International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-10 Issue-3, September 2021

Geospatial Location-Based Study for Establishment of New Public Health Centers: A Case of Adama City, Oromia, Ethiopia

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Abstract: ***This study focuses on establishing adequate public healthcare centers to reduce disease spread and untimely death of human lives in Adama City, Ethiopia. There is considerable evidence, owing to poor geographical accessibility, the primary healthcare facility is not reaching the majority of the population in developing nations. This case study has been carried out to identify and prioritize the suitable areas to develop healthcare centers using a Geographic Information System (GIS). Thematic maps and ancillary data are used to analyze location-allocation analysis in ArcGIS-10.4. Required field data was collected using GPS in Adama, Oromia, Ethiopia, and required supporting data from the Municipality of the City. The density of population is the significant input in calculating the standards for services-based location-allocation. Therefore, road networks, existing healthcare facilities, and population density are the critical parameters considered to identify the new healthcare centers to be established to cater to the people's needs. In addition, land use/cover classes and settlement location, proximity to the existing healthcare centers are also considered in GIS analysis for better results. The study identified eight suitable sites to develop healthcare centers in the city. Therefore, the government can utilize the recommendations for infrastructure development planning to improve healthcare facilities based on the accessibility.***

Keywords: ***accessibility, spatial distribution, GIS, health centers***

I. INTRODUCTION

Identification of suitable location is commonly believed as the most vital factor in leading facilities in the success of any region. Appropriate sites help keep to reduce overhead costs and improves accessibility. In addition, a good location can improve access facilities, such as healthcare centers, fire stations, schools, emergency response services, and libraries, which can deliver excellent service to the public at a low cost (ESRI, 2016). Ensuring equitable access to healthcare and promoting population health is critical (Panda and Thakur, 2016, and Obrist et al., 2007). Proponents of human rights believe that healthcare is a human right that is both practical and morally sound (Ram-Tiktin, 2012 and Schraufnagel and Schraufnagel, 2017). People's access to healthcare is thought to be improved by a rights-based approach, particularly in low- and middle-income nations (Durojaye, 2017). However, because healthcare is a finite resource that must be rationed, understanding the root reasons for high healthcare costs is essential for implementing successful solutions (Berdine, 2017). Others contend that the right to health and healthcare must find a balance between societal and individual interests (Brudney, 2016). The use of Geographic Information Systems (GIS) in different organizations has been increasing rapidly in recent years, with the growing recognition of geographical barriers to healthcare access. The spatial planning of healthcare services implies that the use of GIS has been increasing for identifying a suitable site for a given number of services in a defined region. Any healthcare needs spatial distribution of population can be served in an essential factor (Amer, 2007). Ethiopia is Africa's second most populated country and one of the world's least developed countries. The Ethiopian government has committed to enhancing access to vital healthcare services for all citizens through decentralization, supporting private-sector partnerships, and involving all stakeholders. Healthcare has been reorganized to achieve universal access to PHC by 2017 and improve healthcare's responsiveness to the needs and expectations of the public (Balabanova et al., 2011). Despite this, insufficient infrastructure, regional distribution networks, and low service quality have hampered universal access to healthcare (Chaya, 2007). The availability and accessibility characteristics of access were the focus of our research. Accessibility relates to the physical and human components of healthcare services and is dependent on the availability of adequate healthcare resources and their equitable distribution. As a result, either a place-based or a people-based approach can assess the accessibility of healthcare resources and services. The place-based system needs an understanding of the geospatial proximity between the location of service production and the stable dwellings of service users. The second method considers the characteristics of service users, such as their culture, lifestyle, time, and other resources available to them to use the services (Neutens et al., 2010 and Lucas, 2016). In many developing countries, the lack of political access may be the major weakness of the local government.

Manuscript received on September 17, 2021.
Revised Manuscript received on September 25, 2021.
Manuscript published on September 30, 2021.
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Despite having these circumstances, the trend in recent decades has been for national governments to reduce the financial capacity of local governments in absolute terms (UN Documents, 2002). The fast rise of cities with significant populations, particularly in urban areas, has created a shortage of adequate healthcare services (Amer, 2007).

The objective of location-allocation of an area is to give equal access facility of the people most resourcefully. As the name specifies, location-allocation is a twofold function that simultaneously locates services and allocates demand points to the services (ESRI, 2016).

