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Design of logistic criteria to establish healthcare facilities in vulnerable regions in Mexico

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Abstract: According to the World Health Organization (WHO), health inequities refer to those dimensional, measurable, and avoidable differences between socially, economically, demographically, or geographically defined population groups. In Mexico, despite several advances in health services and infrastructure, there are health inequities in rural communities, particularly those with indigenous population. These communities have limited or non-existent healthcare facilities, medical equipment, transport infrastructure, medicines, and human resources such as doctors and nurses. In this work, a conceptual design of a healthcare network is proposed to serve a region with several rural communities with limited healthcare resources. The designed network allocates rural communities to the most appropriate facilities based on (a) a vulnerability community index, and (b) a facility service index. The application of the conceptual network led to a hierarchical referral scheme between communities and different types of healthcare facilities to improve medical services and infrastructure planning. These results can support the decisions aimed to expand already existent facilities, replace multiple basic facilities with an appropriate number of larger and more advanced facilities, and determine the transportation infrastructure required to reach these facilities.

1 Introduction

According to the World Health Organization (WHO), health is the result of a complete state of well-being which is achieved by a reduction in disease occurrence and improvement in medical care, ensuring that people can live each stage of their lives with dignity and quality of life. Thus, health is a fundamental human right and all people must have fair access to healthcare services [1]. However, within the sociocultural context of rural and indigenous communities, there are health inequalities which affect the fair access to healthcare services [2]. Health inequalities are defined as “systematic, avoidable and unfair differences in health outcomes that can be observed between populations, between social groups within the same population or as a gradient across a population ranked by social position” [3].

In Mexico, the increase in life expectancy indicates the positive effect of improvements in social conditions and health policies. However, this is not correlated with the life expectancy of the population in rural and indigenous communities which account for 20% of the country´s population. In fact, there is a significant gap in socio-economic and developmental indicators between indigenous and non-indigenous populations [4]. As an example of the health implications of this gap, monitoring, diagnosis and treatment of cancer have led to improved survival in people living in developed cities than in rural and indigenous communities [5]. This is associated with access to high-quality healthcare services which is dependent of economic, geographic and social factors. This has contributed to health disparities across the country where there is limited coordination between public health and healthcare system initiatives [6].

This limited coordination has been a factor for inefficient planning of services and infrastructure which includes facility location, allocation of communities, medical referrals, and land transportation. Not having appropriate infrastructure negatively impacts the eligibility of communities for the establishment (or allocation) of resources and assistive governmental programs [4].

In this context, the logistic field can contribute with a structured approach to improve the coordination between healthcare facilities. It also can contribute to determine the types of required facilities (i.e, health homes, clinics and hospitals) considering the communities’ characteristics of population density, geographical location, and infrastructure.

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Hence, the present work addresses this problem from a logistic approach, proposing the conceptual design of a healthcare network to serve a region with several vulnerable communities with limited healthcare facilities. The designed network allocates rural communities to the most appropriate facilities based on the following innovations: (a) a vulnerability community index, and (b) a facility service index. The application on the case study, which consisted of indigenous and rural communities within the municipality of Zacapoaxtla in the Mexican state of Puebla, led to a hierarchical referral scheme between communities and different types of healthcare facilities to improve medical services and infrastructure planning. These results can support the decisions aimed to expand already existent facilities, replace multiple basic facilities with an appropriate number of larger and more advanced facilities, and determine the transportation infrastructure required to reach these facilities. Hence, it is expected that the proposed network design can reduce inequality in healthcare services for the inhabitants of indigenous and rural communities in developing economies.

The advances of the present work are described in the following sections: in Section 2 a review of the healthcare services in Mexico and the municipality of Zacapoaxtla is presented; then, the methodological steps to design the network are presented in Section 3; the results of the application on the case study are analysed and discussed in Section 4; finally in Section 5 the conclusions and future work are presented.

2 Healthcare conditions in rural communities

Due to a predominant sedentary lifestyle in Mexico, the occurrence of chronic degenerative diseases have overcome the incidence of infectious diseases. In general, the Mexican population has a high prevalence of chronic diseases and obesity: 18.4% of adults are currently diagnosed with hypertension and 10.3% diabetes. With respect to risk factors, 36.1% of the adult population is obese while 11.4% smokes [7].

Regarding the health system in Mexico, it is difficult and complex, not only in terms of the citizen's perception, but also for managers, health employees, doctors, nurses, specialists, and health workers [8]. Some regions are characterized by precarious medical service delivery, poor health infrastructure, and difficult access to healthcare [9,10]. Particularly, southern regions are characterized by a high prevalence of indigenous populations living in conditions of high marginality and economic inequality [10]. In such cases, networks are the main resource to deal with health-related issues, food, medicine, and out-of-the-pocket medical expenses [11,12].

In rural indigenous communities, health services are provided through a basic structure of "health homes" which are managed by a member of the community who has been trained (a general practicioner or doctor) to care patients with mild illnesses such as the common cold, follow-up of pregnancies, non-severe respiratory and diarrheal infections. In more severe cases, patients are referred to the nearest (or geographically reachable) public clinic or hospital. The service hours in the health homes are 4-hours a day, adapted to the needs of the communities and support in case of emergencies. The Ministry of Health provides these facilities with healing material, office and medication codes. The information of the activities carried out in these facilities is recorded and reported to the state authorities.

In emergency situations, the volunteering general doctors (who oversee the health homes) have the responsibility of referring patients to intensive care units located in these communities (i.e., clinics or hospitals). It is important to mention that not all rural and indigenous communities have healthcare units and there is an absence of mobile phone or internet signal. This leads to inefficient communication between doctors in the different healthcare facilities to make a proper referral of the patients.

Regarding clinics, these facilities have a basic infrastructure of furniture, equipment, instruments, medicines and biological products. This affects the diagnosis of the doctors, as sometimes they must perform assessments of patients with chronic complications with basic instruments such as sphygmomanometers and stethoscope. The operative team frequently consists of a general practitioner, an intern, a director, and two nursing assistants. The services which are provided are outpatient general medicine, preventive medicine, and emergency care. Also, they promote the following programs: vaccination, care of chronic degenerative diseases, epidemiological surveillance, child malnutrition, prenatal control and sexual education. General medical consultation is provided from Monday to Friday within the schedule of 8 a.m. to 4 p.m. However, emergencies can be referred 24-hours a day.

Because health service demand is large, sometimes it cannot be covered by the personnel of the clinic. Thus, there are patients who must travel from their communities to other municipalities to receive the required medical attention. In example:

- patients living in the Tacuapan community must be referred to the Ixtepec hospital, which is located two hours away from the nearest Santiago Yancuitlalpan municipality.
- the municipality of Cuetzalan in Puebla has 18 medical units (1.5% of the total number of medical units in the state), 50 doctors (0.6% of the total number of doctors in the state) and the ratio of physicians per medical unit is 2.8, compared to the ratio of 7.5 in the state. This represents a low concentration of health professionals available for the attention of the population [13].

