Using GIS to Measure Physical Accessibility to Health Care

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Abstract

Public health and health care are important concerns for developing countries and access to health care is a significant factor that contributes to a healthy population. In response to these issues, the World Health Organization (WHO) has been working on the development of methods and models for measuring physical accessibility to health care using several layers of information integrated in a GIS. Two of these methods are presented and compared in relation to a particular public health problem in Central America. The results of these methods are used for cost effectiveness analysis, population coverage estimates as well as for resource planning within countries. The paper finally discusses the benefits for better health planning and policy development through the use of these methods before describing potential improvements to the models in the future.

1. Introduction

Access to health care is an important component of an overall health system and has a direct impact on the burden of disease that affects many countries in the developing world. Measuring accessibility to health care contributes to a wider understanding of the performance of health systems within and between countries which facilitates the development of evidence based health policies.

Accessibility to health care is concerned with the ability of a population to obtain a specified set of health care services, with the concept of "specific" having the potential to vary depending on the policy focus or impact of disease (Oliver & Mossialos 2004). Many factors affect a population's ability to access appropriate levels of health care. According to both Penchansky & Thomas (1981) and Oliver & Mossialos (2004) we can group these factors into three categories:

1. Availability
2. Acceptability & Affordability (Socio-economic)
    - Ethnicity, Religious
    - Gender, Age
    - Cost
3. Geography

Geographic accessibility often referred to as spatial or physical accessibility is concerned with the complex relationship between the spatial separation of the population and the supply of health care facilities and thus has a strong underlying geographic component. The concept can also be extended to incorporate different types of health intervention (Shengelia *et al* 2003). Although it is intuitive that the level of public health of a population may be affected negatively by the distance to health care services, there remains limited quantitative information regarding this impact (Guagliardo, 2004).

The use of Geographic Information Systems (GIS) for the measurement of physical accessibility is well established and has been applied in many areas including retail site analysis, transport, emergency service and health care planning. GIS are well suited to measuring spatial accessibility to health care as they contain the core components needed for such analysis namely:

- Data capture storage, management and manipulation tools for both spatial and attribute (textual) data
- Core analysis algorithms such as buffering, overlay, proximity analysis, shortest path and raster cost-distance analysis
- Programming environments to customize and extend existing algorithms and create new analysis tools
- Mapping and visualization tools to communicate the results of analysis

There is a large volume of literature relating to the use of GIS for measuring physical accessibility to health care and a number of publications review the various methods used including Wilkinson *et al* (1998), Albert *et al* (2000) and Cromley & McLafferty (2002). Several examples of applications of theses methods to different type of health care providers in developing and developed countries can be found in Bazemore *et al* (2003), Guagliardo (2004), Parker & Campbell (1998), Luo (2004), Noor *et al* (2003), Noor *et al* (2004), Mallick & Routray (2001) and Perry &Gesler (2000).

The World Health Organization (WHO) through both its Evidence and Information for Policy Cluster (EIP) located at the headquarters in Geneva and the Health Analysis and Information Systems (AIS) group at the Pan-American Health Organization (PAHO), located in Washington DC , which also operates as the WHO Regional Office for the Americas, have been involved in a number of initiatives to measure and analyze physical accessibility to health care using GIS. Within these initiatives, there has been a strong focus on providing countries with the necessary tools, guidelines and protocols that will allow them to perform reliable analysis of their capacity to provide physical access to specific health interventions.

Two methods for measuring physical accessibility to health care have emerged from these different initiatives. They are presented and compared in the context of their application to a specific case study area. Such a comparison provides an opportunity to review the relevance of this work for decision makers and investigate the potential for future model improvements and possible integration of approaches into a tool that would be beneficial for developing countries.

2. The Case Study area

Honduras' Ministry of Health, along with the Pan American Health Organization (PAHO) has undertaken a project to identify accessibility problems to primary health care (PHC) using GIS. The results of this project will provide information to assist the restructuring of health resources for disadvantaged populations in this country.

The Honduras health system is made up of public and private sub sectors with the public sector consisting of the *Ministry of Public Health* and the *Honduran Social Security Institute (IHSS)*, the *National Water Supply and Sewerage Service* and the *National Institute for the Prevention of Alcoholism, Drug Addiction and Drug Dependence*. In the review period, the estimated coverage for the Ministry of Public Health was 60%; Social Security covered between 10-12% and the private sector covered 10 % of the population. The Ministry of Public Health is organized into 9 health regions[1]. As the main provider of the services in the public sector, the Ministry of Public Health has more than 1272 health facilities distributed across the whole country. Among these there are 28 hospitals, however, modern technology and complex health care interventions are mainly concentrated in the six national hospitals with five of these in the capital. Of the 1272 health facilities throughout the country, 341 are Health Centers with a Physician and a Dentist (referred to by the Spanish acronym CESAMO) and 865 are Rural Health Centers (referred to by the Spanish acronym CESAR). The CESAR's are the partners in the Primary Health Care (PHC) of the CESAMOs, which have only nursing staff. The comparison presented here has been done using the location of these CESAMOs in one of the health regions of Honduras without taking the corresponding CESAR's into account.

Health Region 7, shown in Figure 1 was selected as the case study area due to the variety of land use, terrain and population characteristics in addition to the fact that it contains a relatively "closed health system" meaning that there is minimal movement of patients into or out of this region. 6.1% of the total of public health facilities in the country are located in health region 7, among which there are 27 CESAMO's, 24 of them with available physicians at the time of the survey. This case study builds on the work already undertaken by PAHO in identifying problems associated with accessibility to health care.

Figure 1: Location of the Case Study Area in Honduras (Health Region 7)

A number of input data sets were required to support the application of the two methods for the case study area. The data sets that have been compiled involve the following parameters:

- Population and Populated Places (Towns and Villages)
- Landcover
- Road Network
- Digital Elevation Model (DEM)
- Municipality Boundaries
- Health facilities location (CESAMOs)

In the context of this study, the river network has not been taken into account. It would usually be considered as a barrier to movement for the population accessing health care, whilst in some cases, it may also constitute a component of the transport network.

The two methods presented in the context of this paper utilize different formats of representation of the geographic information. The method implemented in SIGEpi© uses layers in vector format while AccessMod© is based on raster layers. Such differences necessitate the manipulation of some of the source data sets in order to convert them into a suitable format for their use within both methods. It is also important to mention that the application of AccessMod© requires that all the raster layers are based on the same resolution. For this particular case study a resolution of 30" (approximately 1km at the equator) has been chosen as this represents the highest resolution for some of the available layers necessary for the application of the method.

2.1 Population & Populated Places (Towns and Villages)

Population data can be derived from existing global data sets such as the Gridded Population of the World (GPW) data set[3] provided by Centre for International Earth Science Information Network (CIESIN) at Columbia University or the Landscan database[4] or may also come from country specific census data.

In the context of the case study area, population data at the locality level (populated place) was obtained from the 2001 population census[5]. The total population of Health Region 7 is 378,456 inhabitants. The distribution of this population is one of the data sets that needs to be stored in both raster and vector formats. A vector layer containing the location of populated places with the population attached is used for the SIGEpi© approach. In order to maximise the comparison of the two methods presented, it has been decided not to use a global data set but to convert the vector layer containing the location of the populated places, with the corresponding population figures to a raster grid to be used with AccessMod©. The population grid extracted from the landscan database[4] as well as the location of the populated places for the study area are shown in Figure 2a.

2.2 Landcover

The Landcover layer is used within AccessMod© as one of the input data sets for the generation of the travel time surface. For the case study area, the 1998 Landscan Land Cover Database[4] which is derived from the U.S. Geological Survey's (USGS) Global Land Cover Characteristics database[2] has been chosen. Some modification was made to this dataset as the classification used in the original grid was too detailed. The final grid is reclassified into 6 classes as presented in Table 1 and is further manipulated by integrating built up areas which were digitized manually using Landsat satellite images[6].

Land cover simplified used in this study	Class
Water	1
Urban and built-up area	2
Low dense vegetation	3
Fairly dense vegetation	4
Dense vegetation	5
Bare soil	6

Table 1: Landcover Classification

2.3 Road Network

Road network data in vector format is derived from data supplied by Geographic National Institute of Honduras (IGN)[7]**.** The original layer classified roads into 6 categories which were reduced to 3 to reflect the nature of the maximum speed that vehicles can reach. Table 2 outlines the road classifications used in this study. The quality of the road network data was assessed by comparison with satellite data. This comparison showed the road network data to be incomplete for this area. Additional road network data from the Global Insight database[8] as well as manually digitized roads based on satellite data were integrated in order to supplement the initial data set. At the completion of this process the road network data set was converted to a raster layer in order to be integrated into the land cover grid at a later stage in the process. The results of the overlay of the road network on the Landcover grid are shown in Figure 2b.

