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ORIGINAL ARTICLE

A GIS-Based Spatial Decision Support System for Facility Location Planning in Nigeria

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Abstract

Public facilities are to be located optimally in the interest of society. In Nigeria, public facilities' locations are largely influenced by administrative constraints and politics, rather than efficiency and equity. This practice limits access, most especially, in rural communities where the population is dispersed. Studies on efficiency and equity in access to public health facilities focused on urban centres. The aim of this study, therefore, is to advance the understanding of the application of the spatial decision support system (SDSS) to evaluate efficiency and equity in access to public facilities in rural regions. The study used Ogun State, Nigeria as a case. The data used include the population and coordinates of the location of the settlements, coordinates of the location of health facilities and the transport networks. This study showed that 38.5% of settlements do not have access to primary care and the application of the p-median model showed that the efficiency of the existing location of health facilities can be improved by 40.6%. Application of the maximal covering location model showed that the existing maximum travel distance of 26.3km can be reduced. It can be reduced for the sake of equity to 9.9 km. This study demonstrated ways to develop evaluative tools for analyzing the distribution of public facilities in Nigeria. It is suggested that planners in rural regions of other developing countries can adopt these techniques and tools to make their location decisions more logical.

Keywords: Geographic Information System, Public Health Facilities, Spatial Decision Support System, Location Efficiency, Location Equity

Introduction

Planning the location of health facilities in rural regions can be problematic because of the low population density and the dispersed nature of settlements. These lead to long travel distances in such regions. Lack of coherent policy on health care provision and lack of a normative planning framework for health facility planning have been identified as the cause of the problem (Owoola, 2002). However, it is the right of the people in rural regions to have access to public services and it is the obligation of the government to provide such services efficiently and effectively. In trying to fulfill its obligation the government must rationally deploy the resources and minimize wastages. Following the identified problems above this study demonstrated through the use of a geographic information system (GIS) based spatial decision support system (SDSS) framework, ways of analysing the location, and operationalising location objectives for public facilities. The SDSS is a computer-based system for the storage and analysis of data for facility location planning (Keenan, & Jankowski, 2019). The study aims to advance the understanding of the application of GIS and SDSS to location and distributional principles concerning health facilities, using Ijebu North Local government area of Ogun State, Nigeria as a case. This paper is divided into four sections. The first section is the introduction and it discusses the objective of the study and literature. Section two discusses the study area and the methods used to collect and analyse the data. Section three contains a discussion of the results of the study and the last section is the conclusion.

Facility Location Planning Methods

Planning of public facilities in rural regions can be challenging, given the dispersed nature of settlements, multiple location objectives, multiple stakeholders/ interest groups, the inability of public planners to operationalize location objectives/ concepts, *etc*. In such a context, decision support is often needed to aid analysis and decision-making. This study proposes a spatial decision support system (SDSS) that integrates a Geographic Information System (GIS) and location-allocation (L-A) models to support public facilities' location planning. Keenan, & Jankowski (2019) defined SDSS as an interactive, computer-based system designed to support a user or group of users in achieving a higher effectiveness of decision-making while solving a semi-structured spatial decision problem. Location-allocation models generally are concerned with identifying the location of one or more facilities (the location problem) and then allocating consumers to these facilities in a way that optimizes certain objectives (called the objective function) such as: minimizing cost or distance or maximizing population covered or maximizing market share/ profit. There are many variants of location-allocation models. The most commonly used location-allocation models are those based on minimizing distance and those based on maximizing coverage (Al-Sabbagh, 2020). These models are the central facilities location (p-median) and the covering models. The basic p-median model formed by Hakimi (1964) is widely applicable to the siting of public facilities (Carling, Han, Hakansson, & Rebreyend, 2015), The p-median location model fixes the location, on a network, of public facilities and the allocation of consumers such that the total or mean distance or cost is at a minimum (Ayeni, 1992). The p-median model also called the central facility location model, is applicable in operationalising the concept of efficiency in public facility location planning (Dantrakul, *et. al*, 2014**).** The maximal covering location problem is however designed to take care of the situation where there is a need to find the location for a stated number of facilities such that the maximum population is catered for within a favoured maximal service distance (Ayeni, 1992). The maximal covering location model is often used where there is a need to provide emergency services such as ambulances, police, and fire stations where the worst condition is of primary interest. It can also be used to implement a more equitable distribution of public facilities by ensuring that users are not travelling beyond a maximum distance to use a facility. Thus, it is used to operationalize the concept of equity in public facility planning.