Mortality of patients who have been urgently transferred to these units has been associated with ineffective processes to contact ambulances and doctors, difficulties to reach the communities due to poor or null

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road infrastructure, absence of ambulances, and long distances between the clinics / hospitals and the communities. Within the aspect of transportation, most clinics have no ambulances, so patients must arrange private transportation. The mortality risks are more significant in communities without basic services (drinking water, electricity) or roads.

Hence, it is necessary to generate the necessary structure in the organization of the services at the following levels: general medicine consultations (first level, I); healthcare and disease prevention, nursing, and vaccinations (second level, II); and highly complex medical procedures such as surgeries which require advanced technology and specialized equipment (third level, III). Here it is important to mention that patients referred from levels I and II frequently present pathologies that require attention of high diagnostic and treatment complexity, however, these have minimum coverage.

3 Design methodology

The present research work analysed and evaluated the healthcare units that provide coverage to 501 rural and indigenous communities in the municipality of Zacapoaxtla in the Mexican state of Puebla. As presented in Figure 1, this municipality is located within the northern region of Puebla, with parallel geographical coordinates between 19º44'18” and 19º59'18” north latitude, and meridians between 97º31'42” and 97º37'54” west longitude [14,15]. Figure 2 presents an overview of the methodological stages considered to design the healthcare network.

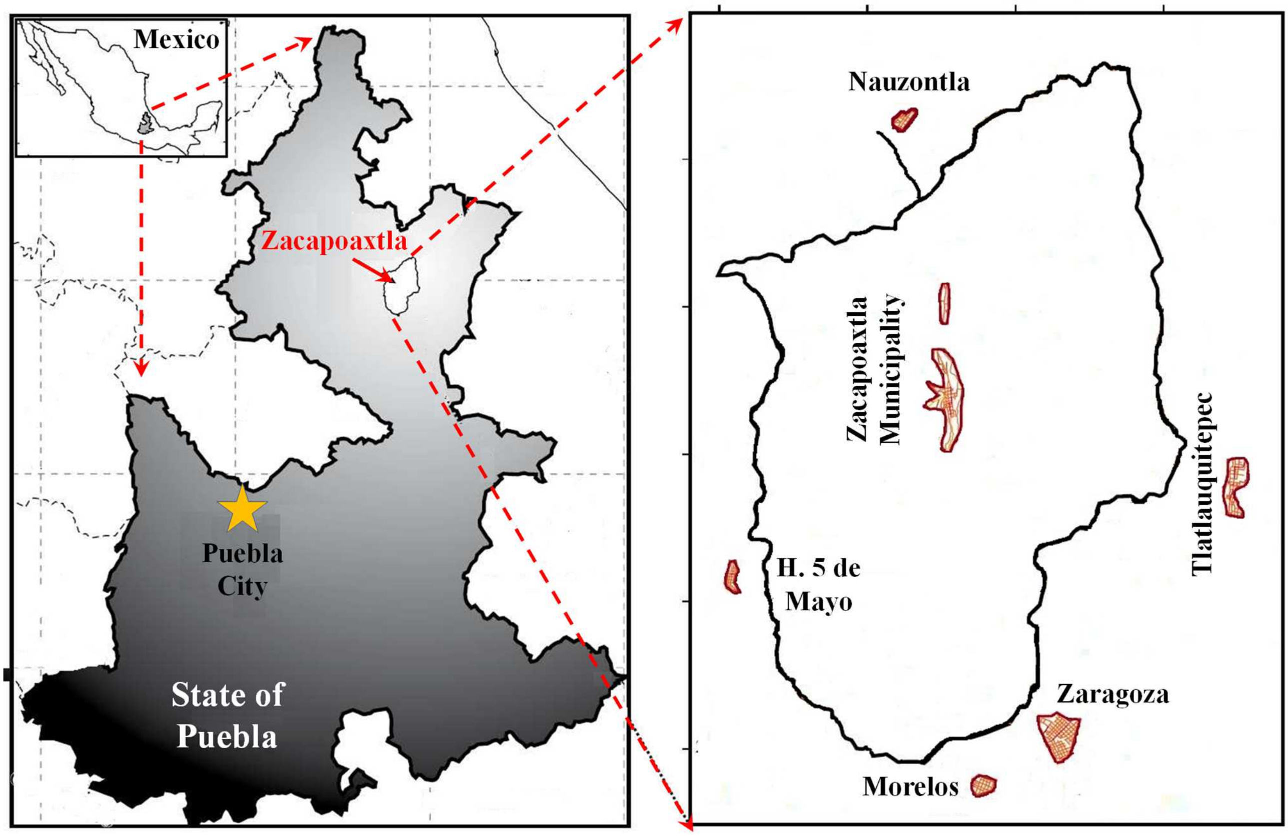

Figure 1 Geographical location of the Municipality of Zacapoaxtla (adapted from [15])

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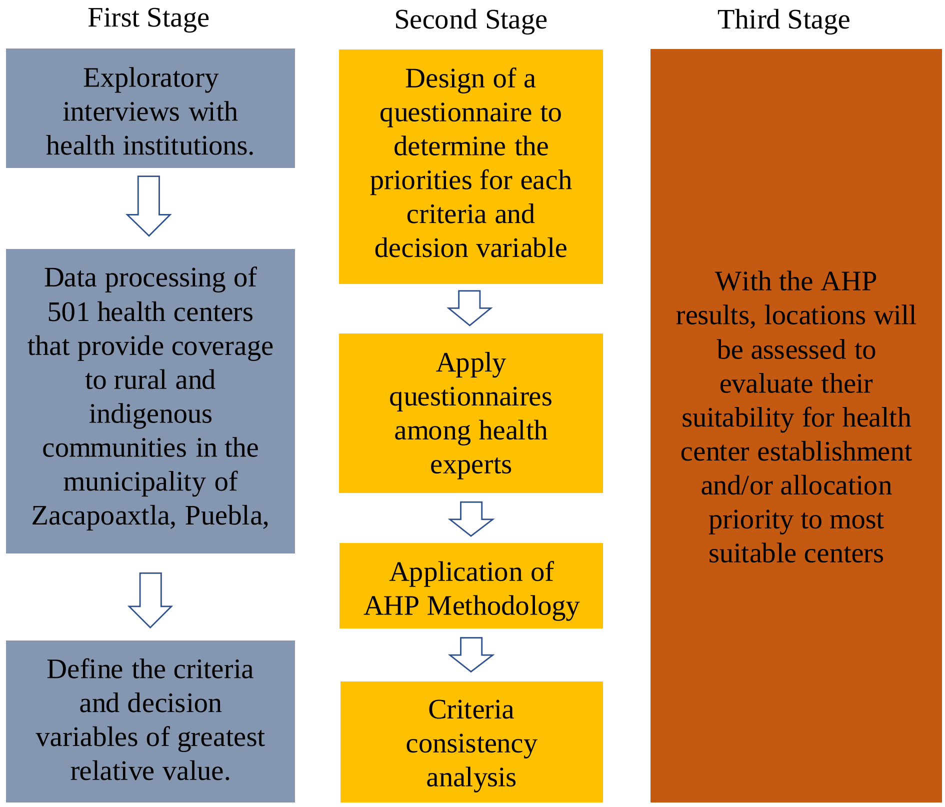