Roads type used in this analysis	Class
Primary roads	7
Secondary roads	8
Rodera	9

Table 2: Road Classification

2.4 Digital Elevation Model (DEM)

The use of a Digital Elevation Model (DEM) allows the inclusion of slope as one of the parameters that affects traveling time to the nearest health facility. The DEM used (Figure 2c) has been derived from the USGS GEOTOP30 dataset, tile W100N40[9]. The DEM has been aggregated to obtain a grid resolution of 30''. Slope has been derived from this DEM using the ArcView© Spatial Analyst slope function.

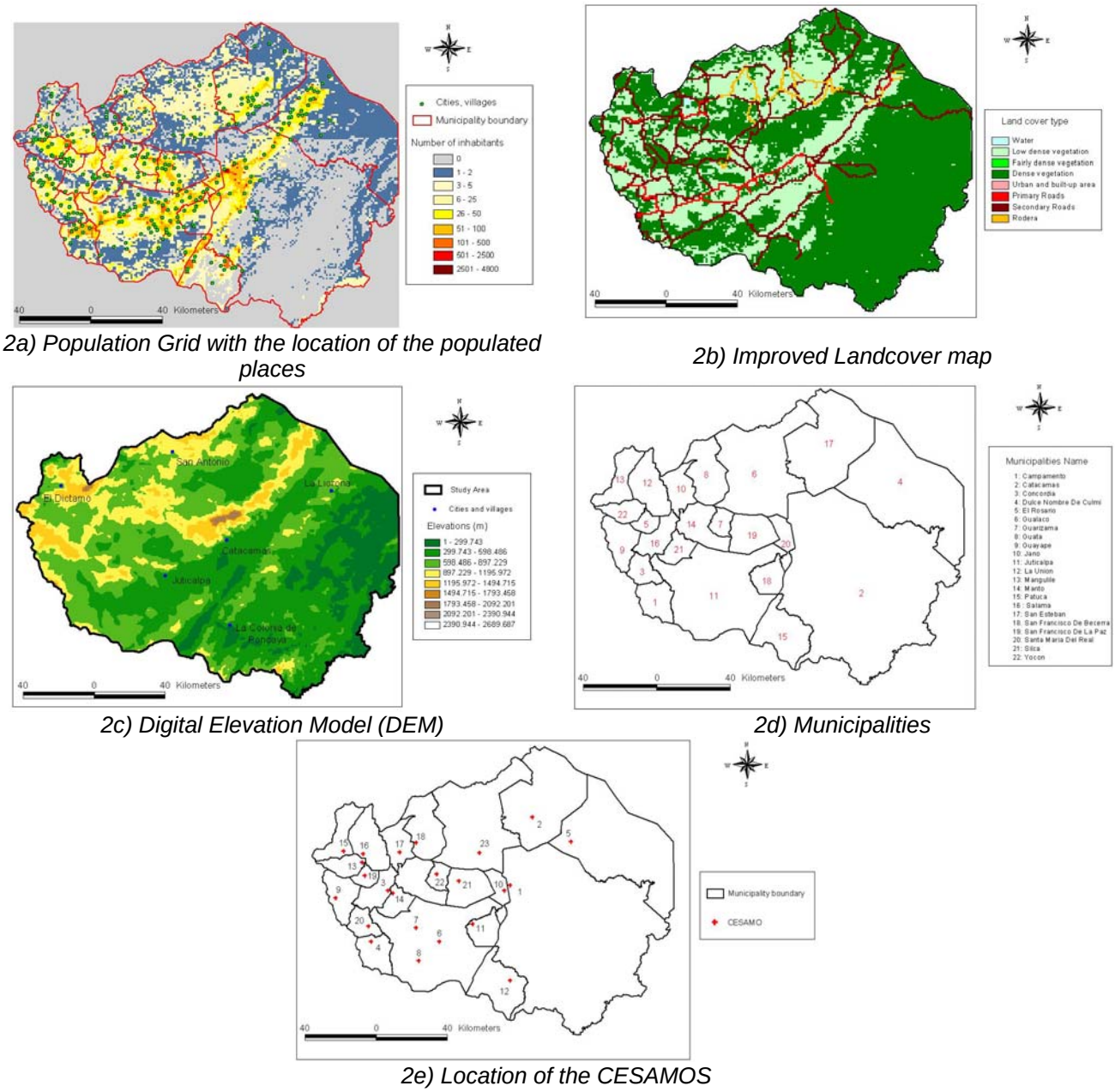
2.5 Administrative Boundaries

For data representation and the performance of some analysis, a layer delineating the municipal boundaries of the Health region 7 has been used. This layer has been obtained from the Geographic National Institute of Honduras (IGN)[10]. Village locations were overlaid with the administrative boundaries to identify errors in municipal boundaries and these have been corrected using various sources of information. The extent and name of these municipalities are shown in Figure 2d. This layer has also been used in order to adjust the population grid that is presented in Figure 2a to the municipality level population figures coming from the census.

2.6 Health Facility Location (CESAMOs)

Health facility data can come from various sources including the Ministry of Health, census data or field based health facility surveys. In the case of Honduras, health facility data was obtained from the health facilities national survey developed by the Ministry of Health's Information System for health facilities Regulation (Sistema de Información para Regulación de Establecimientos de Salud, SIRES) [11].

The location of the CESAMO's for the case study area are presented in Figure 2e. The number attached to each of them correspond to a code that is used later when presenting the results of the analysis. The number of doctors in each of these CESAMO can be found in table 7.



2a) Population Grid with the location of the populated places

2b) Improved Landcover map

2c) Digital Elevation Model (DEM)

2d) Municipalities

2e) Location of the CESAMOS

Figure 2: Input Data Sets for the Case Study Area

The different layers of information that have been presented in this section have been complemented by tabular data that will be described in the context of the presentation of the two models in the following sections.

3. Measuring Physical Accessibility using SIGEpi©

The objective of the Health Analysis and Information Systems Area's (AIS) project on Geographic Information Systems in Epidemiology and Public Health (SIGEPI)[12] is to contribute to the strengthening of health workers capacity in epidemiological analysis by providing them with efficient tools integrated in a GIS. These computerized tools help to develop health situation analysis, monitoring, and evaluation of the effectiveness of health interventions required for decision-making and planning in health. In order to achieve the objectives of the AIS project, several SIGEPI applications have been developed for various areas of health in addition to the provision of training materials, courses, workshops and the establishment of a network of users (OPS, 2002). The SIGEPI concept involves the design, development, and use of GIS tools and their application in a number of areas of health including the description of the existing health situation, epidemiological analysis and public health management.

Among the tools offered by the project, the development of the SIGEpi© software (Figure 3) presents a set of simplified techniques, procedures, and methods for the analysis of epidemiological data. SIGEpi© provides a range of data management and processing functions such as the integration of attributes from data tables with digital spatial data, display and visualization of multiple geographic layers via a map display as well as the selection and querying of spatial data to generate new layers based on attributes and spatial operations between layers. SIGEpi© implements methods for quantitative analysis in Epidemiology, which are particularly useful in exploratory data analysis. Among them are descriptive statistics to calculate the set of measures of central tendency and scatter and prepare frequency distributions; correlation analysis; and both simple and multiple linear regressions. Some functions for the calculation of rates, ratios, and proportions are included, as well as adjustment using direct and indirect methods and spatial smoothing.

