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Strategy for the Location of Shelters in Communities of High Seismic Risk in the Central-South Zone of Mexico

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Authors' contributions

This work was carried out in collaboration between both authors. Authors DSP and SOCM designed the study, performed the data analysis, developed the programming code for the two-stage solving approach and wrote the first draft of the manuscript. Author SOCM revised the final draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Earthquakes cause diverse damages on human settlements, from disruption of services, collapse and destabilization of buildings, to the rise of diseases and death of people. Mexico is one of the countries with the highest risk of earthquakes given its location in the so-called "Ring of Fire" which registers the majority of telluric movements worldwide. In particular, the central-southern zone of Mexico has been severely affected by recent earthquakes. Since the greatest impact has been the immediate loss of housing and basic service infrastructure, a strategy is imperative to locate shelters that cover these needs during and after the seismic event until the affected housing and services are restored. Similarly, these shelters must have the capacity to receive the majority of the long-term affected population. Therefore, this paper develops a logistics strategy to locate these centers for the state of Puebla, which has been severely affected by these events. The strategy makes use of Weber's multiple location model which is solved using a nearest neighbor heuristic and mixed programming. The results provide coverage for high-risk areas that can be implemented in other regions of the country.

Keywords: Humanitarian logistics; facility location; weber problem; heuristics; natural disasters.

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1. INTRODUCTION

Due to its geographical location, climatic, orographic and hydrological characteristics, as well as its volcanic and seismic activity, Mexico is prone to the impact of a wide variety of natural phenomena with the potential to cause disasters. The negative consequences of these events are increased by the poor social and economic conditions that exist in large sectors of the population, which generates high levels of vulnerability in many regions of the country [1].

Natural disasters are measured by the economic and social impacts they generate, such as: injured people and deaths, houses, schools and hospitals damaged, among others. Frequently, the greatest effects are found in the most vulnerable and highly marginalized communities [2].

One of the most devastating events was the 1985 earthquake of 8.0 magnitude which caused nearly 5,000 – 45000 deaths, 3000 injuries and economic losses of more than 4.1 billion dollars. In 2017, another earthquake of 7.1 magnitude caused 369 deaths, 6000 injuries and losses of 3.3 billion dollars [2-4].

After the earthquake event, it is important to have an effective shelter infrastructure to reduce further damages to injured people and survivors. Note that this kind of infrastructure is nearly inexistent in most of the affected communities. Thus, research has been performed on shelter planning by using facility location models which are frequently used in logistics [5,6].

In this context, the present work contributes with a logistics strategy to locate these shelters in the state of Puebla, which has been severely affected by these events [4]. The strategy makes use of Weber's multiple location model which is solved using a nearest neighbor heuristic and mixed programming. The results provide coverage for high-risk areas that can be implemented in other regions of the country.

The paper is structured as follows: in Section 2 we extend on the seismic events in Mexico and the region under study; then, in Section 3 we review the features of the shelters; in Section 4 we present the details of our shelter location strategy, including data acquisition and the twophase solution method; the results regarding shelter location and allocation of communities are presented and analyzed in Section 5; finally, our conclusions and future work are discussed in Section 6.

2. SEISMIC RISK IN MEXICO

Earthquakes are phenomena caused by movements of the Earth's crust which produce vibrations that can spread in various directions. Earthquakes in Mexico are mainly due to two types of movements:

- Subduction, which occurs when two plates collide at a convergent boundary and one plate is driven beneath the other, back into the Earth's interior. This happens along the coastal portion of the states of Jalisco and Chiapas;
- Transform fault, which occurs when two plates slide past each other, horizontally. This happens between the Pacific and North American plates through a lateral sliding movement [7].

The country is located in one of the most active seismic zones in the world, the Pacific "Ring of Fire", whose name is due to the high degree of seismicity resulting from the mobility of four tectonic plates: North American, Cocos, Rivera and the Pacific. In the last 200 years in Mexico there have been 75 relevant earthquakes due to the damages or losses they generated, of these, 60 had a magnitude greater than 7.0 [3,4,8].

In the state of Puebla, three regions of seismic risk have been identified (see Fig. 1) [8]:

- High Risk (113 municipalities): the epicenters are frequent and include communities such as Tehuacan, Acatlan, and Izucar de Matamoros.
- Medium Risk (53 municipalities): epicenters are less frequent and include communities such as San Martin Texmelucan, Cholula, Puebla, Oriental, Lara Graiales. Ciudad Serdan. Tecamachalco, Acatzingo and Atlixco.
- Low Risk (51 municipalities): epicenters are rare, such as Sierra Norte and Nororiental, Cuetzalan region, Teziutlan and Zacatlan.