Figure 2 General structure of the methodology for design the health service network for rural communities in Zacapoaxtla

3.1 First stage: criteria for community eligibility and facility infrastructure

In this stage, exploratory interviews were performed with directors and doctors who work in health institutions that provide services in some indigenous and rural communities. The interviews were designed to determine the most important criteria to evaluate the eligibility of each location for the establishment of a new healthcare facility, or improving an already existing facility. These criteria were the following:

- Number of inhabitants: communities with low population density had limited or non-existent basic healthcare services.
- Geographic accessibility: the geographic locations of the communities represent physical barriers for patient mobility and access to appropriate healthcare facilities.
- Available Infrastructure: the existing healthcare facilities are a major factor in healthcare service quality. It is also important for elimination and upgrading plans. In this context, the following facilities were identified:
  - Health Homes: these are small spaces or rooms which are frequently loaned by families within their home premises to provide intermittent basic care (i.e., general consultation, application of seasonal vaccines, general monitoring of glucose / blood pressure, informative health recommendations, etc.). One doctor and one nurse are the main health personnel at these premises.
  - Regional Clinic: these are medium-sized premises with limited beds and rooms. These are managed by the Ministry of Health and are frequently located near the local government house. These clinics are mainly used for stabilization care, and they are assisted by three-to-six doctors and nurses.
  - Hospitals: these are medium and large-sized facilities where complex procedures such as surgeries can be performed. There are doctors with different specializations and equipment. These facilities are assisted by 10 to 15 doctors and nurses.

3.2 Second stage: assessment of community eligibility

In this stage, the Analytic Hierarchy Process (AHP) decision-making model was applied to assess the location of each community to determine its suitability to establish a healthcare facility. For this purpose, the criteria defined in the previous section were considered.

AHP is an analytical method where quantifiable and non-quantifiable data can be analysed to support decision making [16]. This is important because experience and knowledge mixed with data are the basis to make appropriate decisions [17]. This tool was developed by Thomas Saaty and it is performed in two steps [16]:

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- A hierarchical structure is designed to associate criteria with alternatives.
- The assessment of each identified criterion with each alternative is computed as a comprehensive metric. This is performed through comparison of pairs (criterion vs. criterion, alternative vs. alternative for each criterion). In this regard, the Saaty scale (see Table 1) provides a metric (score) to prioritize and weight the importance or contribution of one element over another.

Table 1 9-point Saaty scale for paired comparisons

Numerical Scale	Verbal Scale	Explanation
1	Equal importance	Both elements contribute equally to the property or criterion
3	Moderately more important one element than the other	Judgment and previous experience favor one element over the other.
5	Strongly more important one element than the other	Judgment and prior experience strongly favor one element over the other.
7	The importance of one element is much stronger than the other	One element dominates strongly. Its dominance is proven in practice.
9	Extreme importance of one element over the other	One element dominates the other with the largest possible order of magnitude.
2,4,6,8	Intermediate decision values	They are intermediate decision values

The importance of the AHP methodology is in the determination of relative weights to qualify the alternatives. If there are n criteria in some specific hierarchy, the AHP establishes a $n \times n$ pairwise comparison matrix A, which measures the decision maker's judgment of importance concerning each criterion. The pairwise comparison is performed such that the criterion in row i ($i = 1, 2, 3, \ldots, n$) is scored against each alternate criterion. If $a_{ij} = 1$ it represents that i and j have equal importance for the expert. Then $a_{ij} = 9$ indicates that i is extremely more important than j (in contrast, $a_{ji} = 1/9$). Note that the matrices have to fulfill a series of features:

- Reciprocity: if $a_{ij} = x$, then $a_{ji} = 1/x$, with $1/9 \leq x \leq 9$.
- Homogeneity: if the elements i and j are considered equally important, then $a_{ij} = a_{ji} = 1$.
- Consistency: it is satisfied that $a_{ik} + a_{kj} = a_{ij}$ for all $1 \leq i, j, k \leq q$.

Figure 3 presents the AHP structure considered for this work. Note that the 501 locations represent the alternatives to be assessed based on the following criteria: number of inhabitants, geographic accessibility, and infrastructure for healthcare facilities. Then, Table 2 presents the type of questions established when assigning the Saaty weights for the comparison of importance between all criteria. In other words, this instrument seeks to prioritize the factors that influence healthcare services and determine the relative weight between them, for each of the different alternatives.

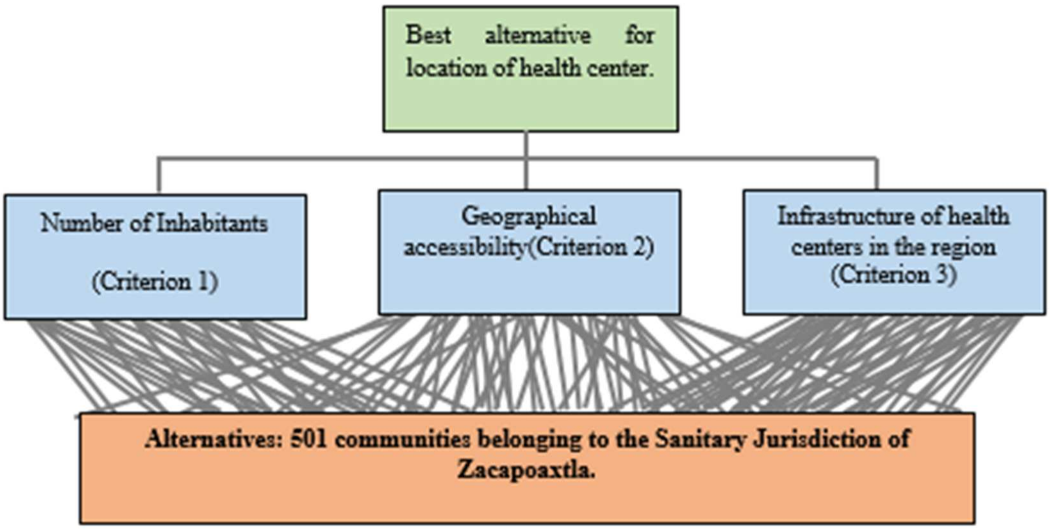

Figure 3 AHP hierarchical structure

It is important to mention that validation of the Saaty weights was performed with 15 experts (directors and doctors who have worked in healthcare institutions in rural communities). Each expert was asked individually to make an estimate of the Saaty score for each question. A group meeting was not required to avoid biases caused by group interaction.