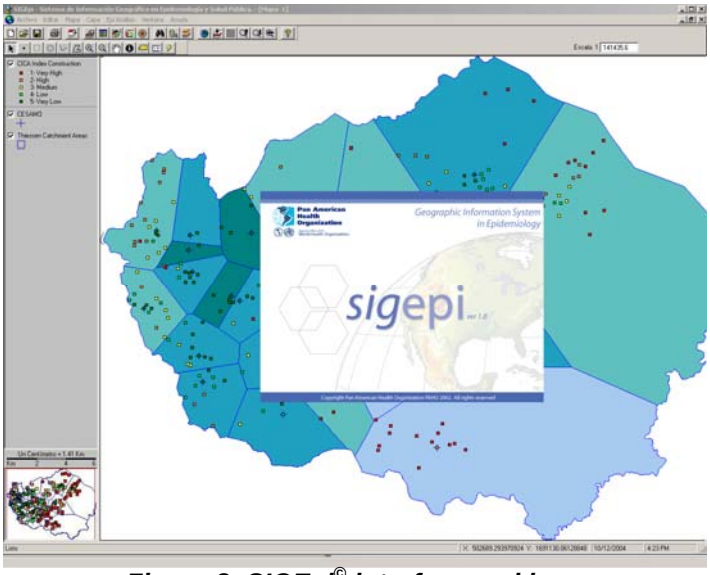


Figure 3: SIGEpi© interface and logo

SIGEpi© also contains a range of useful methods for analysis and decision support for public health practice. These include: identification of critical and priority areas; construction of *composite indexes - such as basic unmet health needs, poverty, accessibility* - or identification and detection of spatial and time-space clusters; measurement of the association between environmental exposure factors and health events for case-control or cohort epidemiological studies; and evaluation methods for access to health services (based on the radial schemes technique), such as a simple measure of accessibility using linear origin-destination distances.

SIGEpi© has been developed for personal computers and the Microsoft Windows operating system. The minimum and recommended hardware requirements for SIGEpi© are as follows:

- Processor (CPU), minimum Intel/Pentium class CPU (350 MHZ or better recommended)
- 128 MB of (RAM) memory (64 MB or better are recommended)
- 100 MB of free hard drive space (1 GB is recommended)
- A color graphics card and monitor (SVGA is recommended)
- A mouse

SIGEpi© has been designed to take into account the conceptual elements and systemic framework of a GIS. SIGEpi©'s graphic user interface handles multiple types of documents in a single work environment. Each document type is presented in its own window, maintaining a dynamic link among some of them. The types

of documents are Project, Map, Table, Figure, Result, and Presentation, each of them having functions, menus, buttons and tools of their own (Martinez, 2001).

Two kinds of ESRI software and components (ArcView 3.2 along with the Spatial Analyst and/or 3D Analyst extensions) were used in order to prepare the data to be used in SIGEpi© and to calculate critical conditions in accessibility to primary health care for the health region 7 in Honduras. The majority of the spatial data was in vector format due to the nature and limitations in the GIS software used within the Honduran health sector. The TIN was calculated from the Honduras Digital Elevation Model (DEM) with the 3D Analyst, extension which allowed the calculation of slopes. After the analysis the cartographic databases are delivered to the Ministry of Health personnel in vector format; including the reclassified DEM.

3.1 Application of SIGEpi© to the case study area

Geographical accessibility, in the framework of *Health Situation Analysis*, is conceived as part of the process of search and obtaining health care, where population is located in one extreme of the spectrum and services availability in the other extreme (Donabedian 1988). Thus, accessibility is considered an intermediate variable that reflects the functional relationship between groups of obstacles originated in the geographic location of services (distances, travel times) and the capacities of the population to overcome these obstacles (road availability, vehicles). (Frenk, 1985). In this work, travel times and distances are the geographical indicators of accessibility. No cultural, organizational or economic accessibility are considered in this framework, since travel costs in some rural environments in Latin America seemed to show a different distribution than other geographic accessibility indicators (Nájera-Aguilar 1996). They could be studied separately and complementarily.

From the SIGEpi© perspective, geographical accessibility considers the relative location between population and health services taking into account specific environmental conditions. A Composed Index of Critical Accessibility Index (CICA) was calculated in SIGEpi©, taking advantage of the simplified estimation of composed measurements indexes. This estimation has been done by adding up z scores of distances and travel times (corrected by terrain slopes) among villages, roads and CESAMOs. CICA Inverse Distance Weight (IDW) interpolation was then generated to draw up the boundaries of accessibility critical areas.

The main processing and analysis steps followed for the application of the method implemented in preparation for the SIGEpi© analysis were:

- Standardization of databases to UTM 16 projection
- Thiessen polygon analysis to identify catchment areas based on the nearest facility
- Spider diagram analysis providing distance to the closest CESAMO
- Distance analysis to nearest roads edges using the ArcView Extension “Nearest Feature”.
- Conversion of the Honduras DEM (USGS - GEOTOP30) into a 100m TIN and conversion to UTM16 projection based on WGS 84
- Average slope measurement and assignation to trajectories and roads was done using “Surface tools for points, lines and polygons”
- Transfer of all indicators to the Villages database
- Calculation of Composed Index of Critical Accessibility (CICA)
- Accessibility Interpolation surfaces calculation.

Most of computation steps for individual indicators were prepared in ArcView 3.2.

Human resources availability and other infrastructure features were calculated for each Thiessen polygon including the total population (adding up the individual values of each village), the total physicians inside each area, availability of Physicians per 10,000 inhabitants and well as the health and infrastructure resources (Table 3).

Headquarter Village's Code	Headquarters villages' name	Villages	Physicians	Total population Thiessen area	Physicians per 10,000 pop
151801	San Francisco de Becerra	24	1	53,241	0.19
152309	Nueva Choluteca	14	1	31,736	0.32
152001	Santa Maria del Real	8	1	24,055	0.42
150165	Zopilotepe	17	1	17,153	0.58
150901	Guarizama	12	1	15,443	0.65
151901	San Francisco de La Paz	12	1	15,256	0.66
150501	Dulce Nombre de Culmi	29	2	28,702	0.70
150801	Gualaco	9	1	12,744	0.78
151401	Mangulile	21	1	12,547	0.80
151101	Guayape	15	1	11,348	0.88
151001	Guata	11	1	11,017	0.91
150139	Las Minas	13	1	9,698	1.03
151701	San Esteban	25	3	24,537	1.22
152101	Silca	8	1	7,838	1.28
150201	Campamento	11	2	15,130	1.32
150301	Catacamas	9	7	52,773	1.33
150401	Concordia	12	1	6,790	1.47
150110	El Bijao	4	1	6,797	1.47
150601	El Rosario	11	1	6,107	1.64
151301	La Union	2	1	4,223	2.37
152201	Yocon	3	1	3,885	2.57
151201	Jano	5	1	2,155	4.64
151601	Salama	5	3	5,281	5.68
Total		280	35	378,456	1.43

Table 3: Population and human health resources estimates for Thiessen catchment areas in health region 7

For each populated place (towns and villages), specific component indicators of availability and accessibility to the nearest facility were calculated. These indicators are as follows:

- Available physicians inside each Thiessen polygon catchment area was calculated to identify general availability of Primary Health Care (PHC) human resources (Figure 4a)

  Physician x 10,000 inhabitants = (number of physicians / adding up the villages total population inside a Thiessen polygon catchment area) * 10,000

- Distance to the nearest CESAMO (Dist km to nearest CESAMO). This was done using the Spider diagram Avenue script (Figure 4b).

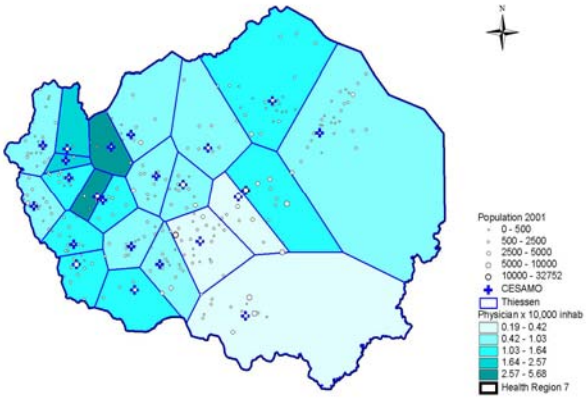
  Dist km to nearest CESAMO = linear km from every village to the closest CESAMO

- Pedestrian movement was assumed where no roads exist. Because of that, an estimation of linear trajectories from villages to the closest available road was made. This was calculated with "Nearest feature" tool that locate the closest edges or centroids of geographic elements. The average 5 km per hour speed was weighted by the slope % scale, taking into account that 45 degrees are equivalent to 100%. Weight = (100 – Slope %)/100 to obtain 0 to 1 scale, and the travel times obtained dividing linear distances by corrected speed (Figure 4c).