Access to healthcare is seen to accomplish objectives such as enhanced efficiency and better service quality. Universal health coverage (UHC) is crucial in ensuring that everyone accesses healthcare services, despite the rigorous processes required. Under the Sustainable Development Goals (SDGs), the goal of universal health coverage is not considered a goal in and of itself. Instead, Universal Health Coverage is a political decision to strengthen countries' complicated, ever-changing health systems to achieve long-term health improvement (Das et al., 2018, and Reich et al., 2016).

In health care, equality can be defined as equal access, utilization, or results, among other things. From a public policy standpoint, most people think that is the most appropriate approach (Oliver and Mossialos, 2004).

The fight about access to healthcare and access to information is still going on. As a result, there is no single technique for assessing healthcare access. Despite different perspectives on access, such as political, the ability of healthcare use, the first step toward universal healthcare, and the usage and obtainability of health service resources, none of these definitions adequately explain access. Access is a broad term that refers to how clients and the healthcare system are compatible. The availability, accessibility, accommodation, cost, and acceptability dimensions are unique, interconnected, and interdependent variables that help maximize and quantify access to healthcare (Penchansky and Thomas, 1981).

For determining the optimum site for a given service, the location-allocation technique will use one of the following methods: Minimize Impedance, Maximize Coverage, Maximize Capacitated Coverage, Maximize Attendance, and Maximize, and Target Market Share. Subsequently, concerning the quantity and social infrastructure planning, different situations might need another solution. So that, the choice of which method is to be used for optimum site allocation and site confirmation (ESRI, 2016).

The p-median problem is one of the location allocations models used in various applications, ranging from optimizing services placement to the location of new facilities. To minimize the weights of the transportation distances between the benefits and served population, the number p of services is calculated for a given demand in this model (Daskin, 2004). This assumes that the service users use the nearest facility.

The goal of the p-median problem is to locate a set of facilities so that the total travel distance between service centers and demand points is as short as possible. It's a more basic version of the location-allocation modeling techniques (Toregas et al., 1971).

In spatial decision support systems for evaluating the quality of urban life, GIS tools are potent; four main spatial processes are usually used to generate alternative decisions: connectivity (Heywood et al., 2011), communication (Chang K, 2019), proximity (Montgomery et al., 2016), and overlay (Montgomery et al., 2016) and (Grima et al., 2018).

In Adama City, Oromia, Ethiopia, there is a significant insufficiency in the distribution of healthcare centers. The current healthcare service distributions result in limited physical accessibility, significantly impacting the city's growth. Health and social inequalities are exacerbated by the concentration of healthcare services in a single location, poor accessibility, and a lack of healthcare services (Gebreselassie and Rao 2021).

It is a well-known reality that essential healthcare services cannot reach evenly to the population due to limited geographic access, as revealed in a prior study by Gebreselassie and Rao (2021). And therefore, the spatial distribution of healthcare services in Adama is influenced by the city's urban expansion, infrastructure development, and population density variations. In this study, the researcher used the p-median or minimal impedance location-allocation model, which is a network analyzer tool in ArcGIS10.4, to allocate additional healthcare centers based on these factors.

II. LOCATION OF THE STUDY AREA

Adama is located in the Rift Valley, on flat land with mountains and ridged topography surrounding it. The city's most recent approved land-use plan was completed in 2004. This plan's administrative boundary is chosen to limit the scope of the spatial analysis. The city is divided into two main watersheds: Awash and Mermersa, each covering 7, 329.7 ha and 6, 036.8 ha, respectively. Adama city is located 100 km from southeast of Addis Ababa, about 8025'00" and 8036'00" North Latitude and 39011' 57" to 39021'15" East Longitude (Figure 1) at an average altitude of 1620m above the mean sea level. Adama is situated in the Eastern Shewa region, part of the central plateau (Regassa et al., 2020).

Adama city is surrounded by rural districts and rural communities that dwell on farming. There are seven public health centers in the city: Geda health centers, Dembela health centers, Adama health centers, Hawas health centers, Biftu health centers, Anole health centers, and Boku health centers. An institution-based cross-sectional study was conducted at six health centers (Hafiza, 2019)