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Table 2 Questions to weight importance scores between criteria

Questions	Moderately important	Strongly more important	Much stronger the importance	Extreme importance
For the location of a health center in a rural community, how important is the total number of inhabitants with respect to geographic accessibility?	3	5	7	9
For the location of a health center in a rural community, how important is the total number of inhabitants with respect to the healthcare infrastructure?	3	5	7	9
For the location of a health center in a rural community, how important is geographic accessibility with respect to healthcare infrastructure?	3	5	7	9

Table 3 presents the comparison matrix for all criteria and the final composite score. As shown, the number of inhabitants in the community is the most important criterion to establish a healthcare facility.

Table 3 Weighted scores for each criterion

	# Inhabitants	*Geo Accesibility*	*Infrastructure*	*Score*
# Inhabitants	1	9	3	**0.66394895**
Geo Accesibility	1/9	1	3	**0.20075623**
Infrastructure	1/3	1/3	1	**0.13529481**

Then, as presented in Figure 3, for each criterion all alternatives (communities) were compared with each other. By integrating these comparisons with the criterion score, a final *AHP Score* was computed for each community. Note that this metric represents how a community complies with the eligibility criteria for the establishment of a healthcare facility. Hence, large values involve better infrastructure and geographic accessibility. In contrast, small values involve poor or null infrastructure and difficult geographic accessibility.

The *AHP Score* is proposed as a *vulnerability index* to support the decision regarding the type of facility to be established in the community. Here, communities which small values have higher vulnerability for the establishment of a facility. Although this would represent a barrier for the establishment of large facilities such as a clinic or hospital, it provides the analysis to support the need for improved road infrastructure.

3.3 Third stage: eligible communities for each facility type

From the *AHP Scores* estimated for all locations, the average (μ) and standard deviation (σ) values were computed. As presented in Figure 4, if considering μ as the cut-off point to establish a healthcare facility, approximately 50% were suitable locations.

Then, μ and σ were used as metrics to define statistical intervals to establish the most appropritate location for each type of facility. These intervals were considered as *facility service indexes* which, as presented in Figure 4, were set at $[\mu \rightarrow \mu + \sigma]$, $[\mu + \sigma \rightarrow \mu + 2\sigma]$ and $[\mu + 2\sigma \rightarrow \mu + 3\sigma]$ for Health Homes, Clinics, and Hospitals respectively.

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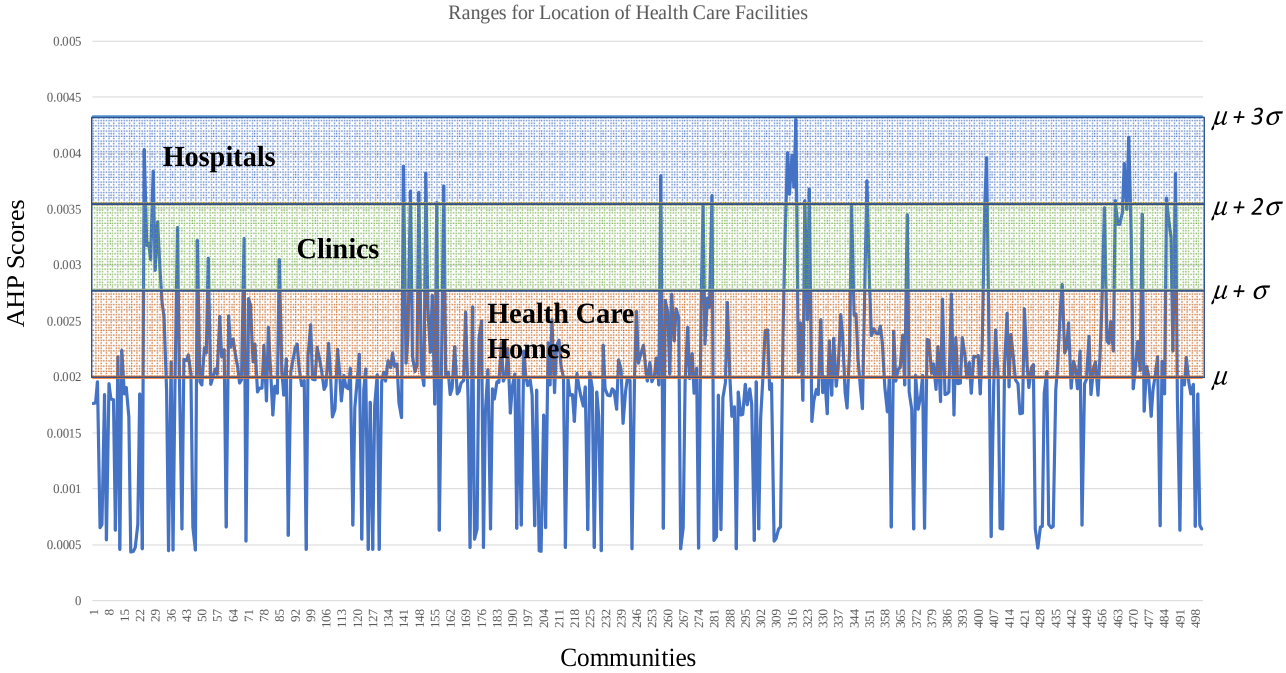

Figure 4 AHP scores and intervals to define eligible locations for each type of healthcare facility

4 Analysis of results

Table 4, Table 5, and Table 6 present the details of the communities eligible for health homes, clinics and hospitals within the region of Zacapoaxtla. There are 165,728 inhabitants through all communities, and according to Table 4, there are 77,459 inhabitants (46%) in the 198 communities which are eligible for equipped health homes. Then, according to Table 5, there are 22,575 inhabitants (14%) in the 28 communities which are eligible for equipped clinics. Finally, according to Table 6, there are 33,491 inhabitants (20%) in the 24 communities which are eligible for hospitals. The remaining inhabitants (20% within the communities with scores lower than μ) must be served by the closest health homes, clinics or hospitals which are located in the eligible communities.

Figure 5 presents all communities, marking those eligible for each type of healthcare facility. Note that there are three communities which are located far away from the cluster of communities. According to the AHP analysis, these were scored within the first interval, thus, they are candidates for the establishment of health homes which can transfer patients to the communities with clinics or hospitals.