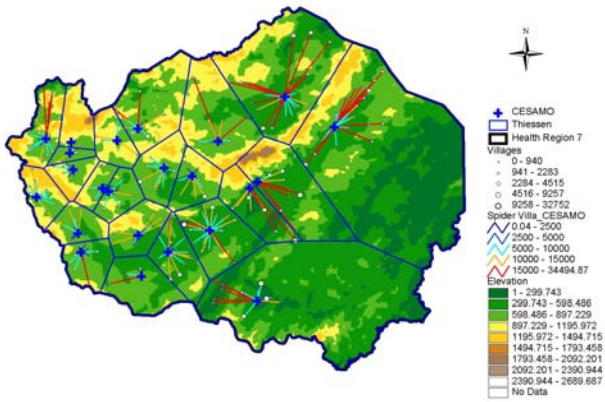
  Hrs Nearest Road = (distance to nearest road / (average walking speed * slope % weight)

- Travel calculations using motor vehicles were made for all types of roads: including primary secondary and "Rodera's" (Table 4). The average speed for each type of road was weighted by the slope % weighted scale, and the travel times were obtained dividing the Thiessen available roads' length by that weighted speed (Hrs Available Road Network). The projected speed along the roads type was 100 km/hr for primary roads, 70 km/hr for secondary roads and 20 km/hr for Rodera's. This estimated speed also was corrected by slope Figure 4d).

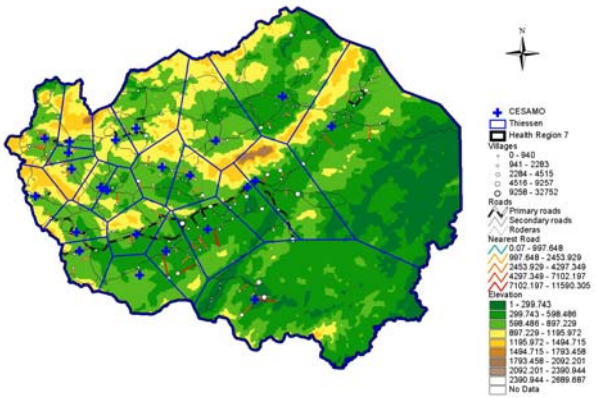
  Hrs Available Road Network = (length of the available road network in each Thiessen polygon / (average road speed * slope % weight)



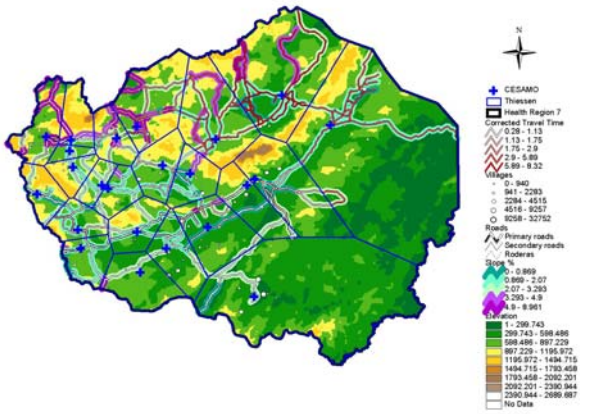
a) Available physicians inside each Thiessen polygon were a populated place is located



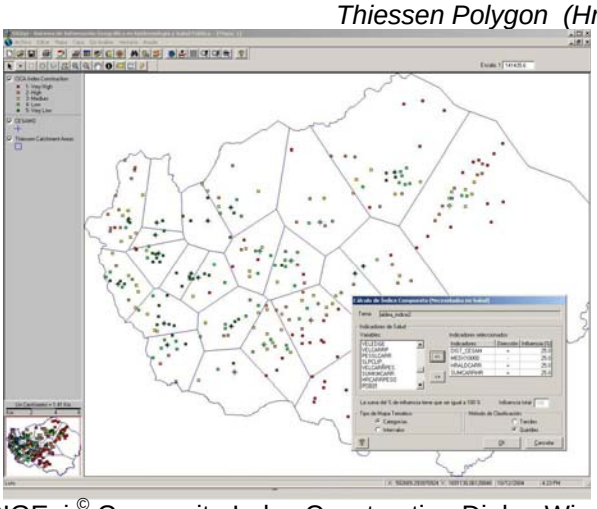
b) Distance to the nearest CESAMO (Dist km to nearest CESAMO)



c) Estimated traveling time (walking) to the closest road corrected for slope (Hrs Nearest Road)



d) Estimated traveling time in hours corrected for slope along the available road network inside each Thiessen Polygon (Hrs Available Road Network)



e) SIGEpi © Composite Index Construction Dialog Window

Figure 4: Indicators of availability and accessibility to the nearest health facility

Type of Road	Projected Speed	Slope%	Slope Weight Scale	Corrected Ave Speed	Ave Km / Thiessen	Estimated Travel Time Hrs
Primary roads	100	3.88	0.9608	96.08	7.4497	1.5471
Secondary roads	70	4.42	0.9559	66.91	8.7630	2.3764
Rodera's	20	3.01	0.9700	19.40	7.9813	6.4465

Table 4: Travel time estimation along available Thiessen catchment area's road network.

After the transfer of each of the above indicators to every populated place, the Composed Index of Critical Accessibility (CICA) was calculated in SIGEpi© (Figure 4e), taking advantage of the simplified estimation of composed measurements indexes. The calculation of composite indexes is a simple method for aggregating or grouping several indicators for integrated analysis. Fundamentally, z scores explain how many standard deviations the scores are from the mean (Hinton, 1999).

For Honduras Health Region 7, the composite Index was calculated by adding up z scores of all the indicators. The composite health index is the total of the Z values for all the indicators as shown in (Figure 5):

$$CICA_j = \sum_{i=1}^{n} Z_i$$

$$Z_i = (x_i - \overline{x})/s$$

Where:

CICA = Composed Index of Critical Accessibility
i = Indicators
j = Geographic Unit (villages)

Z = Z score
X = I values for j
$\overline{x}$ = mean

Figure 5: SIGEpi© Construction of Composed Index of Critical Accessibility.

As the composed index was generated for each populated place (villages), they can be classified and arranged in quintiles, in order to identify the population amount exposed to higher or lower risk of accessibility problems. Table 5 sort the number of populated places and averages for the main indicators in each corresponding CICA quintile.

CICA	Tot Pop	Number of Populated places	Physician x 10,000 inhabitants	Dist km to nearest CESAMO	Avg. Hrs Nearest Road	Avg. Hrs Avail Road Network
1- Very high	97,848	56	0.60	15.65	0.62	2.64
2- High	61,293	56	0.81	10.98	0.36	2.70
3- Medium	80,186	57	0.84	9.37	0.20	2.30
4- Low	51,258	56	0.94	5.82	0.11	2.45
5- Very low	87,871	55	2.03	3.15	0.08	1.61

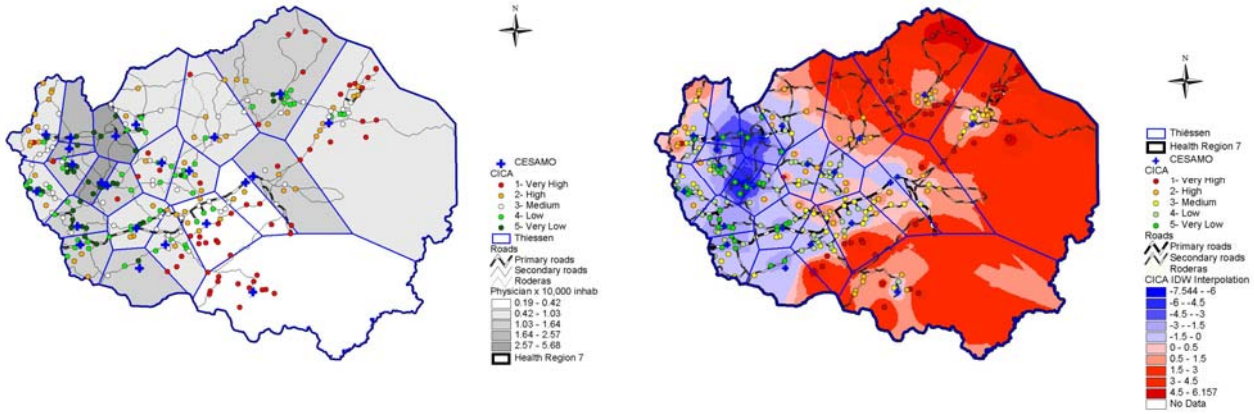
Table 5: Composed Index of Critical Accessibility & Component Indicators

The analysis undertaken using the SIGEpi© approach identified populated places that had poor accessibility levels to the road network, taking into consideration travel times to, and along the available road network, as well as the CESAMOS allocation and physician rates. Indicators of Travel time to the nearest road, travel time along available road network and linear distance to the closest CESAMO had a **positive** weight into the formula. Physicians' availability rate had a **negative** weight.