Sánchez-Partida and Caballero-Morales; JGEESI, 26(5): 72-82, 2022; Article no.JGEESI.87216

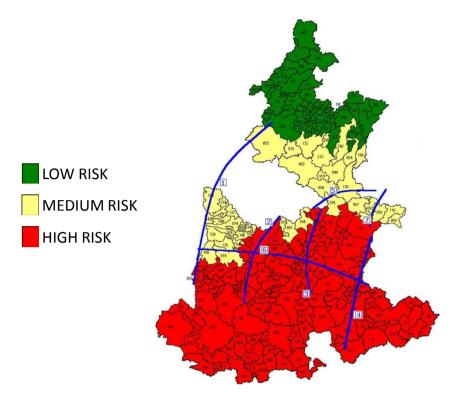


Fig. 1. Seismic Risks in the State of Puebla: Green – Low Risk, Yellow – Medium Risk, Red – High Risk (adapted from [8])

3. CHARACTERISTICS OF TEMPORARY SHELTERS

In Mexico, the term "Temporary Shelter" refers to the physical installation enabled to temporarily provide protection and well-being to people who do not have immediate possibilities of access to a safe room in case of imminent risk, an emergency or disaster [9].

One of the strategies established by the Ministry of the Interior, through the National Civil Protection System, consists of the installation of temporary shelters to provide shelter from inclement weather for the population when an emergency or disaster has occurred. These sites should be considered of great interest in terms of public health, because diseases are more prone to disseminate in reduced spaces with high population density [9].

The World Health Organization (WHO) recommends that ventilated and easily accessible spaces with a dimension of 3.5 m^2 or 10.0 m^3 per person should be guaranteed for emergency accommodation. Similarly, it must have infrastructure for food preparation, storage, collection, hygiene, and recreation, with the

following supplies: drinking water, garbage dumps, cleaning material, non-perishable food, clothing and diapers, and medicines for infections [9].

4. SHELTER LOCATION STRATEGY

4.1 Analysis of Data

The first step in designing the strategy for the location of the shelters in the areas of greatest seismic risk is to collect the geographic and population information of the same. For this, public information available by the National Institute of Statistics and Geography (INEGI) was consulted regarding the number and name of the municipalities or communities in the state of Puebla and the most updated number of inhabitants in each of them [10]. The second step consists of identifying the geographical location of each municipality. To do this, the Google Maps © geolocation tool was used. Table 1 and Table 2 present this information for the municipalities in the areas of low/medium and high seismic risk respectively. As presented, the state capital Puebla is in the high-risk region, so are the municipalities of Tehuacan, Amozoc, Tepeaca and Izucar de Matamoros.

Table 1. Geographic location and population density in the low and medium risk zones ofpuebla [10]

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50 215 ZONGOZOTLA 19.9791 -97.7292 4539 50 199 XIUTETELCO 19.914 -97.3239 42943 51 216 ZOQUIAPAN 20.0062 -97.5954 2452 51 200 XOCHIAPULCO 19.8167 -97.6559 3443												
51 216 ZOQUIAPAN 20.0062 -97.5954 2452 51 200 XOCHIAPULCO 19.8167 -97.6559 3443							.,					
52 211 ZARAGOZA 19.7685 -97.5520 16752	51	216	ZOQUIAPAN	20.0062	-97.5954	2452						
							52	211	ZARAGOZA	19.7685	-97.5520	16752

4.2 Analysis with Logistical Approach

Depending on the set of clients in an area of interest, it may be that a single facility or center does not have the capacity to cover them for a specific service. In this case, it is advisable to open a greater number of facilities or centers. In this context, this logistics scenario can be addressed using the multi-facility location model which has the following mixed programming model [11]:

minimize
$$Z = \sum_{j=1}^{P} F_j y_j + \sum_{j=1}^{P} \sum_{i=1}^{N} c_{ij} x_{ij}$$
 (1)

19.7198 -97.6886

20717

ZAUTLA

Subject to:

212

53

$$\sum_{i=1}^{N} d_i x_{ij} \le b_j, \, j = 1, \dots, \, P \tag{2}$$

$$\sum_{j=1}^{P} x_{ij} = 1, \, i = 1, \dots, \, N \tag{3}$$

$$x_{ij} \le y_j, i = 1, ..., N \text{ and } j = 1, ..., P$$
 (4)

$$x_{ij}, y_j \in \{0,1\}, i = 1, ..., N \text{ and } j = 1, ..., P$$
 (5)