In contrast, there are two locations which are not suitable for the establishment of any healthcare facility. However, these are located closer to the cluster of communities, and thus, to healthcare facilities. Within the main cluster of communities and municipalities, a homogeneous distribution of non-eligible locations with candidate locations for healthcare facilities is observed. Thus, a suitable allocation between all communities and healthcare facilities can be performed.

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Table 4 Communities suitable for allocation or improvement of health homes

#	Community	Population	#	Community	Population	#	Community	Population
1	TIERRA NUEVA	321	67	BARRIO ALTO	394	133	TAMALAYO	499
2	EJIDO PALO GACHO	360	68	AMATETEL	617	134	TANHUISCO DEL C.	475
3	EL CARMEN	271	69	ATEHUETZIN	647	135	TEHUAGCO	473
4	ANIMAZCO	185	70	COL. MORELOS	435	136	TEPANZOL	522
5	CUAUHTEMOC	296	71	CONTA	562	137	TEPEHICAN	420
6	URUAPAN	210	72	CUAXOCOTA	250	138	ATALPA	485
7	LA LAGUNILLA	310	73	LIMONTITAN CHICO	417	139	IXMATLACO	396
8	SAN FCO. ATECACALAX	304	74	LOMAS DE ARENA	289	140	TEZIUTANAPA	266
9	COPALES	334	75	LLAGOSTERA	380	141	ACOCOGTA	462
10	LA UNION	219	76	MECATEPETL	224	142	S.A CHAGCHALTZIN	354
11	ACAXILOCO	382	77	EJIDO HUEYTAMALCO	430	143	TUNEL II	217
12	ALAHUACAPAN YANCTL.	350	78	PALMAGTITAN	214	144	XALTENANGO	429
13	EQUIMITA XOCOYOLO	255	79	TACOTALPA	415	145	BUENA VISTA	427
14	LA GALERA XOCOYOLO	224	80	TEPACTIPAN	571	146	CANAL	228
15	IXTAHUATA CUETZ.	594	81	TETEYAHUALCO	395	147	XALTETA	288
16	LIMONCO	319	82	TILAPA	427	148	PABLOGCO	392
17	PAHPATAPAN	362	83	TLACUILOLAPAN	349	149	ATIOYAN	729
18	TACUAPAN YANCTL.	597	84	SOLORZANO	230	150	TOZANCO	770
19	TAXIPEHUAL CUETZ.	390	85	COLONIA LA VIRGEN	302	151	HUITZILTEPEC	438
20	TENEXTEPEC+ MONTE ALTO	432	86	PAPALOAPAN (HUEYTAMALCO)	399	152	REYES DE VALLARTA	522
21	TEPANGO ZACAT.	351	87	EL CRUCERO	305	153	RICARDO FLORES MAGON	331
22	TEPETITAN ZACAT.	271	88	LA CRUZ DE CHACA	249	154	EL TUTI	295
23	XALPANZINGO TZICUIL.	732	89	LA TRANCA + CATINIX	209	155	ALTO LUCERO	405
24	XALTIPAN TZINACAPAN	673	90	CHAGCHALOYAN DE Z.	282	156	CHAPAS	319
25	XOCOYOLO	296	91	S.A. TLALZINTAN	623	157	BARRIO CHIQUITO	327
26	ZOQUITA TZICUIL.	409	92	SAN MIGUEL ACATENO	292	158	S.A. COYOTITLAN	365
27	TENANGO TZICUIL.	397	93	XINACHAPA DE A.	421	159	AGUAJE ATOLUCA	351
28	XOCHICAL	501	94	SAN JOSE ACOTZOTA	473	160	LA PALMA (XIUTETELCO)	493
29	CAXALTEPEC	245	95	PARAISO	278	161	LA REFORMA (XIUTETELCO)	287
30	PESMAPAN ZACATIPAN	313	96	CHAGCHALOYAN DE I.B.	295	162	VISTA HERMOSA	280
31	QUEZAPAN ZACATIPAN	240	97	COSOLTEPEC	215	163	ZAPOTE	611
32	CHICUEYACO TZINACAPAN	368	98	PEZMATA + PAPALOCONTITAN	316	164	LA CANTERA	470
33	TUZAMAPAN XILOXOCH.	450	99	SAN MARTIN	728	165	LA POSTA	313
34	XIUTECUAPAN XILOXOCH.	407	100	ESCATACHUCHUT	616	166	CRUZ VERDE	635
35	CACATECUHUTA XILOX.	258	101	CAXTAMUSIN	221	167	ATZALAN	292
36	COSAMALOMILA	327	102	PATY	879	168	LA MANZANILLA	262
37	TECOLTEPEC TZINAC.	534	103	TAKALZAPS	498	169	YAUTETELCO	284
38	SANTIOPAN YOHUALICH	391	104	ECATLAN	738	170	CUAUTAMANIS	242
39	CAPOLA YANCTL.	312	105	TECPANZINGO	583	171	AMATITAN	279
40	TATAHUITALTIPAN	245	106	SAN RAFAEL AXOLOTLA	503	172	HUAPALEGCAN	628
41	REYES HOGPAN DE HGO.	482	107	TEPANYEHUAL	345	173	OCOTEPEC DE C.	351
42	CUAMONO CUETZ.	221	108	LA UNION ATIOYAN	257	174	TZONTECOMATA	386
43	LIMONTITA ZACATIPAN	370	109	BIBIANO HERNANDEZ	672	175	XALTIPAC	551
44	TECUAHUTA ZACATIP.	243	110	IGNACIO ZARAGOZA	407	176	CHICUACENCUAUTLA	300
45	LAS HAMACAS ZACATIPAN	217	111	KUYUMCHUCHUT	733	177	XOCOYOLAPAN	250
46	CUAUTAMANCA	258	112	SANTA CATARINA	641	178	AHUATA	358
47	CAHUAYOLCO TZICUILAN	338	113	LA LIMA	704	179	TATEMPAN	453
48	ATEMOLOJ CUETZ.	253	114	JUNTA ARROYO ZARCO	302	180	ATEMEYA	258
49	TIXAPANTENO	218	115	COACALCO	490	181	TEPANTILOYAN	297
50	TALCUILOL CUETZ.	236	116	TEXCALACO	491	182	CALCAHUALCO	317
51	ZOQUIACO	304	117	COYOPOL	481	183	CUACUILCO PB	639
52	TENANIKAN	269	118	LOMA BONITA	238	184	GONZALO BAUTISTA	424
53	XILCUAUTA	351	119	SAN M. CAPULINES	546	185	IXTACAPAN	413
54	CUATRO CAMINOS	275	120	MAXTACO	573	186	JILOTEPEC (ZACAPOAXTLA)	555
55	ZILTEPEC	288	121	EL FRESNILLO	573	187	NEXPANATENO	357
56	LA AGUARDIENTERA	292	122	ACAMALOTA	211	188	COL. INDEPENDENCIA	240
57	LOS PARAJES	445	123	AJOCOTZINGO	495	189	COHUATZALPAN	423
58	ASERRADEROS	324	124	CALATEPEC	437	190	COL. INSURGENTES	248
59	COATZALAN + TLATZINTAN	307	125	CUACUALAXTLA	252	191	SAN CARLOS	276
60	TENEXTEPEC	278	126	CUAUTLAMINGO	603	192	MORAGCO	217
61	CUAPALTEPEC	313	127	CHICUACO	461	193	OCTIMAXAL 1º SECCION	235
62	PUTAXCAT	767	128	ELOXOCHITAN	374	194	NEXPAN (ZACAPOAXTLA)	321
63	CHILOCOYO GPE.	426	129	HUAXTLA	602	195	XICOTENCATL 4A. SECCIÓN	298
64	KUWIC-CHUCHUT(S.F.I.M.)	767	130	EL CARMEN ILITA	608	196	SN. JOSE BUENA VISTA	358
65	TETELILLA COPLADE	290	131	JILIAPAN	313	197	XALEHUALA	211
66	PASO REAL	237	132	EL PROGRESO	461	198	AMATLAN	317