Populated places were classified according to the level of critical accessibility index to CESAMO's as shown in figure 6a with populated places having high risk of accessibility problems classified in red and low accessibility problems classified dark green. The highest risk of negative accessibility conditions correspond to the highest quintile, in which there are 76, 490 people while very low risk of poor accessibility conditions cover 88, 434 people (Table 5)..

Using this classification along with spatial interpolation techniques an accessibility surface was generated. Inverse Distance Weighted interpolation (IDW) with nearest neighbors was used supposing that each input point has a local influence that diminishes with distance. No barriers were included. Figure 6b shows this

accessibility surface with areas having low accessibility to CESAMOS shown in red while areas with high accessibility to CESAMOS shown in dark blue.



a) Populated places classified according to CICA (Critical Accessibility Composed Index) to CESAMOS

b) Accessibility surface created by interpolation of CICA classified populated places

Figure 6: Accessibility Classification & Surface

As a result of the above procedures, it is possible to identify critical accessibility conditions for each populated place, inside the Thiessen polygons; as well as to establish the limits of areas that share the same accessibility conditions (good or bad). This classification sets the opportunity to prioritize and focus health interventions over the places classified as highest risk (Figure 7); for Health Region No. 7, the identification of the nearest Rural Health Center (CESAR) located into the priority areas to examine the restructuring possibilities.

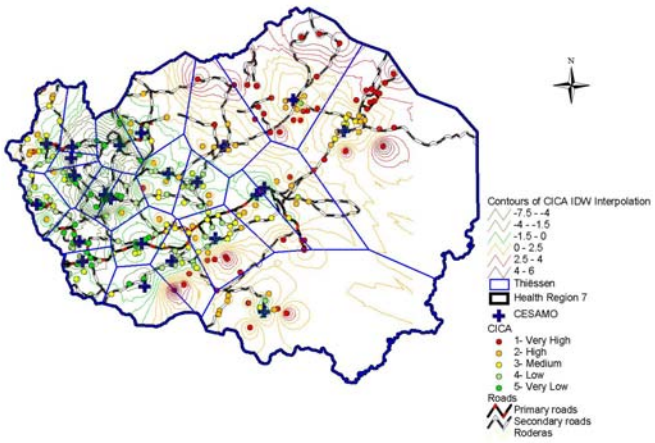


Figure 7: Boundaries of accessibility problematic areas inside Thiessen polygons

4. Measuring Physical Accessibility using AccessMod©

As part of its initiatives for developing evidence based health policy and assessment, the Evidence and Information for Policy cluster (EIP) at WHO has undertaken a project in collaboration with the faculty of Medicine of the University of Sherbrooke, the department of Geography of the University of Geneva and the School of Mathematical and Geospatial Sciences at RMIT University, Melbourne with the contribution from the Networks of Centers of Excellence (GEOIDE). The objective of this project is to assess the use of GIS to improve the measurement of physical access to health care. This investigation has led to the development of a GIS based module called AccessMod©.

The actual version of AccessMod© has two fundamental modes of operation:

- Analysis of an existing health facility network through the generation of the catchment areas and determination of the population covered by each of the facilities. This analysis can be done when considering inpatients or outpatients and can include different type of facilities at the same time.
- Determination of locations for new health facilities in order to scale up the existing network or to perform different analysis when no information about the location of the existing health facility networks is available (e.g. for cost-effectiveness analysis). This capacity can be applied for inpatients or outpatients when dealing with only one type of facilities at the time. In case of several types of facilities to be considered simultaneously this capacity could only be applied to outpatients based systems for the moment.

The significant difference between the application of a simple cost-distance algorithm and AccessMod© is the fact that this model integrates both the population and the capacity of treatment of the health facilities when determining the catchment areas or proposing scaling up solutions.

AccessMod© has been developed using the ESRI ArcView 3.2© GIS software along with the Spatial Analyst© (raster analysis) extension. These two components are necessary for using AccessMod©. The avenue scripting language has been used to automate the model process and provide a series of easy to use intuitive dialogs allowing the model to be used by non specialist GIS users.

The minimum and recommended hardware requirements for AccessMod© are as follows:

- Processor (CPU), minimum Intel/Pentium class CPU (350 MHZ or better recommended)
- 32 MB of (RAM) memory (64 MB or better are recommended)
- 500 MB of free hard drive space (1 GB is recommended)
- A color graphics card and monitor (SVGA is recommended)
- A mouse

This module has been designed to use global data sets that are “readily” available from UN agencies or research institutions in order to insure the exportability of the method and facilitate its use in developing countries as there would be limited additional data costs when applying the model. This approach also ensures the possibility to substitute these global layers with alternative regional or national data sets if their use is more appropriate and if they are available. The fundamental input data sets for the application of AccessMod© are travel time and population stored in grid format as well as the location of the health facilities, if available, which are stored in a separated vector layer. The important factor is the consistency between these different layers in terms of resolution, content and map projection.

The following sections illustrate the application of the two modes of operation of AccessMod© in the context of the case study area described earlier. The analysis of the existing network involves the following process:

- Specific preparation and integration of the data in ArcView
- Application of the AccessMod© module

4.1 Specific preparation and integration of the data in ArcView

The first step in the preparation of the data required by AccessMod© is the generation of the travel time grid based on the different layers mentioned earlier. The creation of this grid firstly requires the definition of the travel scenario to be considered when the population goes to the nearest CESAMO. In the context of this paper, we have only considered pedestrian movement where no roads exists and travel by motor vehicle where roads do exist.

Considering this scenario the traveling time grid has been generated by firstly assigning the corresponding average speed to each landcover and road categories that have been defined earlier (Table 1 and 2) for a slope equal to 0° based on figures found in Nelson (2000) and Toxopeus (1996). These average speeds are presented in Table 6. In this analysis, we have considered water bodies as barriers for patients wishing to reach a CESAMO. We have therefore attributed a traveling time of 1000 minutes to these cells which correspond to a traveling speed of 0.06 km/h.

Land cover type	Class	Speed (km/h)
Water	1	0.06
Urban and built-up area	2	5
Low dense vegetation	3	5
Fairly dense vegetation	4	4
Dense vegetation	5	3
Bare Soil	6	6
Primary Road	7	100
Secondary roads	8	70
Rodera	9	20

Table 6: Traveling speed estimation per land cover type for walking and motor vehicle scenario

The layer obtained after this operation has then been corrected in order to take the slope into account. This has been done through the use of Tobler's formula (1993) for corrections to be applied on walking velocity:

$$V = 6 * e^{-3.5*abs(S+0.05)}$$

Where:
V - representing walking velocity (km/hour),
S - representing slope (degrees)

For the roads, no correction factor has been applied as slope was considered not to have significant influence on the speed of motor vehicles. The two speed distribution grids obtained have then been merged and converted into the final traveling time grid, expressed in minutes using the following formula:

$$TTmn = \frac{P * 60}{TS * 1000}$$

Where:
TTmn - traveling time (minutes)
P - pixel Size (meters)
TS - traveling speed (Km/hour)

In order to consider the Health Region 7 as a closed system, a mask has been applied to the traveling time grid attributing a travel time of 1000 minutes to cells located outside of the health region 7 (Figure 8).

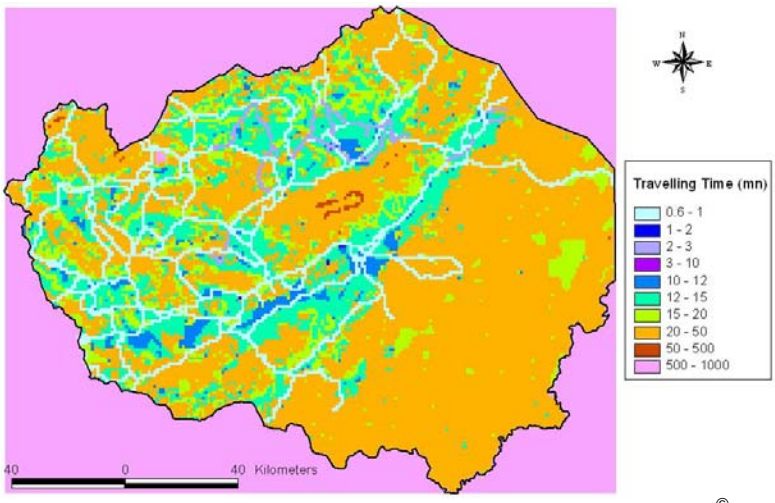


Figure 8: Travel Time grid generated for AccessMod©

In addition to the traveling time grid and in order to take into account the capacity of treatment available in the CESAMOs, it is necessary to integrate specific information in the model. The methodology used to determine the number of patients that can be served by a health centre is based on formulas developed in Doherty *et al*. (1996). To summarize the approach of this method, the number of patients that a health centre can serve per year, at a standard capacity, is calculated by using the following formula:

Total Population Served = (number of health workers * number of patients seen in one average day * number of days worked per year) / (average number of outpatient/inpatient visits per capita per year)

However, in areas where there are seasonal diseases, such as malaria, the peak utilization of health centers at a particular time of year may be much higher than the average utilization throughout the year. In this case, the peak utilization rates should be considered rather than the average. This particular correction has not been applied in the context of the present study.