#	Code	Community	Latitude	Longitude	Inhabitants
1	3	ACATLÁN	18.1943	-98.0438	37955
2	5	ACTEOPAN	18.7643	-98.7118	3070
3	7	AHUATLÁN	18.5673	-98.2563	3162
1	9	AHUEHUETITLA	18.2135	-98.2201	2207
5	10	AJALPAN	18.3785	-97.2690	74768
6	11	ALBINO ZERTUCHE	18.0157	-98.5397	1885
7	12	ALJOJUCA	19.0971	-97.5321	6591
;	13	ALTEPEXI	18.3645	-97.2957	22629
)	15	AMOZOC	19.0477	-98.0680	125876
0	18	ATEXCAL	18.4009	-97.7342	3859
1	20	ATOYATEMPAN	18.8203	-97.9156	7704
2	20	ATZALA	18.5455	-98.5522	1512
3	21	ATZITZIHUACÁN	18.3433	-98.5322	12857
4	23	ATZITZINTLA	18.8964	-97.3265	9051
5 6	24	AXUTLA	18.1885	-98.3899	976
	27	CALTEPEC	18.1821	-97.4800	4128
	31	COATZINGO	18.6107	-98.1729	2820
	32	COHETZALA	18.1942	-98.8069	1382
	33	COHUECAN	18.7835	-98.7212	5403
)	35	COXCATLÁN	18.2595	-97.1548	20653
	36	COYOMEAPAN	18.2844	-96.9910	14806
	37	COYOTEPEC	18.4007	-97.8276	2334
	40	CUAUTINCHÁN	18.9550	-98.0169	12340
	42	CUAYUCA_DE_ANDRADE	18.4825	-98.1778	3315
_	45	CHALCHICOMULA_DE_SESMA	18.9776	-97.4465	47410
	46	CHAPULCO	18.6092	-97.4114	8193
	47	CHIAUTLA	18.3001	-98.6022	21699
	51	CHIETLA	18.5176	-98.5754	37030
_	52	CHIGMECATITLÁN	18.6447	-98.0749	1215
	55	CHILA	17.9734	-97.8665	5082
	56	CHILA DE LA SAL	18.1077	-98,4846	1317
	59	CHINANTLA	18.2060	-98.2617	2846
	61	ELOXOCHITLÁN	18.5023	-96.9545	14461
	62	EPATLÁN	18.6450	-98.3724	4943
	63	ESPERANZA	18.8576	-97.3740	14766
	65	GRAL. FELIPE ANGELES	18.9918	-97.7011	22694
	66	GUADALUPE		-98.1206	6451
			18.0864		
	69 70	HUAQUECHULA	18.7705	-98.5444	29233
		HUATLATLAUCA	18.6760	-98.0507	6111
	73	HUEHUETLÁN_EL_CHICO	18.3741	-98.6902	9760
	79	SANTA_CLARA_HUITZILTEPEC	18.7675	-97.8822	5782
	81	IXCAMILPA_DE_GUERRERO	18.0314	-98.6989	4065
	82	IXCAQUIXTLA	18.4605	-97.8309	8804
	85	IZÚCAR_DE_MATAMOROS	18.6002	-98.4652	82809
	87	JOLALPAN	18.3234	-98.8442	13308
	92	JUAN_NMÉNDEZ	18.5194	-97.7220	5293
	95	LA_MTLATLAQUILOTEPEC	19.8462	-97.4962	650
	97	MIXTLA	18.9086	-97.8918	2668
	98	MOLCAXAC	18.7475	-97.9135	6668
	99	CAÑADA_MORELOS	18.7379	-97.4205	20659
	103	NICOLÁS_BRAVO	18.6146	-97.3047	6644
	106	OCOYUCAN	18.9757	-98.2971	42669
	110	PALMAR_DE_BRAVO	18.8356	-97.5472	50226
		PETLALCINGO	18.0879	-97.9147	9350
	112				
	112		18,1968	-98.2562	4627
	112 113 114	PIAXTLA PUEBLA	18.1968 19.0387	-98.2562 -98.2019	4627 1692181

Table 2. Geographic location and population density in the high risk zone of Puebla [10]

Note that j = 1, ..., P which is the location index for the required facilities, where there are P possible locations available. Each location *j* has a capacity determined by b_i . i = 1,..., N is the customer index, where there are N customers. Each customer *i* has a given demand d_i , F_i is the cost of opening facility j, c_{ij} is the cost/time/distance to serve customer i from facility *j*, and y_i is a binary decision variable which has a value of "1" if facility j is opened, and has a value of "0" if contrary. On the other hand, x_{ii} is another binary decision variable that has value of "1" if customer *i* is assigned or served by facility *i*, and has a value of "0" otherwise.