Analytical models such as the location-allocation models are often integrated with Geographical Information System (GIS) procedures within SDSS to solve complex spatial problems. GIS is designed and developed to enable the acquisition, compilation, analysis, and display of topological interrelations of different spatial information. SDSS and GIS can work independently to solve some simple problems, but many complex situations demand the two systems to be integrated to provide better solutions (Keenan, & Jankowski, 2019).

SDSSs have been identified to provide a comprehensive framework for resolving problems of service delivery (Rushton, 1988). McLafferty (2003) identified that SDSSs are evolving along two general frontiers: one that aims at incorporating expert knowledge and another that emphasizes participatory decision-making. In an attempt to simplify participatory decision-making in location planning fuzzy logic is being applied by researchers to simplify the decision-makers input by allowing the use of linguistic terms which are consequently processed using fuzzy logic (Jiahang, Cunbin, Wenle, Ding, & Xiaopeng, 2018).

The p-median and the maximal covering location models are optimization techniques that can be used to operationalize concepts of efficiency and equity. Efficiency and equity are two key objectives in public service planning and provision. Morrill and Symons, (1977) described an efficient system as "one whereby service provision cost are minimised or benefits to the users are maximized". Rushton (1988) observed that "a useful method of determining locational efficiency is to compare the performance of particular spatial pattern of public services in achieving its goals with other possible alternative patterns". Equity is an elusive concept and has been subject to a variety of understandings and meanings. Lyseen, *et. al*. (2014) observed the need for more studies on equity in the provision of health care. They noted disparities in access to health facilities for segments of the population across the globe. Owoola (2002) observed that the idea of equity developed from the need to guard that section of the society less able to participate in the national/regional space economy.

Materials and Methods

The study area and the spatial decision support system (SDSS) used in this study are discussed in this section.

The Study Area

Ijebu North local government area in Ogun State, Nigeria is the study area for this work. It is mainly a rural region and it is made up of eleven wards. See Figure 1. There are sixty-five identified settlements out of which only three are medium sized urban centres. There are ten public primary health centres (PHC) in Ijebu North local government area. The population size of Ijebu North local government area grew from 148,342 (1991 population census) to 280,520 (2006 population census) - an increase of 89.1%. The 2021 projected population of the local government area is 235,075 based on the 2006 population. Thus, there is a need to examine this population's access to health facilities. The above-listed characteristics of Ijebu North local government area made the area to be theoretically suitable for examining public facilities planning. This made the study area ideal for this research. The focus of this study is on primary health centres (PHC) because of their fundamental role in the general well-being of the population. PHCs provide primary services and are the first direct link with the people (Randall, 2016). The criterion currently being used by the Ogun State government on access to PHC is to have primary health care facilities within a maximum distance of ten kilometers to the users and that an average journey to PHC of 5km is desirable (Ogun State, 2010). These parameters are used to evaluate the provision of health services in the study area.

The Spatial Decision Support System (SDSS)

The spatial decision support system (SDSS) in this study has three main components, namely the data, the model, and the dialog or user interface. As shown in Figure 2, the database management system (DBMS) is to manage the geographic and attribute database; while the model base management system (MBMS) is to manage the models and the dialog generation and management system (DGMS) manages the interface between the user and the rest of the system.