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Table 5 Communities suitable for allocation or improvement of clinics

#	Community	Population
1	SAN AMBROSIO = LAS CANOAS	631
2	SAN NICOLAS	751
3	TEZOMPAN	544
4	EL CUATRO	468
5	LAS DELICIAS	855
6	HUEXOTENO	520
7	GACHUPINATE (RANCHO N.)	798
8	RANCHO NUEVO	679
9	CUAHUTAPANALOYAN	551
10	XALCUAUATLA REYES H.	703
11	XALTZINTA ZACATIPAN	543
12	CHIPAHUATLAN	996
13	HUEHUEYMICO	891
14	GOMEZ ORIENTE	1008
15	OCOTA	921
16	PLAN DE GUADALUPE	875
17	ILITA	916
18	SAN ISIDRO	1181
19	PAHUATA	871
20	FCO. I. MADERO	971
21	PROGRESO	839
22	TALZECUALA	839
23	TEZOCOYOHUAC	921
24	XALTIPAC	948
25	H. 5 DE MAYO	719
26	XILITA	918
27	ACUACO	887
28	LAS TRANCAS E.E.C	831
		22575

Table 6 Communities suitable for allocation or improvement of hospitals

#	Community	Population
1	CALA NORTE	1677
2	TANHUISCO	1367
3	YOPI	1478
4	ANALCO	1137
5	TEPEPAN	1131
6	LIPUNTAHUACA	1515
7	AHUATEPEC (HUEYAPAN)	1037
8	NEXPAN	1164
9	IGNACIO ALLENDE	1324
10	PUMACACHOCOCHUCHUT	1114
11	IXTICPAN	1647
12	IXTLAHUACAN	1117
13	SAN DIEGO	1629
14	SAN JUAN TEZONGO	1151
15	XOLOATENO	2899
16	CUAXOSPAN	1066
17	SECCION 23	1147
18	PEZMATLAN	1221
19	SANTIAGO	1617
20	NEXTICAPAN	1066
21	XALTETELA	1514
22	SAN FRANCISCO ZACAPEXPAN	2044
23	NANACATLAN	1072
24	MORELOS (ZARAGOZA)	1357
		33491

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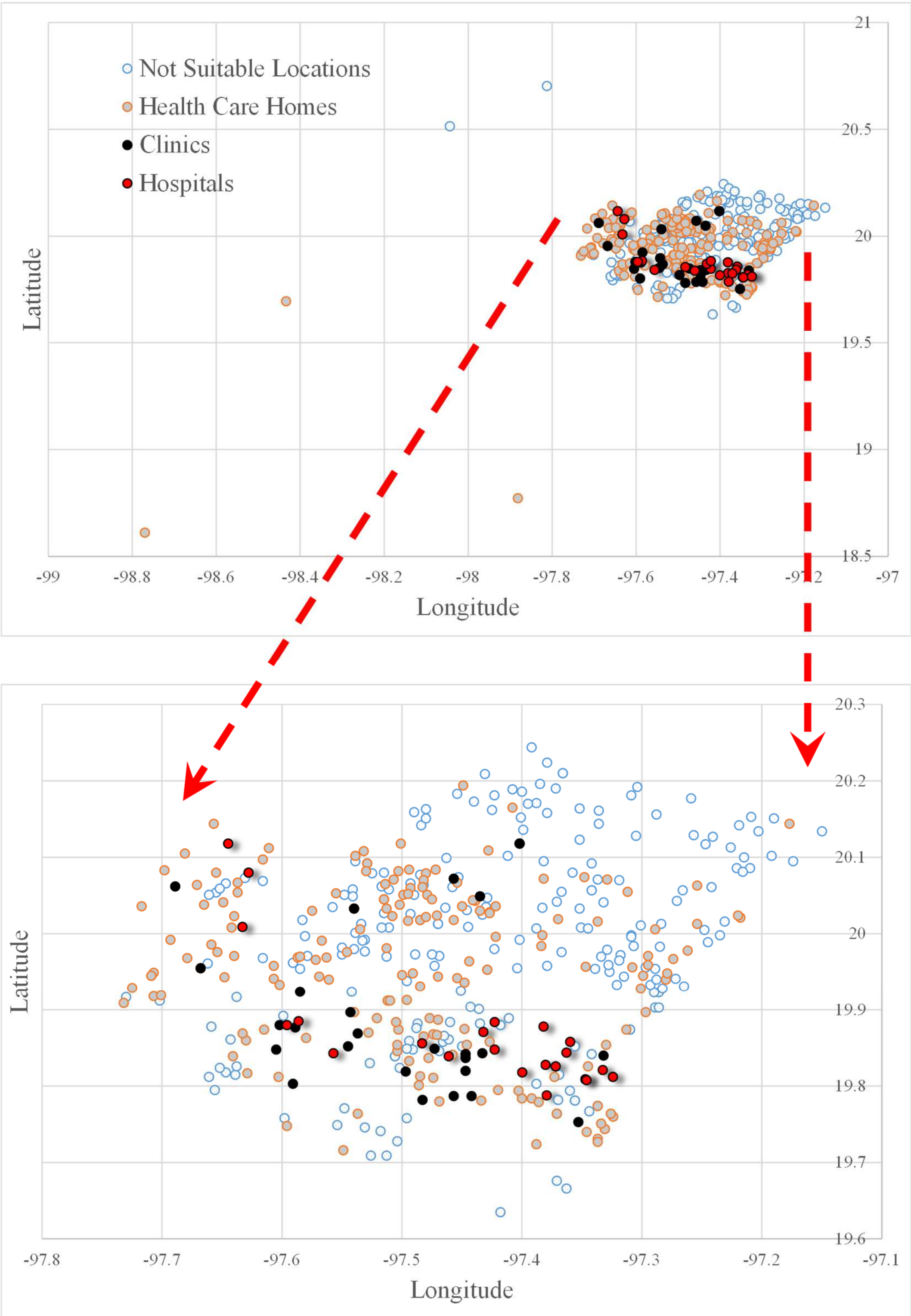