In the context of our problem, P is defined as the number of shelters to establish, while N is the number of municipalities to cover in case of a seismic-type disaster. c_{ij} is determined as the distance in km between municipality i and shelter

#	Code	Community	Latitude	Longitude	Inhabitants
8	118	LOS_REYES_DE_JUÁREZ	18.9433	-97.8049	30021
59	120	SAN_ANTONIO_CAÑADA	18.4988	-97.2857	5938
50	121	SAN_DIEGO_LA_MESA_TOCHIMILTZINGO	18.8112	-98.3306	1270
51	124	SAN_GABRIEL_CHILAC	18.3280	-97.3469	15954
52	127	SAN_JERÓNIMO_XAYACATLÁN	18.2185	-97.9140	3606
53	128	SAN_JOSÉ_CHIAPA	19.2401	-97.7672	10443
54	129	SAN_JOSÉ_MIAHUATLÁN	18.2905	-97.2884	14018
55	130	SAN_JUAN_ATENCO	19.0852	-97.5391	3604
56	131	SAN_JUAN_ATZOMPA	18.7452	-98.0246	975
57	133	SAN_MARTÍN_TOTOLTEPEC	18.6516	-98.3455	692
58	135	SAN_MIGUEL_IXITLÁN	18.0015	-97.7737	526
59	137	SAN_NICOLÁS_BUENOS_AIRES	19.1646	-97.5539	10464
70	139	SAN_PABLO_ANICANO	18.1225	-98.0846	3759
71	141	SAN_PEDRO_YELOIXTLAHUACA	18.1165	-98.0765	3488
72	142	SAN_SALVADOR_EL_SECO	19.1347	-97.6400	30639
73	144	SAN_SALVADOR_HUIXCOLOTLA	18.9165	-97.7756	16790
74	145	SAN_SEBASTIAN_TLACOTEPEC	18.4080	-96.8014	13189
75	146	SANTA_CATARINA_TLALTEMPAN	18.6152	-98.0799	749
76	147	SANTA_INÉS_AHUATEMPAN	18.4128	-98.0193	6341
77	149	SANTIAGO_MIAHUATLÁN	18.5438	-97.4395	30309
78	150	HUEHUETLÁN EL GRANDE	18.7296	-98.1623	6105
79	151	SANTO TOMÁS HUEYOTLIPAN	18.8919	-97.8642	9315
30	152	SOLTEPEC	19.1249	-97.7144	12631
31	153	TECALI DE HERRERA	18.8995	-97.9729	23625
32	154	TECAMACHALCO	18.8806	-97,7328	80771
33	155	TECOMATLÁN	18,1086	-98.3131	6830
34	156	TEHUACÁN	18,4609	-97,4068	327312
85	157	TEHUITZINGO	18.3312	-98.2721	12672
36	159	TEOPANTLÁN	18.7129	-98.2627	3836
87	160	TEOTLALCO	18,4691	-98,7782	3689
88	161	TEPANCO_DE_LÓPEZ	18.5553	-97.5606	22218
89	164	TEPEACA	18.9723	-97.8987	84270
90	165	TEPEMAXALCO	18.7357	-98.6293	1216
91	166	TEPEOJUMA	18.7234	-98.4466	8918
92	168	TEPEXCO	18.6414	-98.6893	7523
93	169	TEPEXI DE RODRÍGUEZ	18.5781	-97.9259	22331
94	171	TEPEYAHUALCO DE CUAUHTEMOC	18.8137	-97.8768	3851
95 95	176	TILAPA	18.5959	-98.5545	9664
96	170	TLACOTEPEC_DE_BENITO_JUÁREZ	18.6789	-97.6478	54757
97	179	TLACHICHUCA	19.1136	-97.4192	31639
98	182	TLANEPANTLA	18.8626	-97.8854	5390
99 99	182	TLAPANALÁ	18.6964	-98.5337	10344
99 00	185	TOCHTEPEC	18.8405	-98.3337	22454
00	189	TOTOLTEPEC DE GUERRERO	18.8405	-97.8237	22454
01	190	TULCINGO	18.2221	-97.8556	9871
02	191	TZICATLACOYAN	18.0452	-98.0473	6476
03	195	VICENTE GUERRERO	18.8406	-98.0475	26559
04	195		18.5427	-97.1996	26559
05 06	196	XAYACATLÁN_DE_BRAVO			
06	201	XICOTLÁN XOCHILTEPEC	18.0605 18.6489	-98.5250 -98.3406	1312 3375
08	203	XOCHITLÁN_TODOS_SANTOS	18.6987	-97.7734	7178
09	205	YEHUALTEPEC	18.7907	-97.6630	26392
10	206	ZACAPALA	18.5934	-98.0658	4647
11	209	ZAPOTITLÁN	18.3301	-97.4686	8595
12	214	ZINACATEPEC	18.3355	-97.2450	18359
13	217	ZOQUITLÁN	18.3325	-97.0192	20335