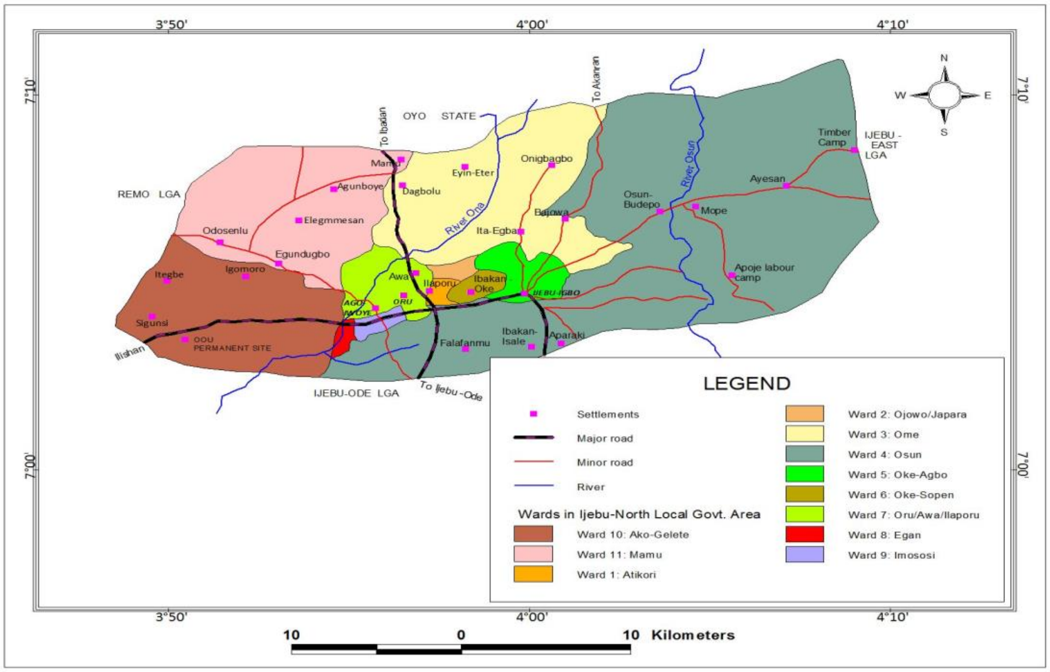
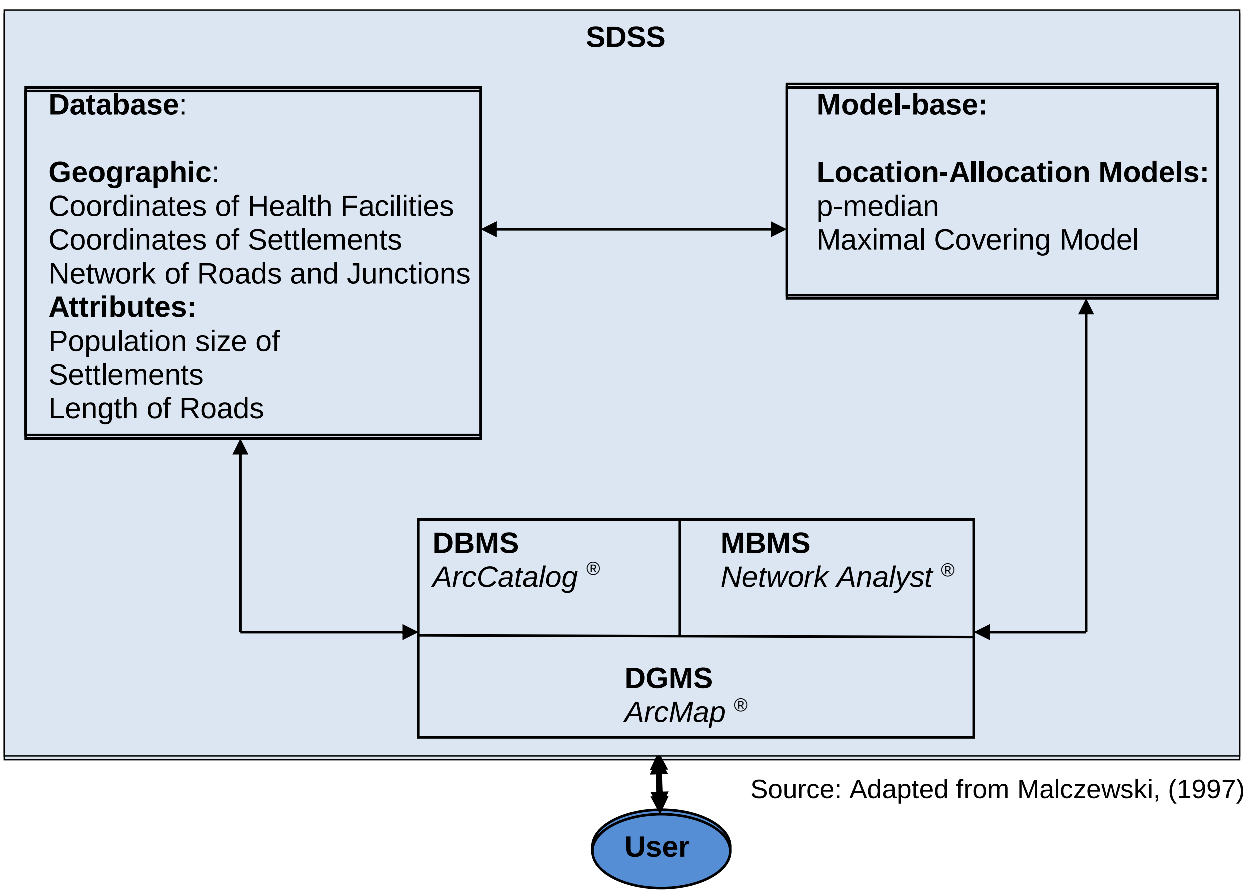