The following information has been used in order to apply the formula:

- Number of doctors in each CESAMO, extracted from the SIRES data set[11]
- Average number of patients seen by each CESAMO in one day – Obtained from the "Ex-Post Evaluation of the Honduran Social Investment Fund" (Walker *et al*, 1999) . The figure obtained from this report was of 34.4 patients which was regarded as an average value for a CESAMO. As the number of doctors varies from one CESAMO to another it was necessary to determine a weighted average taking into account the specific number of doctors in each CESAMO. Using the total number of doctors (542)[11] working in all CESAMO's (341)[11], an average of 1.59 doctors per CESAMO was calculated. Using the daily patient load reported earlier by Walker et al (1999) the average number of patients seen by a CESAMO with one doctor is then equal to 21.64
- Number of days worked per year – Fiedler & Suazo (2002) report the total number of patients seen in one year as 9,980. Dividing this by the number of patients seen in an average day as reported by Walker et al (1999) provides a result of 290 days for the year 1999 (common year used in both studies).
- Average number of outpatient visit per capita per year for the CESAMOs – Obtained from Fiedler (2000): 1.7 visits

The adopted formula mentioned earlier has been applied to each of the CESAMO in the Health region 7 in order to define the total population that each of them can serve. A CESAMO with 6 doctors would for example be able to serve a population of 22,162 when a CESAMO with only one doctor would serve a population of 3,694. As there were two CESAMOs in the Town of Catacamas (one with 6 doctors, the other one with 1), the number of doctors for this location were merged into a single CESAMO with 7 doctors.

The maximum travel time for a patient wishing to access a health facility depends on the severity of the patient's condition. In the context of this paper, one hour has been used as the maximum traveling time for designing the catchment areas around each CESAMO in the first instance. In this regard, the analysis focuses on the general function of the CESAMO system in the study area rather than a specific intervention.

The traveling time grid as well as the population distribution are then directly loaded in ArcView 3.2 © as raster grids. Once the total population served and maximum traveling time information stored as two new columns in the attribute table of the Health facility location this layer is also loaded in ArcView 3. 2 ©.

4.2 Application of AccessMod© to the case study area

Once the data has been prepared and integrated into ArcView 3.2 © it is possible to run AccessMod© (Figure 9) which has been loaded as an additional extension. Once the user has specified the different layers of information to be used and the name of the files in which the results will be stored, the model calculates the population living within 5 km of each health facilities in order to provides this as one of the parameter that the user can chose to decide about the order of treatment of the facilities during the analysis. The other parameters that can be used for determining this order may include health facility capacity, patient numbers, facility type or any other characteristic associated with health facilities and integrated in the attribute table of this particular layer. This may play an important role especially when analyzing different type of facilities at the same time. For the context of this paper we have decided to treat the CESAMO by decreasing order of population number living around them.

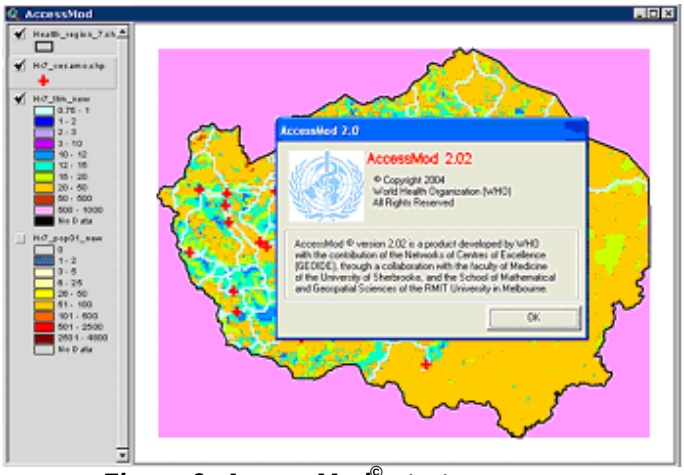


Figure 9: AccessMod© start-up screen

The extension of each facility catchment area is then designed using the cost-distance algorithm which involves an iterative process taking into account the total population that can be served and the travel time being considered for each CESAMO. Once the maximum population capacity and/or travel time has been reached the spatial extent of the catchment area is recorded and the accessibility measure (population, travel time etc) are assigned to the corresponding health facility. The population that has been "allocated" for that health facility is subtracted from the population grid as illustrated in Figure 10 and the model continues processing until all health facilities have been analyzed.

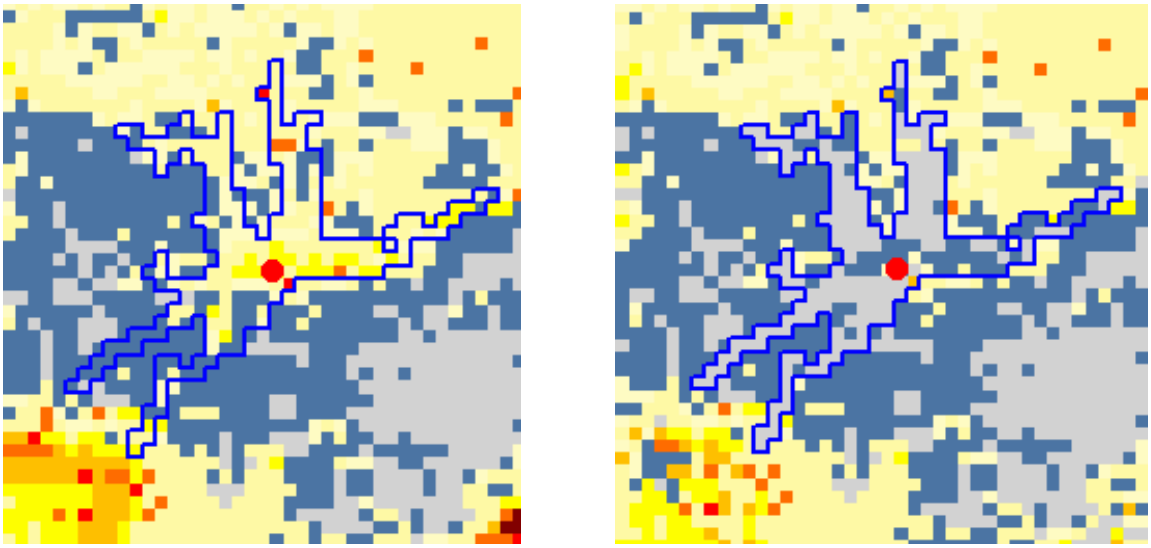


Figure 10: Distribution of the population before and after the application of the model, (the CESAMO is shown as a red point while its catchments area is shown in by the dark blue line)

At the completion of the modeling process, AccessMod© has determined the spatial extent of the catchment area for each CESAMO. The shape of most of the catchment areas is not circular due to the impact of the road network on travel time as this can be seen in Figure 10. Catchment areas can also overlap and extend around each other leading to a visually complex result. Information about the population covered by each facility and its respective catchment area is stored as a result of the model process and can be used for analysis of the existing network (Table 7).

As we can see the capacity of all the CESAMOs is covered before reaching one hour of traveling time which confirms that they are operating at their maximum capacity utilization. This is due to the fact that the population is concentrated in dense areas (villages and towns) where we also find CESAMOs. The results would have been different if the population would have been more dispersed or if we would have used one of the population distribution grid instead of the populated location data set. From the initial 378,456 inhabitants, 229,521 are not covered by the existing facility network which represents 61% of the population of Health Region 7. The percentage of population by village having access to a CESAMO (Table 8) indicates that the population not covered by the existing network is located in a large number of populated places. If more appropriate for decision making, this analysis could also be done at the municipality level.