i. To do this, we will use the geographic arc length metric which requires the longitude and latitude coordinates of each community and refuge to estimate the distance in kilometers considering the dimensions of the Earth [12]. Regarding the capacity of the shelters, this is a matter of controversy since there is no standard for it. Also, not all inhabitants in a community are affected in the same way (only a fraction of the population effectively will require the use of the shelter). For this, we consider the most recent data regarding the earthquake of 7 and 19 of September of the year 2017, where an approximate of 12,000,000 people were affected by these events in 9 states: Chiapas, Oaxaca, Tabasco, CDMX and Mexico State, Tlaxcala, Hidalgo, Puebla, Morelos and Guerrero [13].

These damages do not only cover the aspect of housing, they also cover the interruptions of basic services (water, electricity), schools and culture. For this seismic event, the Federal Government reported for the state of Puebla the following statistics: 23,680 houses with partial damage, 3,214 houses with total damage, and 918 relocations [14]. Considering the houses with total damage and those that required relocation, and that on average there are 5 people per house, there is an approximate of (3,214+918) 5 = 20660 people in need for temporary and long-term shelter.

Taking as a reference the capacity limits for the shelters used to receive groups of migrants, a lower limit of 140 people was set [14,15]. In the same way, according to what was reported in [15], these shelters have shown an overcrowding of 180%, which establishes an upper bound of 252 people.

Considering the long-term use of these shelters during and after the seismic events, a bound of 260 people is established for b_{j} . It is worth mentioning that the shelters cannot be larger given that the high density of people in limited spaces favors the proliferation of diseases, gastrointestinal disorders and insecurity [9].

In general, for the state of Puebla in the high-risk area, approximately 20,660 / 260 = 80 shelters would be required. The number of people in this area is approximately 3,738,881. This provides a ratio of 20,660 / 3'738,881 = 0.05% of the population that can be affected in this type of events. Note that this calculation includes the capital in which, despite having the highest

population density, is the one with the greatest resources to solve a disaster situation. The same happens with the municipalities of Amozoc and Tehuacan. Therefore, these three municipalities will not be considered in the assignment problem.

Finally, the estimation of d_i for each municipality *i* in the high-risk area is estimated as 0.05% of the population registered in it. For convenience, F_j is set to 1.0 for all shelters.

4.3 Solution Method for the Location Problem

The solution to the location problem consists of two stages:

- Location: determine the number and location of the centers (shelters) required to provide coverage
- Allocation or Assignment: determine the clients (communities) whose demand (inhabitants) will be covered by each center (shelter). A client must be covered by only one center. This allocation must meet the facility's capacity constraint.

These stages must be carried out in parallel, ensuring that the cost minimization criterion is met (in this case, distances between the shelters and the affected communities). Fig. 2 illustrates this iterative process of location and assignment as well as the tools used in each stage.

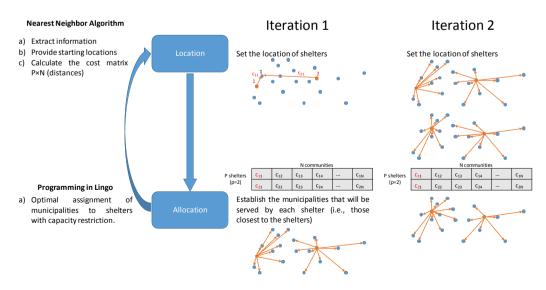


Fig. 2. Solution Strategy for the Problem of Location and Assignment of Municipalities and Shelters

Step 0: Obtain value for P (number of shelters) and b_i (capacity of each shelter
j). Give random values to longitude (*lon*_i) and latitude (*lat*_i) coordinates for the P
sheltersStep 1: Calculate the distance c_{ij} between each shelter *j* and community *i*. These
distances will be stored in the distance matrix D of dimension $P \times N$.Step 2: Based on the information in D, assign to each shelter *j* the closest
community *i*.Step 3: Based on Weber's criterion of minimum distance, for each shelter *j*,
determine its new location (*lon*_i, *lat*_i) considering the coordinates of the closest
communities assigned to it (Simplex method).Step 4: Repeat Step 1Step 5: Carry out the optimal assignment of communities *i* to shelters *j* through
mixed programming (LINGO) and considering the constraints of capacity b_i and
demand d_i of each shelter and community, respectively.Step 6: Iterate from Step 3 until S = 10 iterations.