Figure 1. Map of Ijebu North Local Government Area, Ogun State



Source: Adapted from Malczewski, (1997)

Figure 2. The Components of SDSS

This study used the *ArcCatalog*® of *ArcGIS*® v10, a GIS software by Environmental Systems Research Inc. (ESRI) as the database manager (DBMS). The *Network Analyst*® of *ArcGIS*® v10 provided the location-allocation models (MBMS) used in the study. The *ArcMap*® of *ArcGIS*® v10 provided the user's interface as well as the result generator (DGMS).

The Data for the Study

The data used in this study include the population sizes and the coordinates of all the settlements in Ijebu North local government area. The coordinates of the location of all the settlements are obtained from topographic maps of the study area. A digital map was produced by digitizing the paper copy of the topographic map. The map was digitized by first scanning on an Ao-size scanner and the scanned image was digitized on-screen. The coordinates of some known settlements on the map were deliberately taken with the GPS during the field survey to check the compatibility of the GPS readings and the coordinates from the map. The results from the two sources are very close.

The population sizes of the settlements serve as the surrogate for the demand for health facilities. The 1991 population data has been used in this study and this is because the details at settlements level of the more recent 2006 population census data had not been released as at the time of this study. However, the 1991 population data was projected using the 'exponential formula' to 2021. The population projection rates used as stipulated by the National Population Commission (NPC) are: annual growth rate for 1991 – 2000 is 2.60%; 2.75% for 2001 – 2005 and 3.08% for 2006 – to date. The 1991 population data for Ogun State is available at the National Population Commission's office at Abeokuta, Nigeria.

Data on the names and location (addresses) of all ten (10) public primary health facilities in Ijebu-North Local Government Area were derived from the Ogun State Health Bulletin (Ogun State Government, 2010b). Data on the transport network were derived from the topographic maps and preliminary investigation in the study area. Transport network in the study area consists of footpaths, secondary roads, and primary roads. The computation of the shortest routes through the transport network is based on physical distances and not on travel times.

The Database for the Spatial Decision Support System

The geo-database of *ArcCatalog of ArcGIS* supports the storage, operation and analysis of the spatial and attribute data in this study. The coordinates of the location of health facilities and settlements and the road networks form the spatial data, while the population size of settlements forms the attribute data. Geographic representations of features in the database are organized in a series of data layers. A data layer is a collection of common geographic features such as our road network, health facility locations and settlement locations. The concept of arranging data themes in an integrated layer is essential for location-allocation modeling within a GIS environment.