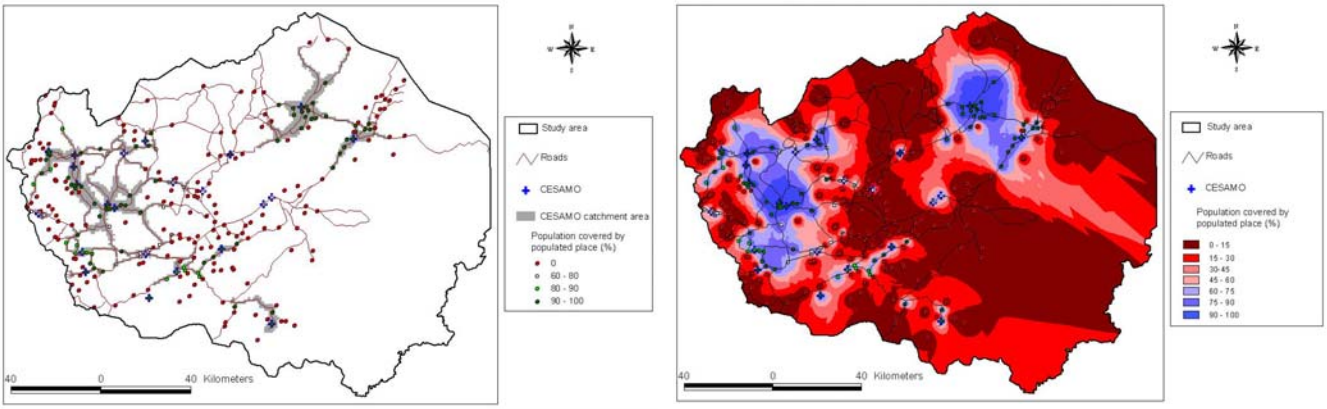
CESAMO Number	CESAMO Name	Number of doctors in the CESAMO	Maximum capacity of treatment	Population served by the health facility	Maximum Traveling time at the border of the catchment area (mn)	Surface of the catchment area (ha)
1	Catacamas, Tatabicoche	7	25855	25855	15	100
2	Cesamo San Esteban	3	11081	11081	31	37400
3	Cesamo Salama	3	11081	11081	18	25400
4	Campamento	2	7387	7387	5	3000
5	Dulce Nombre De Culmi	2	7387	7387	15	12900
6	Zopilotepe	1	3694	3694	11	8900
7	Las Minas	1	3694	3694	10	9400
8	Bijao	1	3694	3694	22	100
9	Guayape	1	3694	3694	3	1700
10	El Real	1	3694	3694	1	100
11	San Francisco De Becerra	1	3694	3694	10	4300
12	Cesamo Nueva Palestina	1	3694	3694	35	9200
13	Yocon	1	3694	3694	13	11900
14	Silca	1	3694	3694	24	48400
15	Mangulile	1	3694	3694	20	19500
16	La Union	1	3694	3694	1	100
17	Jano	1	3694	3694	11	12500
18	Guata	1	3694	3694	4	2900
19	El Rosario	1	3694	3694	24	32700
20	Concordia	1	3694	3694	9	8100
21	San Francisco De La Paz	1	3694	3694	1	100
22	Guarizama	1	3694	3694	7	2700
23	Gualaco	1	3694	3694	1	100

Table 7: AccessMod© results for the 23 CESAMOs located in the Health region 7

Percentage of the population covered by populated place (%)	Total population	Number of populated places
90 - 100	73'215	71
80 - 90	11'939	15
60 -80	63'781	22
0	229'521	172

Table 8: Distribution of villages by percentage of population having access to a CESAMO

If we look at the spatial distribution of the populated places that show a high percentage of population not being covered (Figure 11a) we can observe that they are not necessary located in a specific areas but are dispersed all over the Health Region 7. Two large areas completed by some local spots are presenting a high level of coverage when interpolating the classified populated places (in blue in Figure 11b).



a) Populated places classified according to the percentage of population having access to a CESAMO

b) Accessibility surface created by interpolating the classified populated places

Figure 11: Accessibility classification and surface

The results underline a lack of health care services to cover the total population living in Health Region 7. It is therefore possible to use the second mode of operation of AccessMod© to determine possible locations for new health facilities. In this case the process is very similar to that used for the existing facilities. The major difference is in the order of processing in that the location of the "first" health facility is based on the location of the most populated cell among the remain population distributed in the grid, starting from the principle that it is more cost effective to build a new infrastructure in a density populated area. The type of health facility, and hence capacity utilization and travel time, is determined by the population living within a hypothetical catchment area which extension is only determined based on the maximum traveling time to be considered. A table such as Table 9 for the case study area is used to select the most suitable type of facility based on the population living in this hypothetical catchment area. The minimum coverage for each type of CESAMO is calculated considering that a facility would still be cost effective if 70 % of the occupation capacity was reached. As a CESAMO with one doctor would therefore not be cost effective bellow a population of 2'586 inhabitants an additional category of facility, not defined, as been generated.

Minimum population	Maximum population	Type of facility (Number of doctors)	Occupation capacity	Traveling time
0	2'586	Other Health Facility (?)	2'586	60
2'586	5'170	CESAMO (1)	3'694	60
5'171	7'756	CESAMO (2)	7'387	60
7'757	15'512	CESAMO (3)	11'081	60
15'513	999'999	CESAMO (6)	22'162	60

Table 9: Capacity utilization of the facilities based on the number of the doctors

The cost-distance algorithm described above is then used to measure the accessibility and determine the catchment areas. Following the subtraction of the catchment population from the population grid, the next highest population is determined and the model continues until all population has been allocated to a new health facility. For the case study area this requires the location of 67 new facilities. The results obtained for the municipality of Juticalpa (n°11 in Figure 2d) are reported in Table 10.

The distribution of these 67 health facilities is reported in Figures 12a and b. The CESAMOs have been separated from the other types of facilities in order to facilitate the visualization of their respective location and total extension of all the catchment areas.

CESAMO Number	Populated place Name	Type of facility (Number of the doctors)	Maximum capacity of treatment	Population served by the health facility	Maximum traveling time at the border of the catchment area (mn)	Surface of the catchment area (ha)
27	Juticalpa	CESAMO (6)	22'162	22'162	0	100
27	Juticalpa	CESAMO (6)	22'162	22'162	16	28'400
37	El Bijao	CESAMO (2)	7'387	5'364	60	4'900
39	El Plan de Los Ciruelos	CESAMO (1)	3'694	2'794	60	3'100
44	Pueblo Viejo	CESAMO (1)	3'694	2'764	60	30'400
45	San Antonio de Sara	CESAMO (1)	3'694	3'694	6	100
49	Calpules No.1	Other (?)	2'585	648	60	6'500
52	El Carbonal	Other (?)	2'585	1'342	60	183'700
66	La Concepcion	Other (?)	2'585	2'044	60	13'700
72	Las Flores	Other (?)	2'585	1'262	60	61'700
76	Potrerillos o Campo	Other (?)	2'585	1'011	60	5'900
77	Punuare	Other (?)	2'585	2'361	60	84'500
79	Rancho Quemado	Other (?)	2'585	746	60	126'200
82	San Antonio de Sara	Other (?)	2'585	821	60	3'400
87	Trojas Arriba	Other (?)	2'585	940	60	1'700

Table 10: AccessMod© results for the new health facilities in the municipality of Juticalpa

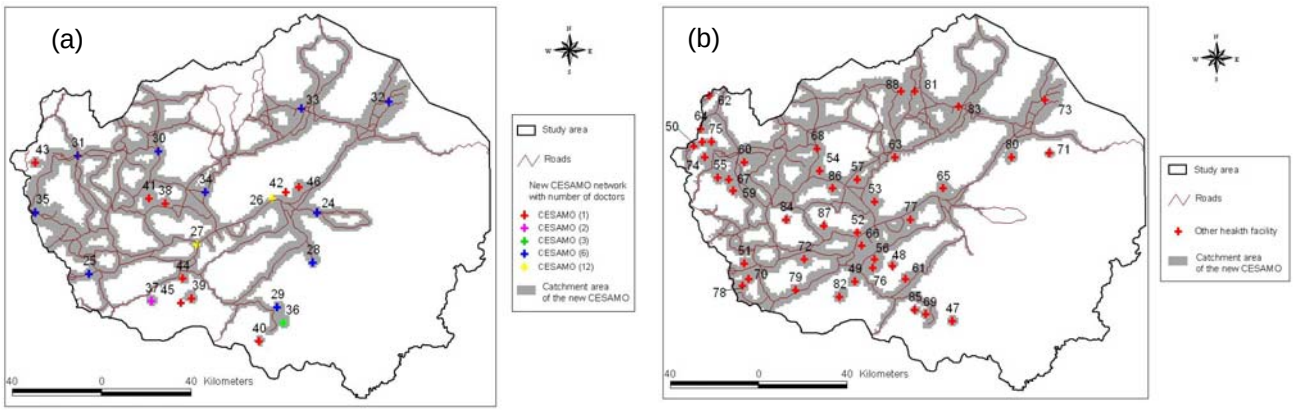


Figure 12: Distribution of the theoretical complement of CESAMOs (a) and other health facilities (b) with the total extension of all the respective catchment areas

The 67 facilities are distributed as follow

- 14 CESAMOs with 6 doctors,
- 1 CESAMOs with 3 doctors
- 1 CESAMOs with 2 doctors
- 9 CESAMOs with one doctor
- 42 health facilities which should be smaller than a CESAMO or operating on a different mode (limited hours of operation or mobile unit)

In two populated places the model has put two CESAMOs with 6 doctors. For these two cases, it has been considered to be more cost effective to only build one structure with a total of 12 doctors which explain the particular category reported in Figure 12a. Further investigation is required to determine if a facility with 12 doctors can still be considered as a CESAMO or as other type of infrastructure.