Figure 5 Geographical visualization of non-eligible locations, and locations suitable for improvement or establishment of health homes, clinics, and hospitals

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Once the locations were identified, a suitable allocation of communities to healthcare facilities must be performed to make appropriate medical referrals. For this, it is expected that policies regarding optimal criteria to establish the medical needs are developed by the Ministry of Health. Figure 6 presents the hierarchical referral scheme between all communities and healthcare facilities. Note that, as equality is sought with this scheme, communities in non-eligible locations can be referred directly to health homes (NSL-HCH), clinics (NSL-C) and hospitals (NSL-H). Then, patients in communities with health homes can be referred directly to locations with clinics (HCH-C) and hospitals (HCH-H). Finally, patients in communities with clinics can be referred directly to hospitals (C-H).

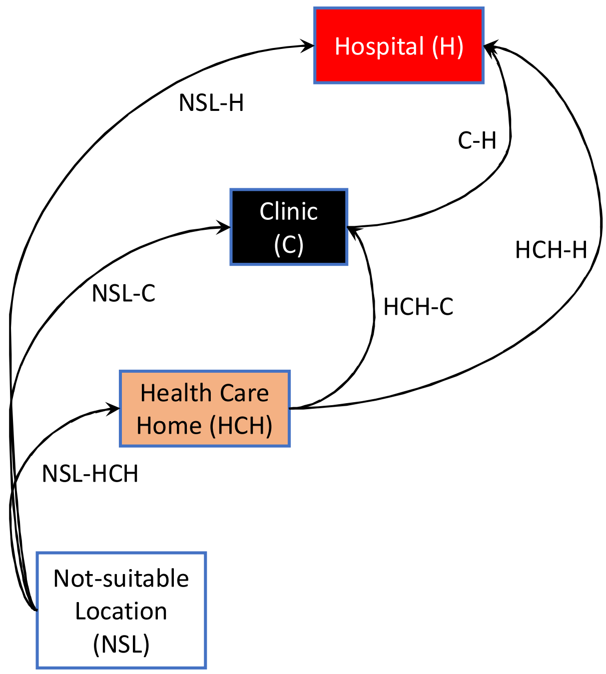

Figure 6 Hierarchical referral decision model for the health service network

Figure 7 presents the allocations of patients in non-eligible locations to facilities in locations with (a) health homes, (b) clinics, and (c) hospitals. This allocation was performed considering the minimum geographical distance metric [18]:

$$d_{AB} = R \times Arcos(sin\varphi_A sin\varphi_B + cos\varphi_A cos\varphi_B \cos(\lambda_A - \lambda_B)). \quad (1)$$

In (1), the distance (arc length) between two locations (A and B) is computed from their latitude coordinates (φ_A and φ_B) and longitude coordinates (λ_A and λ_B). R is the Earths radius which is approximately equal to 6371 km.

Figure 8 presents the allocations of patients in locations with health homes to facilities in locations with (a) clinics, and (b) hospitals. Then, Figure 9 presents the allocations of patients in locations with clinics to facilities in locations with hospitals. These results are important because they contribute to determine an optimal number of required facilities. In example, if considering the minimum distance criterion, there are 10 locations for hospitals which would serve only its community. In such case, resources can be optimized to increase the infrastructure of other hospitals in the network and reduce the number of facilities.

Specifically, cluster W involves three locations for hospitals which would serve five locations with clinics. Due to economical restrictions, and geographic proximity, a single hospital could be established to serve all allocated clinics. The same can be performed for cluster X which involves two locations for hospitals (which are very close) and five clinics. Note that due to geographic proximity, and optimization of resources, all these facilities could be replaced by a single clinic or hospital. This reasoning can be applied to clusters Y and Z. Specifically for cluster Z, there are more candidate locations for hospitals than for clinics (10 vs. 2 respectively). If considering its proximity to cluster Y, cluster Z could be eliminated from the selection process and allocate all communities within it to the health facilities in cluster Y. These are the kind of decisions which can be performed with the results of the present work.

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(a)

(b)

(c)