The database for this study was created in *ArcCatalog* and called INLG_geodatabase. The location settlements, health centres and road networks are stored, separately, as themes and their attributes are stored in tables in a relational database model.

The layers created in the designed geodatabase consist of:

(i) Demand points layer – this refers to the locations of the settlements in the study area

(ii) Facility layer – this contains the locations of the health centres in the study area.

(iii) The transport network layer – this contains the roads and footpaths.

The transport networks contain both the networks and their junctions and were used to model the spatial interaction in the analyses.

The Techniques of Analysis

Specifically, two location-allocation methods, the p-median, and the maximal covering location models were used within the SDSS framework to generate the needed location patterns for this study. The two optimisation models are solved to either minimize or maximize certain objectives. Where the number of nodes in the problem being solved is small exact solution methods are used. However, where the number of nodes is large heuristics are often used to solve such problems. The *Network Analyst* is used to develop the origin-destination matrix, which is basic to location-allocation modeling. Given the needed parameters and type of model, the graphical output and tabular results are generated as used in this work. The details of how to run these models are contained in the user manual of *ArcGIS 10* (ESRI, 2010).

Results and Discussion

The spatial distribution of primary health facilities

One primary objective for locating public facilities is for them to match the spatial distribution of users such that the number of people without access to the facilities would be minimized. This section examines the distribution of primary health facilities vis-à-vis the dispersed population distribution in the study area. The descriptive function of the SDSS framework produced the results contained in Table 1 and it shows some salient statistics on the spatial distribution of primary health centres (PHC) in Ijebu North Local Government Area (INLGA). The area had 10 settlements with PHCs and their combined population represents 86.8% of the total population. Settlements without PHCs are 55 and their population represents 15.2% of the total population. This indicates that PHCs are purposely built in areas with high concentration of population. Result in Table 1 also showed that about 38.5% of the settlements are more than ten kilometers from the nearest PHC. These are settlements without access to primary health care according to Ogun State's government definition of access to primary care (Ogun State Government, 2010a).

Table 1. Spatial Distribution of Primary Health Facilities

Attributes of service delivery	Statistics
Total number of settlements	65
Number of settlements with facilities	10
Percentage of settlements with facilities	15.2%
Percentage of settlements without facilities	84.8%
Percentage of population in centres with facilities	86.8%
Percentage of population in centres without facilities	13.2%
Settlements that are above 10km from the nearest PHC	25
Percentage of settlements that are above 10km from the nearest PHC	38.5%

Source: Generated from the Location-Allocation Procedure of *ArcGIS10*

Efficiency and equity in the locational of health facilities in the study area

The planning of public facilities in a rural region can be challenging because of the dispersed pattern of settlements. However, it is the obligation of the government to provide facilities for the benefit of its citizens. Where these facilities are located without regard to the distribution of population, the government could be ineffective in meeting its obligation. Thus, an attempt is made to examine how the government would have been able to meet its obligations efficiently and effectively if use had been made of a planning framework that allows the evaluation of existing service delivery patterns and assessment of policy objectives. To demonstrate these, location-allocation models have been applied and the results are discussed below.

Efficiency in the location of primary health facilities.

In public facilities planning, it is a good practice to evaluate the existing pattern of facilities by comparing it with an optimal pattern (Rushton, 1988). This will allow us to assess how effective the government had been in planning the location of facilities. The p-median (minimize distance) model of the SDSS framework was used to generate the existing pattern by allocating all settlements and their population to the nearest PHC. The statistics for the existing pattern of PHCs and the allocation of users to them are in column 2 of Table 2. The p-median model was also used to find an optimal distribution by finding locations that will yield the minimum total travel distances from all the settlements to the ten PHCs. Some of the new optimal locations might be different from the old locations. The selection of new locations as part of the optimal solution is the main reason why the application of location-allocation (L-A) models to real-life problems is deemed not practicable.

