencies, organizations, and institutions. These, through different actions in the various phases of a disaster (before, during, and after the disaster), minimize the effects on the victims.

In emergency operations, logistics is required to support the organization of response actions, seeking speed, agility, and effectiveness. A logistics system allows for mobilizing agencies, organizations, and institutions' personnel, materials, and work equipment in the face of the disaster, providing assistance activities, evacuation of injured, and relocation of disaster victims

(OMS, 2001). Within the logistics system, storage allows supplies protection through an organized system until they are delivered to their final destination, anticipating reserve quantities for subsequent activities (OMS, 2001).

Researchers from different parts of the world have developed various methods and techniques that allow care in the different phases of a disaster. Among them are those focused on the location of facilities, either as a shelter, product distribution center, or management center. An example is the research (Ma & Wang, 2021), in which the authors establish a dual-objective mixed integer nonlinear programming model, which allows for minimizing rescue time and maximizing the rate of emergency satisfaction. The design of a genetic algorithm allows for solving the problem of location and assignment of emergency logistics, obtaining optimal solutions in practical examples.

In this same area, we can mention the research by Hongrui & Yahong (2021), in which the authors propose a multi-objective location-allocation optimization model to minimize deprivation, unsatisfied demand, and logistic costs. Subsequently, derived from the complexity, they designed a new algorithm combining the Firefly algorithm and the classic Genetic algorithm. The results illustrate the validity of the proposed solution algorithm. Reference is made to the investigation of (Constantino De La Espriella et al., 2018), which integrates the location of shelters, distribution centers, inventories, and distribution of products with stochastic demand as a problem of humanitarian logistics, specifically in case of flooding in Colombia. The authors design a semi-heuristic model that combines the Genetic Algorithm, Silver Meal, and Clark and Wright with Monte Carlo simulation, allowing the construction of robust solutions. Also, Kurbanzade & Gaudio (2022) propose a novel extension for the problems of the location of facilities by introducing the concept of location by demand. A local search heuristic based on network flow is developed and applied to a hurricane evacuation response case.

Some investigations focused on the location problem have been carried out in Mexico, such as the one carried out by Caballero-Morales et al. (2018), in which the authors provide a metaheuristic based on the K-Means Clustering (KMC) algorithm to determine the location of support centers for 3,837 communities at risk of impact from some natural phenomenon in one of the regions of the state of Veracruz. Likewise, it is found that Barojas-Payán et al. (2019) have created a mixed integer nonlinear mathematical model that integrates the problem of facility location with inventory issues to provide the necessary products to ensure the decent survival of people affected by a natural disaster. This model is tested in the Capital Region of the State of Veracruz. This research is extended in Barojas-Payán et al. (2021); the authors applied the model to 90% of the regions of the same state. Similarly, there is the research by Pineda-Figueiras et al. (2022), in which the authors use the P-median model to identify the optimal municipality that can house a facility that allows the strategic distribution of products to municipalities affected by a natural disaster in Chiapas.

Based on the above, it is possible to highlight the contribution of the present investigation, which, in comparison with the methods developed and applied previously, not only evaluates several points for the establishment of one or several aid stores humanitarian, but rather, through different processes and characterizations, it assesses the points. Likewise, its importance lies in the fact that although the appearance or magnitude of a natural phenomenon cannot be avoided, it can collaborate to reduce the degree of affectation to the victims by providing more quickly the support that allows them to maintain a certain quality of life, as is the case of products for proper nutrition and hygiene.

This case study is made up of a description of the problem of the location of facilities. In this case, various techniques and methods are presented that give way to the investigation; it continues with the description of the problem, which is located in the state of Chiapas, Mexico, a federal entity strongly impacted by natural phenomena, followed by the methodology used to solve the location problem, and the presentation of the results obtained; It ends with the conclusions, the projection of works and the bibliography used.

2 The Facility Location Problem

Facility location problems arise in a wide variety of real situations. Location decisions are perhaps the most important and challenging to achieve an efficient supply chain (Ozuna-Espinosa, 2012).