Fig. 3. Heuristic of Nearest Neighbor for the Problem of Location and Assignment of Municipalities and Shelters

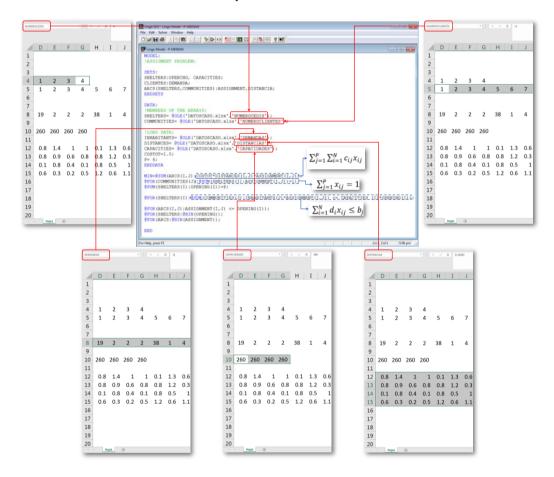


Fig. 4. Lingo Code for Optimal Allocation for the Communities and Shelters Location and Allocation Problem

4.3.1 Nearest neighbor

The nearest neighbor heuristic has the structure described by the steps in Fig. 3. This sequence of steps is performed in accordance with the strategy presented in Fig. 2. As can be seen, the heuristic has the objective of giving an initial (random) location to the shelters in order to later make a direct assignment (without capacity restriction). Based on this assignment, the distance matrix of the problem is calculated and the locations of the shelters are adjusted or updated. Weber's criterion is used to locate the facility where it minimizes the distance between it and its customers or communities. This problem is easily solved by the Simplex method.

Once the first location adjustment for the shelters has been made, the optimum community assignment is done according to the capacity restrictions of the shelters and the demands of the communities. From this assignment, the distance matrix calculation process, shelter location adjustment, and optimal assignment with capacity restriction are repeated.

4.3.2 Programming in lingo

Fig. 4 presents the Lingo code to solve the problem of optimal allocation of communities to shelters considering capacity and demand constraints.

5. RESULTS

The nearest neighbor heuristic was coded in Octave v4.4.1 while the assignment was done

with Lingo v18.0. Both software were executed on a Z230 HP Wokstation with an Intel XEON processor at 3.40 GHz and 8GB RAM.

Based on the analysis in Section 4.2, it was determined that there are a total of 854 people in communities (excluding the hiah-risk the Puebla. Tehuacan municipalities of and Amozoc) who will require shelter in the short, medium and long term. This amount represents 0.05% of the total population in them. Regarding the level for the number of necessary shelters, it was estimated that 854/260 = 3.28 = 4shelters.

Fig. 5 presents the results corresponding to each phase of the solution methodology. The final result, shown in Fig. 5(c), shows the shortcomings of only considering P=4 shelters with the capacity restriction (that is, communities closer to a shelter, due to lack of capacity, have to be assigned to shelters further away). Therefore, options with P = 5, 6 and 7 shelters were explored, obtaining the results shown in Fig. 6.

As can be seen, the solutions with P = 6 and P = 7 shelters maintain an allocation to the closest shelters without compromising capacity constraints. Considering the objective function criterion (equation 1), the solution with P = 7 shelters is the one that meets it (additional tests with more shelters increase the value of the objective function). Table 3 presents the details of this solution, including the geographical location of the shelters.

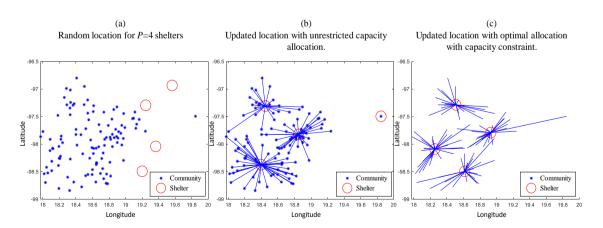


Fig. 5. Location and assignment for P=4 shelters in High Risk Zone: (a) random location, (b) locations adjusted based on unconstrained nearest neighbor direct assignment, (c) locations adjusted based on optimal assignment with demand and capacity constraints

Sánchez-Partida and Caballero-Morales; JGEESI, 26(5): 72-82, 2022; Article no.JGEESI.87216

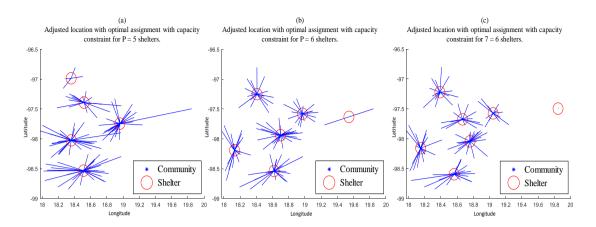


Fig. 6. Locations adjusted based on optimal allocation with demand and capacity constraints for: a) P = 5 shelters, b) P = 6 shelters, c) P = 7 shelters