Statistics for an optimal pattern of PHCs are in column 3 of Table 2 and the generated pattern of PHCs and their allocated settlements are shown in Figure 3. There are currently 10 PHCs in the study area. It is shown in Table 2 that if the government had paid attention to optimality in locating PHCs the average distance travelled in the existing configuration of health facilities could have been 5.31km instead of the existing 8.94 km. The average travel distance of 5.31 km generated by the p-median model is very close to the expected 5.0 km target of the government as contained in the health policy (Ogun State Government, 2010a). Thus, the efficiency of the existing configuration is 59.4%. The geographical efficiency is derived by comparing the average distance travelled in the modeled pattern with the average distance in the existing distribution of health facilities.

Table 2. Primary Health Services Delivery in 2021

Attributes of service delivery	Statistics for the Study Area		
	Existing pattern	**Minimise Distance (p-median) pattern**	**Maximal Covering pattern**
Number of facilities	10	10	10
Average travel distance, all (km)	8.94 km	5.3km	6.5km
Maximum distance ever travelled (km)	26.3km	16.6km	9.9
% population in centres without facilities	13.2%	8.8%	21.7%

Source: Generated from the location-allocation procedure of *ArcGIS10*

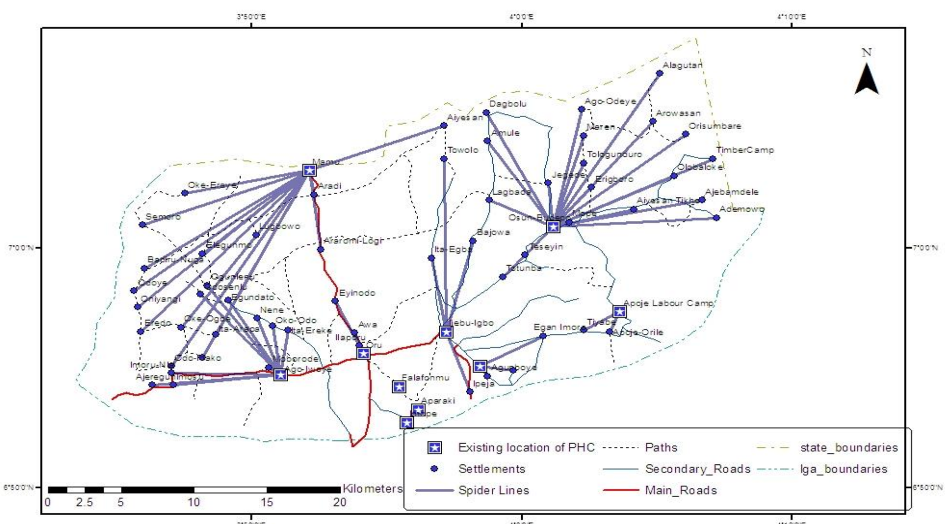


Figure 3. Optimal Allocation of Settlements to the Nearest Primary Health Centres in 2021

Equity in the location of primary health facilities

It has been observed earlier that decision-makers tend to locate PHCs in areas of population concentration and that some settlements are remotely located from existing PHCs. These observations indicate that the distribution of public health facilities in the study area is not equitable. The notion of equity evolved from the need to protect that segment of society less able to compete in the national/regional space economy (Owoola, 2002). Morrill and Symons (1977) considered the use of some measures of locational equity such as a socially imposed minimum standard. The minimum standard in the study area is that no user of PHC should travel more than 10 km. The maximal covering location model of the SDSS can be used to operationalize the concept of equity. It can find the distributional pattern of facilities such that no user would travel more than 10km to PHCs.

The result of the application of the maximal covering location model is shown in column 4 of Table 2 and Figure 4. It is shown that by applying the maximal covering model 10 facility locations can be used to ensure that the maximum distance any user would travel is 9.9 km. This is more equitable than the existing pattern where some users will travel up to 26.3 km to access PHCs. As shown in Table 2, the average distance travelled in the existing pattern of health facilities is 8.94 km and it is reduced to an average distance of 6.5km and a maximum distance of 9.9km in the more equitable maximal covering pattern (Column 4, Table 2). However, in an attempt to be more equitable in the distribution of the facilities the average distance is now higher (6.5 km) compared to the more efficient average distance of 5.3 km and a maximum distance of 16.6km to be travelled in the p-median (minimize distance) modeled pattern. This shows a typical trade-off of locational objectives in public facilities planning. A gain in one criterion will means a loss in another.