The location of a facility is the process of selecting a geographical space among a certain number of these to carry out the company's operations. Managers of any organization in question must weigh various factors when evaluating a location's suitability, including proximity to suppliers or customers, labor costs, and work and transportation costs, to mention a few (Paz-Carro & González-Gómez, 2012). Among the methods for locating facilities, the following can be mentioned:

a) *The method of weighted factors* defines the main factors 1. Raw material; 2. Markets; 3. Environmental control; 4. Electric power and fuels; 5. Community factors; 6. Water; 7. Communications; 8. Means of transport; 9. Legal aspects, and 10. Workforce, among others, determines a location to assign them relative weight weighted values according to their importance. Its main advantage is that it is a simple and fast method; its main disadvantage is the weight assigned and the qualification given as a relevant factor since they depend on the preferences of the person who develops it (Contreras, 2016).

b) *The center of gravity method* is a mathematical technique used to find a distribution center's location that minimizes customer supply costs. It takes into account the location of the markets, the volume of products, and shipping costs. The location will be the one that minimizes the distance between the warehouse and its stores (Heizer & Render, 2004).

c) *The break-even analysis* helps to compare various location alternatives based on quantitative factors that can be expressed in terms of cost by plotting each location's fixed and variable costs. It can be determined which generates lower costs (Krajewski & Ritzman, 2000; Heizer & Render, 2004).

d) *P-median* is responsible for seeking solutions to minimize costs or distances between demand nodes, defining it as a location problem. The formulation of the problem for the application of *p*-median is the following:

Let be:

$J = \{1, \dots, n\}$ the set of indexes for customers.
$N = \{1, \dots, m\}$ the set of indices for the potential locations of the medians.
$J = N$.For each (j,i), $j \in N$, $i \in J$.

Variables:
W_j= total demand to cover the node j.
C_{ji}= distance from the node j to the node i.
P = number of facilities to locate.
X_{ji} = take the value one if the node j is assigned to the installation i and 0 otherwise.
Y_i= takes the value one if an installation is located at i and 0 otherwise.

The mathematical formulation of the problem is as follows:

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

$Subject\ to$

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

$$\sum_{i \in J} Y_i = P \tag{3}$$

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

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

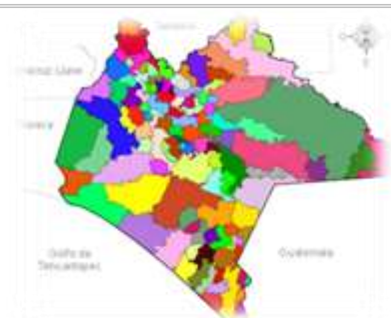
The *objective function (1)* minimizes the weighted sum of the distances associated with the nodes of the client municipalities assigned to the candidate municipalities nodes. The set of *constraints (2)* ensures that all customer municipalities are assigned to precisely one location. *Constraint (3)* sets the number of facilities in *P*. *Constraint set (4)* prohibits any assignment to a site that does not have a facility, i.e., only nodes with a facility will supply the product. The set of *constraints (5)* reinforces the binary nature of the decisions to locate a faculty at a node and assign a client municipality node to an installation (Pineda-Figueiras et al., 2022).

e) *Transportation method* the general transportation problem refers to the distribution of any merchandise from any group of supply centers, called origins, to any set of reception centers called two destinations in such a way that they are minimized the total cost of distribution. This method allows us to find the best distribution of the flows of the network system based on the optimization of transport costs (Pedraza-Rendón, 1995).