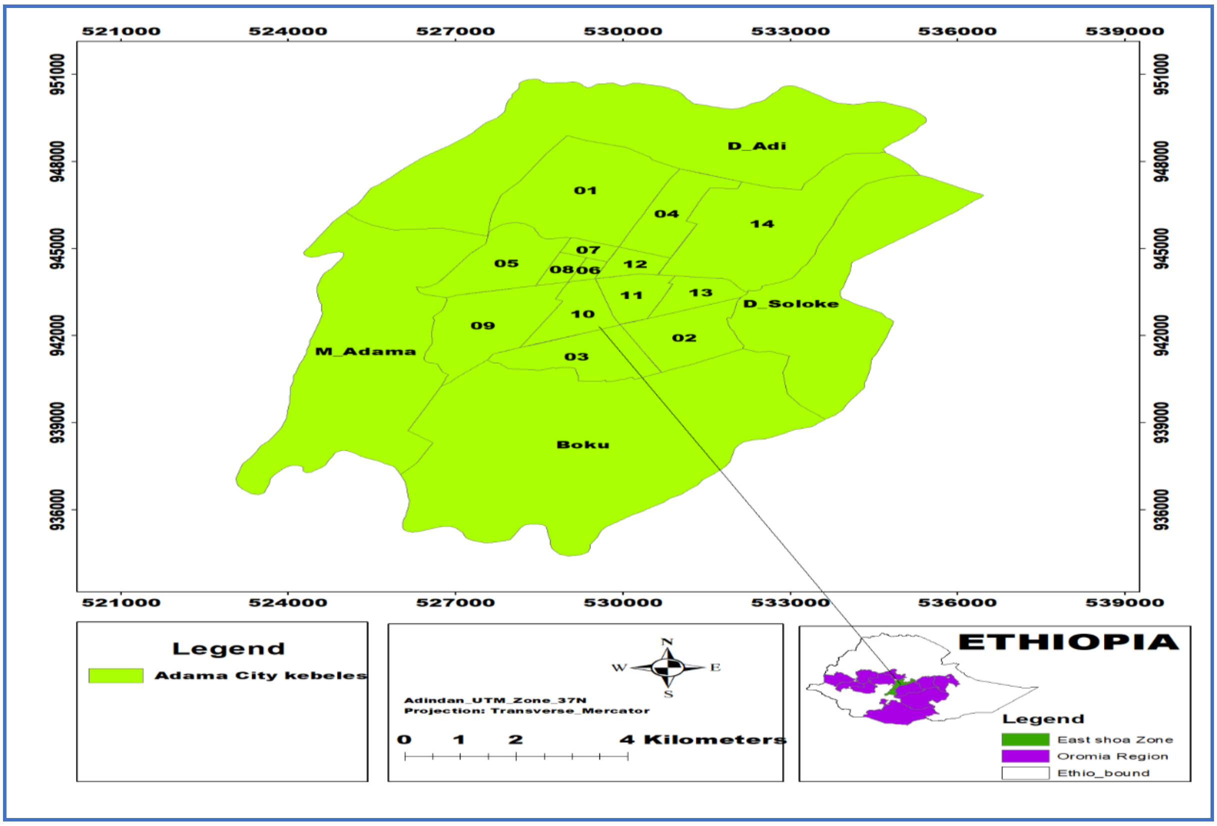

Figure 1. Location of the Study Area

III. METHODOLOGY, DATA PROCESSING, AND ANALYSIS

Data was acquired from primary and secondary sources. GPS was used to obtain location data on existing health services (supply) in all city locations. The Adama municipality and the regional health bureau provided information on the number and location of public healthcare services and national standards. The land use, road network, topographic maps, city boundary, the master plan of Adama city, and population density for each parcel and per block obtained. The total population density of the city was collected from the regional statistics bureau and extracted from the given CAD data, which is the demand point in the analysis. This population data, the demand point in the study, was estimated by the Ethiopian Urban Expansion Initiative Intern Report 2 (Angel et al., 2013). Therefore, the projected population of the city for 2030 is estimated to be around 0.626 million.

In this analysis, three coverages such as healthcare center locations, road network, and the demand point data with relevant aspatial data are used in ArcGIS10.4. All of these data are then used for the service area and location-allocation modeling process. Minimum distance location-allocation model processed the collected point data in ArcGIS for generating service area polygon using Network Analyst Extension. In general, geospatial accessibility is performed by calculating the average weighted distances people have to travel to reach the given healthcare service. On the other hand, the geospatial efficiency is assessed by relating the actual length with the optimum average weighted distances.

The following data is required for siting additional public healthcare centers using the location-allocation model (Table 1).