Table 3. Geographic details of	f shelter locations and comm	unity names assigned to each one

Shelter	1	2	3
Lat	18.1499	18.5634	18.3872
Lon	-98.1585	-98.5945	-97.2215
Communities	ACATLÁN	ACTEOPAN	AJALPAN
	AHUEHUETITLA	ATZALA	ALTEPEXI
	ALBINO_ZERTUCHE	ATZITZIHUACÁN	CALTEPEC
	AXUTLA	COHETZALA	COXCATLÁN
	CHILA	COHUECAN	COYOMEAPAN
	CHILA_DE_LA_SAL	CHIAUTLA	ELOXOCHITLÁN
	CHINANTLA	CHIETLA	NICOLÁS_BRAVO
	GUADALUPE	EPATLÁN	SAN ANTONIO CAÑADA
	PETLALCINGO	HUAQUECHULA	SAN_GABRIEL_CHILAC
	PIAXTLA	HUEHUETLÁN EL CHICO	SAN JOSÉ MIAHUATLÁN
	SAN JERÓNIMO XAYACATLÁN	IXCAMILPA DE GUERRERO	SAN SEBASTIAN TLACOTEPEC
	SAN MIGUEL IXITLÁN	IZÚCAR DE MATAMOROS	SANTIAGO MIAHUATLÁN
	SAN PABLO ANICANO	JOLALPAN	VICENTE GUERRERO
	SAN_PEDRO_YELOIXTLAHUACA	SAN_MARTÍN_TOTOLTEPEC	ZAPOTITLÁN
	SANTA INÉS AHUATEMPAN	TEOTLALCO	ZINACATEPEC
	TECOMATLÁN	TEPEMAXALCO	ZOQUITLÁN
	TEHUITZINGO	TEPEOJUMA	
	TOTOLTEPEC DE GUERRERO	TEPEXCO	
	TULCINGO	TILAPA	
	XAYACATLÁN_DE_BRAVO	TLAPANALÁ	
	XICOTLÁN	XOCHILTEPEC	
Shelter	4	5	6
Lat	19.0447	18.6661	18.7593
Lon	-97.5754	-97.6765	-98.0436
Communities	ALJOJUCA	ATEXCAL	AHUATLÁN
	ATZITZINTLA	COYOTEPEC	ATOYATEMPAN
	CHALCHICOMULA_DE_SESMA	CHAPULCO	COATZINGO
	ESPERANZA	IXCAQUIXTLA	CUAUTINCHÁN
	GRALFELIPE_ANGELES	JUAN_NMÉNDEZ	CUAYUCA_DE_ANDRADE
	QUECHOLAC	CAÑADA_MORELOS	CHIGMECATITLÁN
	LOS_REYES_DE_JUÁREZ	PALMAR_DE_BRAVO	HUATLATLAUCA
	SAN_JOSÉ_CHIAPA	SAN_SALVADOR_HUIXCOLOTLA	SANTA_CLARA_HUITZILTEPEC
	SAN JUAN ATENCO	TECAMACHALCO	MIXTLA
	SAN_NICOLÁS_BUENOS_AIRES	TEPANCO_DE_LÓPEZ	MOLCAXAC
	SAN SALVADOR EL SECO	TLACOTEPEC DE BENITO JUÁREZ	OCOYUCAN
	SOLTEPEC	TOCHTEPEC	SAN_DIEGO_LA_MESA_TOCHIMILTZINGO
	TLACHICHUCA	XOCHITLÁN_TODOS_SANTOS	SAN JUAN ATZOMPA
		YEHUALTEPEC	SANTA_CATARINA_TLALTEMPAN
			HUEHUETLÁN_EL_GRANDE
			SANTO TOMÁS HUEYOTLIPAN
			TECALI DE HERRERA
			TEOPANTLÁN
			TEPEACA
			TEPEXI DE RODRÍGUEZ
			TEPEYAHUALCO DE CUAUHTEMOC
			TLANEPANTLA
			TZICATLACOYAN
			ZACAPALA
Shelter	7		
Shelter Lat	7 19.8462		

6. DISCUSSION AND CONCLUSIONS

This methodology can be applied to other regions of the country (or other countries) to estimate the number of shelters needed to assist people in vulnerable situations, particularly without space to live in the short, medium and long term. Similarly, these shelters could be used for other assistance tasks such as stockpiling food or providing medical services in the absence of a natural disaster.