3 Description of the study area and statement of the problem

The state of Chiapas is one of the 32 federal entities that make up the Mexican Republic, with an area of 74,415 km^2, which represents 3.8% of the country's surface. Chiapas is divided into 15 socio-economic regions, in which 124 municipalities are distributed, housing a population of 5,543,828 inhabitants (Secretaria de Turismo, 2022; CEIEG, 2012). Table 1 shows a) the location of the state of Chiapas within the Mexican Republic, b) the regions that make up the federal entity, and c) the 124 municipalities that make it up. According to (ONU HABITAT, 2019), the state of Chiapas is among the eight states of Mexico most affected by hydrometeorological phenomena, this is due to its geographical location, but the impact is more significant due to its socio-economic level. At the national level, the state of Chiapas, in the year 2020, occupied the second position for the marginalization index, only behind Guerrero, the entity with the highest marginalization index (DIGyE, 2020). Likewise, it is worth mentioning that from 2000 to 2022, the state had 77 disaster declarations, 93 emergency declarations, and 19 weather contingency declarations, with a total of 189. Fig. 1 shows a graph that concentrates on said declarations and to what type of phenomenon it corresponds (CENAPRED, 2022).

Table 1. Chiapas State

Locations (Secretaria de Turismo, 2022)	b) Regions (CEIEG, 2012)
	
c) Municipalities (INEGI, (2020).	
	

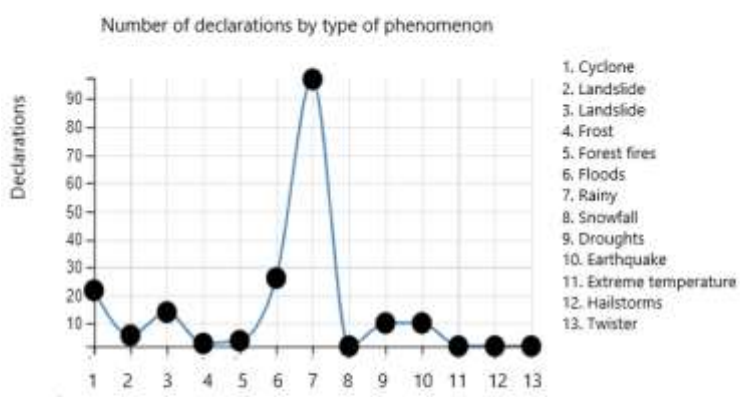


Fig. 1. Declarations by type of phenomenon of Chiapas (CENAPRED, 2022).

The objective of the research is to locate a geographical space (municipality) for the installation of a warehouse that allows supplying essential products to areas affected by a natural phenomenon of a hydrometeorological type in the state of Chiapas through the comparison of different methods of locating the plant, using as elements of supply to the methods the evaluation of different factors that the municipalities have that can become headquarters of the warehouse.

4 Methodology

In order to locate a municipality that, due to its physical and socio-economic characteristics, may contain a warehouse that allows the supply of products to people affected by a natural hydrometeorological event, the following methodology is established, shown in Fig. 2. In it, the following stages can be observed: **1.** Collection of information from the state of Chiapas; in this phase, the matrices, databases, and other elements will be developed that will serve to supply information to the methods of location in the plant, among which we can mention: (a) municipalities impacted during the period 2015-2022; (b) number of victims, by meteorological event (date), municipality, average number of victims; (c) distances between impacted and non-impacted municipalities; (d) coordinates of the impacted municipalities; (e) municipal services such as electricity, water, drainage, telephony, internet; (f) degree of marginalization of municipalities not impacted; (g) suppliers, social interest stores within the municipalities, and (h) federal and state highways that connect the municipalities not impacted. **2**. Application of plant location methods. At this stage, the evaluation of the municipalities that may become headquarters of the warehouse will be carried out in the following order: (a) method of weighted points; (b) center of gravity method; (c) break-even analysis; (d) transport method, and (e) *p*-median. **3.** Results, carrying out the analysis and comparison of the results for establishing a proposal for the host municipality for the emergency warehouse.