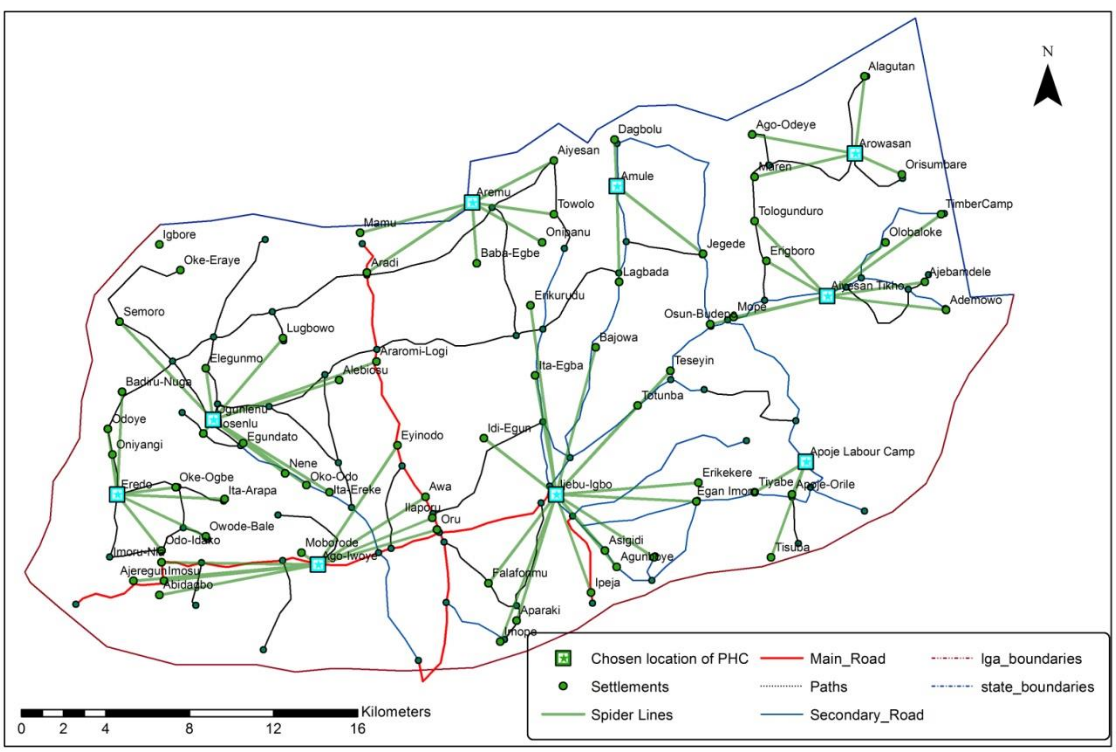


Figure 4. Allocation of Settlements to the Primary Health Centres using the Maximal Covering Model

Conclusion

This study has demonstrated that it is possible to make operational, using a GIS-based SDSS framework, some of the problems facing decision-makers in service development planning in developing countries. Using the SDSS framework this study has demonstrated how to: (i) evaluate the existing spatial pattern of public facilities, (ii) organize facilities more rationally to minimize wastage, and (iii) assess existing government policy on access to PHCs. The argument against the use of the location-allocation (L-A) method in facility planning is that its recommendations cannot be implemented easily. The use of recommendations from the application of L-A models means that facilities that are badly located are to be abandoned and new ones built in more efficient locations. However, if badly located facilities cannot be abandoned then the location of new ones should be ensured to be optimal.

This study has shown how to use a GIS-based SDSS to develop appropriate evaluative tools for the analysis of public facility locations and how to utilize these in the area of health facility planning in Nigeria. Thus, it is hoped that planners in developing countries would adopt these techniques and tools to make their location decisions more logical, consistent, and rational.

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