An additional contribution of the present project is that the population allocation and analysis can provide information to make a better estimate of the final capacity of the shelter. For example, Shelter 4 to which only the Tlatlaquilotepec community is assigned, may have a capacity of less than 260 (i.e., 100). Based on the results obtained, most of the estimated shelters would have an average occupancy of 180 spaces or 70.0%. This can help design more compact and functional shelters. This has been evident in the natural disasters of recent years, and the need for shelters for people made vulnerable by other situations (e.g., immigration for social and security reasons).

A limitation of this work is the value of F_i which was set to 1.0. A change in F_j can lead to significant changes in shelter location and allocation of communities. F_i can be a probability (from 0.0 to 1.0) or a cost (i.e., an opening cost which integrates construction materials and resources for appropriate maintenance). Here, we assumed the same probability and same opening costs because no economic data was available regarding regional building costs for Also, transportation these shelters. costs between these communities and shelters are unknown.

Thus, much work remains to be done because shelter planning is a complex task beyond the location / allocation processes. In example, control of indoor thermal environment may not be available in some communities [16]. Also, transportation infrastructure is important for the construction of the shelters and, in the event of disaster, transportation to/from the shelters and the communities. Particularly, route planning is another logistic aspect which is crucial for evacuation purposes [17].

DISCLAIMER

The products used for this research are commonly and predominantly use products in our

area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors."

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

- SEMARNAT. Report on the Situation of the Environment in Mexico: Compendium of Environmental Statistics - Key Indicators of Environmental Performance and Green Growth. Secretariat of the Environment and Natural Resources (SEMARNAT). Spanish; 2015.
- CENAPRED. Socioeconomic Impact of the Major Disasters in Mexico: Executive Summary 2020. National Center for Disaster Prevention (CENAPRED). Spanish; 2020.
- 3. Moreno-Murillo, J.M. The 1985 Mexico Earthquake. Geofísica Colombiana. 1995;3:5-19.
- Montalvo-Arrieta JC, Pérez-Campos X, Ramirez-Guzman L, Sosa-Ramírez RL, Ruiz-Esparza MC, Leonardo-Suárez M. Macroseismic Intensities from the 19 September 2017 Mw 7.1 Puebla–Morelos Earthquake. Seismological Research Letters. 2019;90(6):2142–2153.
- Hu F, Li X. A modified particle swarm 5. optimization algorithm for optimal of earthquake allocation emergency shelters. International Journal of Information Geographical Science. 2012;26(9):1643-1666
- Xu J, Yin X, Chen D, An J. Nie G. Multicriteria location model of earthquake evacuation shelters to aid in urban planning, International Journal of Disaster Risk Reduction. 2016;20:51-62.
- CNPC. Civil Protection Manual. National Civil Protection Coordination (CNPC). Secretary of Security and Citizen Protection. Spanish; 2012.
- 8. Government of Puebla. Special Program for Seismic Emergencies: Puebla Earthquake Plan. Government of the State of Puebla - General Coordination of Civil Protection. Spanish; 2021.

- CENAPRECE. Temporary shelters: Health care manual in disasters. National Center for Preventive Programs and Disease Control (CENAPRECE). Spanish; 2020.
- 10. INEGI. Information by Entity Puebla: Territory - Municipal Division. National Institute of Statistics and Geography (INEGI). Spanish; 2020.
- Yaghini M, Karimi M, Rahbar M. A hybrid metaheuristic approach for the capacitated p-median problem. Applied Soft Computing. 2013;13(9):3922–3930.
- Sánchez-Sierra ST, Caballero-Morales SO, Sánchez-Partida D, Martínez-Flores JL. Facility location model with inventory transportation and management costs. Acta Logistica. 2018;5(3):79–86.
- Ureste M. What #19S Left Us: The Victims, Damages, and Victims in Mexico. Political Animal - News Portal; 2017. Accessed 01 May 2022.

Available:https://www.animalpolitico.com/2 017/10/cifras-oficiales-sismo-19s/. Spanish

- Government of Mexico: Action Plan for Earthquakes on September 7 and 19. Government of Mexico. Spanish; 2017.
- Bautista M. The Number of Migrants Exceeds the Capacity in Shelters on the Southern Border. Diario del Sur; 2022. Accessed 01 May 2022. Available:https://www.diariodelsur.com.mx/ local/el-numero-de-migrantes-rebasan-lacapacidad-en-albergues-en-la-frontera-sur-7738673.html. Spanish.
- 16. Thapa R, Rijal HB, Shukuya M, Imagawa H. Study on the wintry thermal improvement of makeshift shelters built after Nepal earthquake 2015. Energy and Buildings. 2019;199:62-71.
- 17. Li Y, Chung SH. disaster relief routing under uncertainty: A robust optimization approach. IISE Transactions. 2019;51:869-886.

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