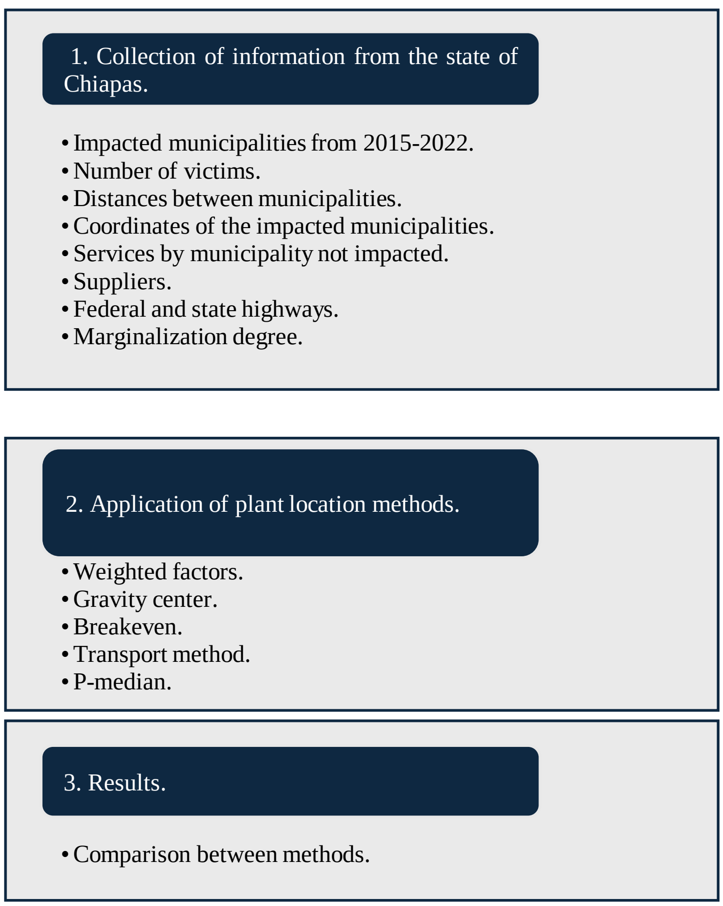


Fig. 2. Methodology for the search for the location with greater feasibility

4.1. Collection of information from the state of Chiapas

1. *Municipalities impacted by* a natural phenomenon of a hydrometeorological type during the period 2015-2022 the database of municipalities affected by a natural phenomenon of a hydrometeorological type during the period 2015-2022 is developed based on data from the Ministry of Civil Protection of the Government of Chiapas of the Emergency Declarations issued by the National Fund for Natural Disasters and the National Center for Disaster Prevention (CENAPRED, 2022; Secretaría de Protección Civil, 2022). The 120 municipalities of the 124 homes in the state under study are obtained. Being unimpacted: 1. Emiliano Zapata; 2. The Parral; 3. Honduras de la Sierra, and 4. Captain Luis Ángel Vidal.
2. *The number of victims* a database of victims by the impacted municipality is developed, which contains: 1. Date; 2. Region; 3. Municipality; 4. The number of inhabitants per municipality; 5. The number of victims per event occurred during the study period, and 6. The average number of victims between 2015-2022. It is based on data from the Chiapas Government Civil Protection Secretariat and the Emergency Declarations issued by the National Fund for Natural Disasters (CENAPRED, 2022; Secretaría de Protección Civil, 2022).
3. *Distances between municipalities,* with the help of the Google Maps® application, a distance matrix is developed between the 124 municipalities belonging to the state.
4. *Coordinates the impacted municipalities* through the application of Google Earth®, the coordinates of the municipalities impacted by a natural hydrometeorological phenomenon during 2015-2022 are obtained.
5. *Services by municipalities not impacted* are taken as essential services for the warehouse: 1. electricity; 2. telephony; 3. Internet, and 4. Water and sewage (CFE, 2022; TELMEX, 2022; SMAPA, 2018).
6. One of the points to be evaluated during the location methods is the proximity to the *suppliers*; for this, social interest stores located in the state are taken as a base (DICONSA, 2022).
7. *For federal and state highways,* information on road access for each municipality is obtained through (SCT, 2022).
8. *The degree of marginalization* by a municipality or locality makes it possible to order hierarchically the geographical areas that require special educational policy efforts to increase equity of access to quality primary education (INEE, 2006).