Among these 67 health facilities only 13 of them do cover a population that make them reach their maximum capacity of treatment (3 in the municipality of Juticalpa, Table 10) but the other facilities could have covered a larger population if we would have considered a more important traveling time, thus reducing certainly the number of facilities to be built for covering the remaining population. Further reflection should therefore take place in order to decide if a one hour is really consistent for this type of analysis.

In addition to the need to build new structures to be located in different populated places than the existing network, these results also underline the important need to increase the human resources necessary for equitably serving all the population living in this area (98 doctors for the CESAMOs). Additional resources will also be necessary in order to provide services in the remaining 42 structure not identified as being potential CESAMOS. It is also important to remember that doctors represent only one part of the human resources needed a functioning health facility. This analysis does for example not consider the number of nurses or administrative staff that would be necessary in order to support the work of the doctors.

5. Discussion

This paper describes two possible methods for measuring physical accessibility to health care. For both of the methods the objective is to provide tools that could be used in countries, and more particularly in developing countries, where the need to access health care is one of the key elements for reducing the burden of diseases. It is therefore important to evaluate their capacity, level of applicability as well as the pertinence of the results obtained for this context.

The major difference in the modeling capacity of the two approaches presented in this paper is the ability of AccessMod© to "scale up" the existing health infrastructure network of an area through the addition of new health facilities in optimal locations. The ability of AccessMod© to measure accessibility for a theoretical or proposed health facility network provides the flexibility to also undertake cost effectiveness analysis, even when the locations of the existing health facilities network are unknown. The study outlined by Adam *et al* (forthcoming) provides an example of such type of analysis. AccessMod© measure accessibility at the individual health facility and catchment level and this may have some benefits over the SIGEpi© approach which mainly analyses accessibility at local level. In the other hand, a benefit of the SIGEpi© approach is the ability to integrate the measurement of the accessibility degrees at local level with the other tools within SIGEpi© for quantitative epidemiology analysis. This integration facilitates the analysis of accessibility whilst including the results of spatial clustering of health data, environmental exposure factors and health events for case-control or cohort epidemiological studies.

Although, the SIGEpi© and AccessMod© applications are both freely or low cost available, they are both based on commercial GIS products and therefore have a cost associated with their implementation at country level. The two methods are also using ArcView for the preparation of the input data sets. In addition, both methods require the ArcView Spatial Analyst which represents an additional cost. The SIGEPI© approach could alternatively use the 3d Analyst extension.

Although the two approaches presented use different source data formats and different analytical techniques, the results obtained from the two methods are comparable when analyzing the accessibility degree and the capacity utilization of the existing health facilities network. This similarity in the results obtained can be seen in the western part of Health Region 7 where the results from the SIGEpi© approach (figure 6b) compare closely with the results obtained from the AccessMod© approach (figure 11b). The comparison of these accessibility surfaces highlights an important benefit of using GIS for measuring accessibility as it allows visual data exploration and comparison techniques that are not available in numerical based approaches such as spreadsheets. The ability to compare the results of these two methods, both with each other, and with other environmental and socio economic data significantly extends the analysis capability of both the AccessMod© and SIGEpi© approach.

Although the results obtained from the two methods were similar for comparable indicates, the conceptual difference between the two methods requires further analysis and investigation. One of these difference resides in the fact that the SIGEpi© use the underlying assumption that all of the population living in a "village" will use the "same" health facility. As the AccessMod© approach takes capacity into consideration, the model includes the concept of the population using a health facility other than the closest one if there is not enough "capacity".

Availability and quality of the input data sets used in any modeling exercise directly influences the usefulness of the modeling outcomes and the quality of decisions based on model results. Both of the methods presented require a number of input data sets as outlined in section 2. In general terms, the AccessMod©

approach has a more intensive data requirement than the SIGEpi© approach due to the additional data sets used to derive the travel time surface and the data required for the calculation of health facility capacity utilization. The emergence of global landcover data sets should enhance the availability of this data for use with AccessMod©; however, the reliance on capacity of treatment data remains one major difference between the two methods and one which may limit the use of the AccessMod© approach. Using vector data, rather than raster data within the SIGEpi© approach may improve the use of this method in countries where administrative boundaries and health facility locations may often be available through various national government agencies.

Further research into both of the methods presented in this paper would be required in order to identify the benefits and limitations of the application of the methods to different geographic areas and populations and their particular benefit for decision makers. In particular, an understanding of the utility of the methods for both rural, semi rural and urban areas would be useful for developing countries which are dealing with both the supply of health facilities to rural areas whilst also trying to fulfill the needs of the population living in areas undergoing rapid urbanization. In this context, a model that includes both the methods outlined in this paper may offer a tool that is more suited a whole country analysis.

6. Conclusion and recommendations

This paper has presented the results of a case study that has compared two different methods for measuring and analyzing physical accessibility to health services. The results of the case study demonstrate the importance of both spatial and health capacity data as a basis for the two modeling approaches. Although research has already been undertaken to evaluate the impact of levels of completeness, accuracy and quality of the road network data on the design of the catchment areas (Ebener *et al*, 2004), little analysis has been undertaken to evaluate the influence of data quality relating to the distribution of the population and location of the health facilities on the results. Additional research should also be done in order to evaluate the impact of the traveling speed figures (e.g. in Table 6) that are considered when applying these type of models as they may have an importance influence on the results obtained.

The comparison of the results obtained using AccessMod© with both the Landscan population grid and the point population data for the case study area, demonstrates the need for further research into the affect of population data on the model results. Based on this initial analysis, the evidence suggests that additional research may lead to the conclusion that the use of population data at a fine level of detail (populated place data level) is the most appropriate approach in terms of model accuracy. However, there is a certain threshold above which the population should be distributed over an area corresponding to the extent of the populated place, especially in larger urban areas. A similar outcome may also occur with respect to further research into the accuracy of health facility locations and the quality of the capacity information. Ideally, the location of populated places and health facility locations would be at a fine level of detail (exact coordinates) thus allowing aggregation up to larger areas for analysis purposes (health regions etc).

The variations in the reported results also identify the need for further research into the methods used for measuring physical accessibility to health facilities. Although the results of this study are encouraging, further research and investigation is required to refine the approaches used. In the context of AccessMod©, the cost distance algorithm used does not take into consideration different “costs” of movement across a cell and instead, uses an average travel cost based on the surrounding cells. Anisotropic algorithms that take into consideration the direction of movement may provide an improvement to the current approach taken in the model. In the context of both AccessMod© and the SIGEpi© approach, greater flexibility in terms of analyzing inpatient, outpatient and population segments may also provide additional benefits. Another area of research concerns the integration of raster and vector approaches into a more complex model that can be used to develop integrated measures of physical accessibility using both grid and raster based data and analysis techniques.

In addition to the two methods describe in this paper, a number of other GIS based systems for measuring physical accessibility exists. These applications include the AccessPlan application developed by the University of Waterloo[13] and the extension developed by the Centro International de Agricultura Tropical (CIAT) (Nelson, 2000). There may be additional benefits in looking at the approaches taken in these applications and undertaking a comparison in terms of techniques and results. Such a comparison may help to improve the approaches taken to measuring accessibility discussed in this paper.

In conclusion, the results of two methods discussed in this paper demonstrate the potential for these approaches to be used within countries for cost effectiveness analysis, population coverage estimates and resource planning which represent a useful asset for improved health planning and policy development.

However, it is important that this capacity be accompanied by consultation and model validation with country representatives and local, regional and national health authorities before basing decisions on model results.

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