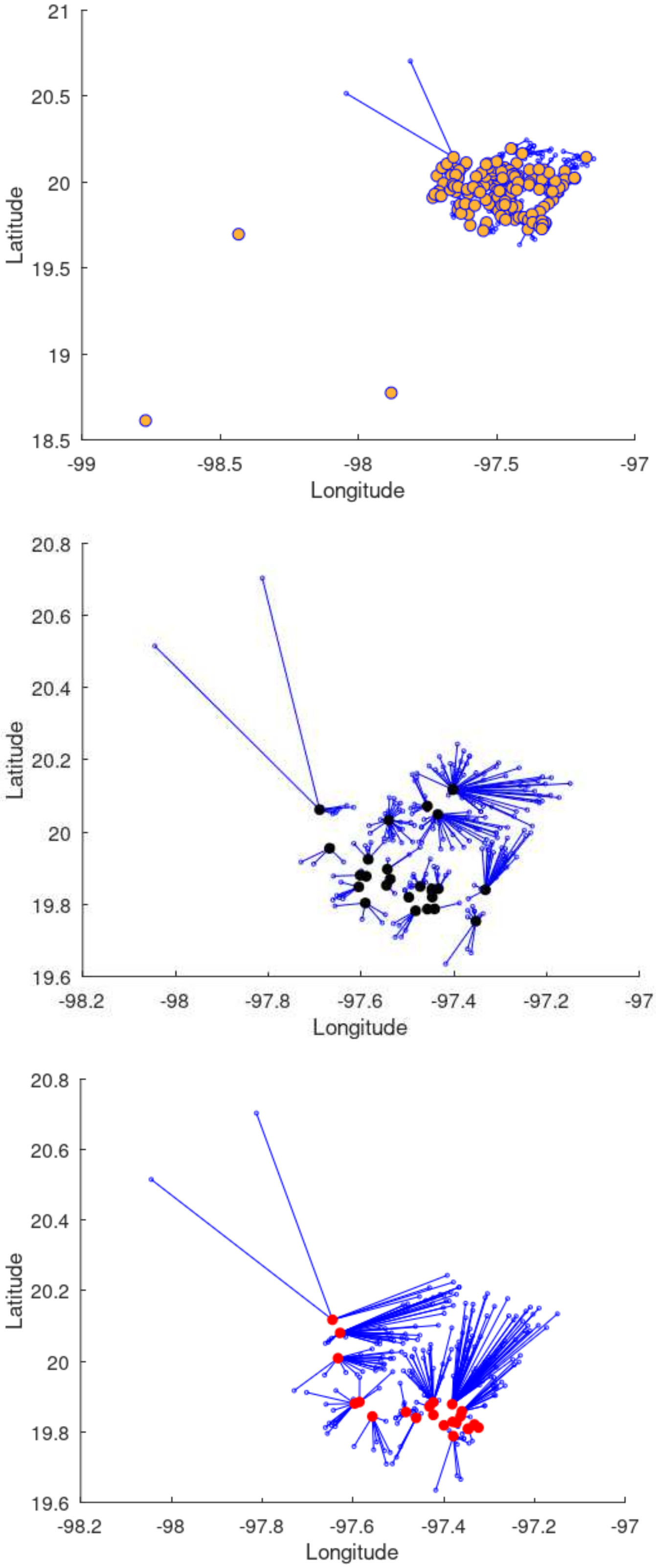

Figure 7 Allocations between (a) NSL-HCH, (b) NSL-C and (c) NSL-H

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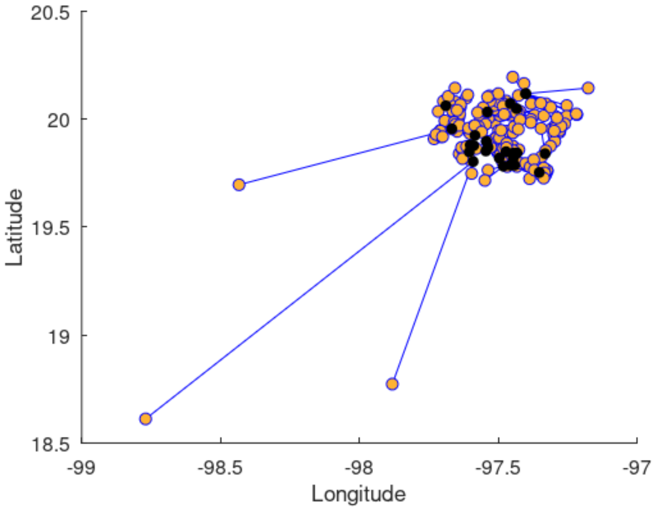
(a)



(b)

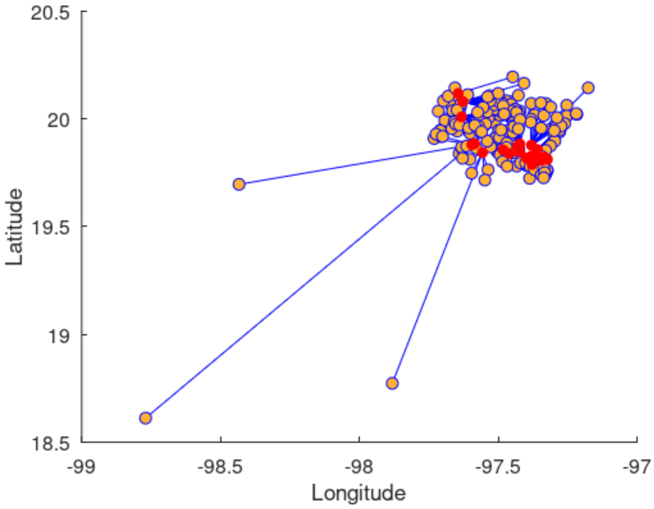


Figure 8 Allocations between (a) HCH-C, and (b) HCH-H

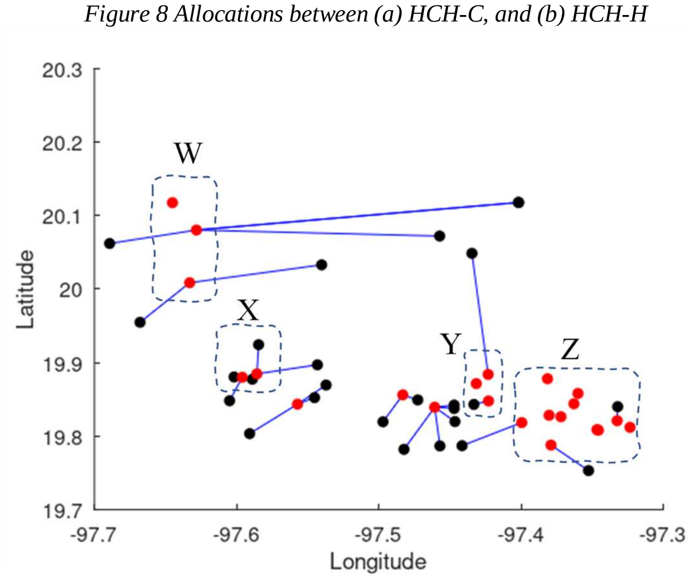


Figure 9 Allocations between clinics and hospitals (C-H)

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5 Conclusions and future work

It is important that the design of the health service network considers governmental policy development. As analysed in [19] policies are important to regulate informal community participation (interactions between health program supervisors and local authorities, and interactions between clinic doctors and villagers) as this has an impact on local health program implementation.

Although governmental economic resources for investment in infrastructure is limited, the present work provides a benchmark regarding the potential number of locations to improve or establish three types of healthcare facilities: healthcare homes, clinics, and hospitals. As presented in Figure 6 a hierarchical decision model, supported by appropriate referral policies and criteria, can be used to optimize the transport of patients throughout the network.

As presented in Figure 9, some locations for hospitals are geographically very close and would only serve its community. As economic resources are deemed crucial for governmental decisions, the present work contributes with the data to support specific decisions regarding the number of facilities of each type to be established within a certain region. This would also include other decisions involving capacities (number of beds, waiting rooms, surgery equipment, personnel profiles, etc.). Once these facilities are formally planned, an appropriate transportation network can be considered to connect them in a more efficient way. Thus, this could support the future planning for development of road infrastructure. In this context, a proposal based on the the capacitated vehicle routing problem (CVRP) can provide the routes and number of ambulances required to serve the communities within the network with the minimum time and distance.

Another opportunity to extend the present work is to gather information regarding the full services which can be provided at each facility. In example, although hospitals have the equipment to perform thoracic surgeries, the equipment is not suitable for brain surgeries. In such case, patients must be referred to top-level hospitals which are frequently located in large cities. The extended network must consider these cases.

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