4.2. Application of plant location methods.

A. Weighted factors.

For its application, the following are determined as weighting factors for the municipalities not impacted: 1. *Services*, the weighting is based on the number of inhabitants who have the following services: drainage, telephone, electricity, and internet; 2. *Suppliers* are based on the size of the store or, failing that, the distance in km and the size of the store closest to the non-impacted municipality; 3. *Highway accesses* are based on the type of road, if it enters the highway or federal classification, if the municipality not impacted has one, two, both, or none, and 4. *The degree of marginalization* is based on the municipality's marginalization levels: very high, high, medium, low, or very low. It is worth mentioning that the percentage of relative weight for each factor is the same, that is, 25% for each one.

With this, a feasible result is obtained, indicating that El Parral's municipality has greater compliance with the established characterization with 8.28 points out of 10, followed by Emiliano Zapata, Capitan Luis Ángel Vidal, and Honduras de la Sierra, in that order.

B. Center of gravity.

For its application, the average number of victims that the impacted municipality has had during the period covered between 2015-2022. Also, the coordinates of the impacted municipalities are used as a demand factor. The results obtained are the coordinates of the town of Buenavista Mirador, located within the municipality of *El Parral*, which is a municipality not impacted, which can be the headquarters of the warehouse for humanitarian aid in case of emergency.

C. Balance point.

The development of the Break-Even analysis as a location method is carried out from the calculation of the so-called fixed costs, variable costs, and total costs. The elements that fall into each classification are mentioned in the following paragraphs. In the fixed costs, the following are considered: (a) stationery, (b) salaries: administrator, warehouse manager, and supervisor [34]; (c) rent; (d) electric light; (e) telephony; (f) internet; (g) water, and (h) drainage.

Within the variable costs, the following are added: (a) purchase cost, for its calculation, the assembly of pantries for four people (a family) is considered, with 21 products for food (basic basket) and hygiene and health, cataloged by (DICONSA, 2018) and the container for delivery. (b) cost of fuel per unit, calculated based on the unit cost of diesel -lt (Comisión Reguladora de Energia, 2022); kilometers traveled for the delivery, the performance of the truck (km/lt), and the number of pantries to supply the victims; coupled with the truck's carrying capacity. These last two points are necessary because the need of some municipalities in terms of the number of pantries is greater than the capacity of the truck to transport them, for which a more significant number of deliveries must be made. (c) cost of delivery personnel: a driver and an unloading assistant are considered; this information is extracted from (CONASAMI, 2022). Fig. 3 shows the results obtained.

Fig. 3. Break-even analysis

The result shows that the municipality of *Emiliano Zapata*, under the established fixed and variable costs, is the most feasible option to host a supply warehouse for areas affected by a phenomenon.

D. Method of transportation.

In the development of the transportation method as a technique for the location of multiple facilities, a series of evaluation elements are established, dividing them into quantitative and qualitative: Among the quantitative elements are those whose value is monetary, that is, the cost: 1. Fuel per trip; 2. Staff salary; 3. Vehicle depreciation, 25% (SAT, 2022); 4. Travel insurance, and 5. Truck maintenance (Barojas-Payán et al., 2022). While among the qualitative elements are: 1. Level of marginalization; 2. Climate (INEGI, 2022); 3. Services; 4. Highway access roads, and 5. Proximity to suppliers.

Based on the qualitative elements, it is determined that the municipalities of *Emiliano Zapata and El Parral* have the most excellent feasibility of hosting a warehouse. In the same way, this classification gives rise to the percentage of pantries that can supply the warehouse of each municipality, in a proportion of 45% and 55%, respectively.

The impacted municipalities supplied by each warehouse are determined using the northwest corner method and, later, the minimum cost method. In this way, the municipality of El Parral will supply 85 municipalities and the municipality of Emiliano Zapata 35.

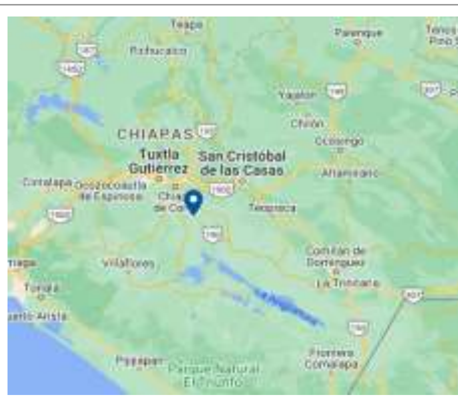
E. P-median.

In order to determine the location of a geographical space that allows the installation of a warehouse for the protection and distribution of essential products to people affected by a natural phenomenon, the programming of the *p*-median model is carried out, in two forms, the first direction, with the only characterization of being a municipality not impacted, resulting in the municipality of *Emiliano Zapata*. Subsequently, a weight factor derived from the characteristics of (a) Services: electricity, water, drainage, telephone, and internet are added; (b) Highway access: federal or highway; (c) Level of marginalization: very high, high, medium, low, or very low, and (4) Suppliers: social interest stores immersed in the municipalities. These factors influenced the change of headquarters, which passed to the municipality of *El Parral.*

5 Results

Table 2 presents the results obtained in each method. In the first column, it shows the method or technique applied; in the second, the result can find the location of the municipality through a map, the result obtained with the application of the method: factor, coordinate, or cut-off point; the name of the municipality, and the distance from the headquarters to the impacted municipalities.

Table 2. Chiapas State

Technique/method	Results
Weighted factors	 *Weighing:* 8.28 points of 10 *Feasible location:* El Parral *Distance:* 49,960 km
Gravity center	*Resulting coordinates:* 16,25498135 -92,89477639 Buenavista Mirador Locality *Feasible location:* El Parral *Distance:* 49,960 km 
Break-even	 *Cut point:* 695 pantries. *Feasible location:* Emiliano Zapata *Distance:* 44,986 km

Transport method	Headquarters municipalities: Emiliano Zapata El Parral *% of supply:* Emiliano Zapata 45% El Parral 55% *Number of municipalities to supply:* Emiliano Zapata: 35 El Parral: 85 *Distance:* Emiliano Zapata: 5,612 km El Parral: 42,738 km Total: 48,350 km 
P-median	 *Without weight factors:* Headquarters municipality: Emiliano Zapata. *Distance*: 44,986 km *With weight factors:* Headquarters municipality: El Parral *Distance:* 49,960 km

6 Conclusions

The research is based on the application of different models for the location of facilities, through which feasible solutions are obtained that allow the location of one or more warehouses to supply essential products to people affected by a natural disaster in the state of Chiapas, Mexico. The characterization of the municipalities that could host the warehouse is based on: (a) services: electricity, telephone and internet, and water and drainage; (b) degree of marginalization: very low, low, medium, high, and very high; (c) proximity to suppliers, (d) road access, and the most important one, which a natural phenomenon has not impacted during the 2015-2022 period. In the same way, the costs generated for the warehouse are divided into 1. Fixed costs: rent, salaries, taxes, and services; and 2. Variable costs: salaries, transportation, and purchase. The distances traveled between municipalities and the coordinates of each of them are part of the information for the supply of the different methods, among which are: Weighted factors; Gravity center; Break-even; Transport method; and *p*-median. The results show that the municipality of El Parral is the best option for the installation, followed by the municipality of Emiliano Zapata. The main difference is that the characterization of El Parral has a higher score than that of Emiliano Zapata in terms of infrastructure and services it has. The importance of what has been presented lies in the fact that although the appearance or magnitude of a natural phenomenon cannot be avoided, it is possible to collaborate to reduce the degree of affectation to the victims by providing support in the shortest time that allows them to maintain a certain quality of life, as is the case of products for adequate food and hygiene.

It brings with it the establishment of future jobs, such as inventory levels with uncertain demand and delivery routing, to mention a few.

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