Table 1 Required Data for Analysis

Data	Source	Function	Obtaining Technique
Healthcare centers	GPS	Location of healthcare centers	Field Survey
Road	CAD data & total station	Road network	Digitizing and editing
Population	AMPPD & Ethiopian Urban Expansion Initiative Report & CAD	Demand point	Extraction and Observation
Land Use Map	Adama Municipality	For new health center site selection	Digitizing and editing

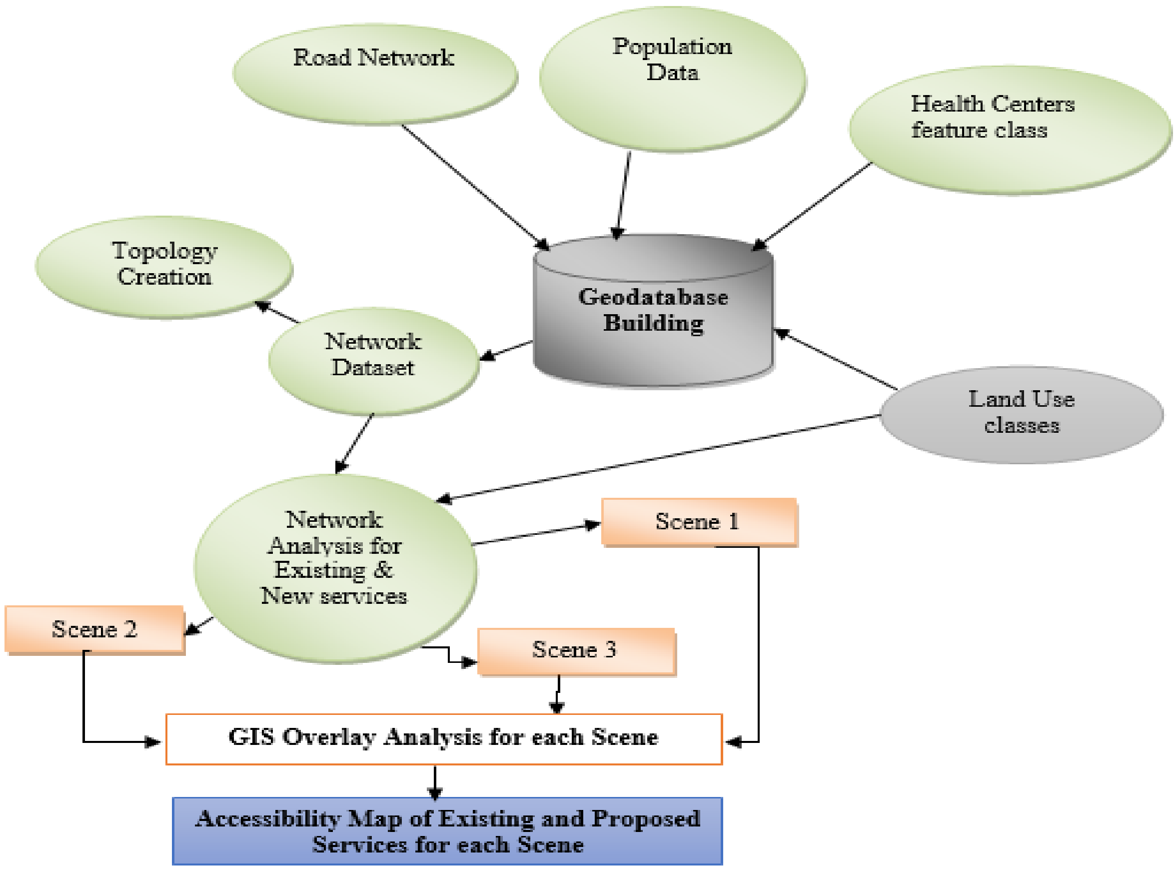

Figure 2. Data analysis workflow

The P-median approach from the location-allocation model was used to determine the best places for additional healthcare centers. To optimize some given measurable objective function, the method includes picking a set of sites for healthcare facilities and assigning spatially distributed groups of needs to these centers. The P-median method is appealing because the shorter the overall weighted travel distance, the easier it is for consumers to reach the nearest healthcare facility. The thematic overlay was performed in consideration of each healthcare center under review to identify the recommended site. Four steps were taken to run the model. The demand items and population density are defined in the first stage. The second phase involves developing a model criterion that uses the minimum distance approach to determine the geographical efficiency of current healthcare centers in terms of weighted distance. The system then performs a location analysis based on the input parameters set in the first two steps in the third step. Finally, after identifying the challenges that people continue to confront, new health centers were proposed. This section used three scenes to map out the spatial distributions of existing and proposed healthcare centers. Accessibility analysis is used to evaluate the performance of each scene's healthcare center.

According to the Health Bureau's norms and guidelines, a 2,000-meter journey distance is utilized as a criterion for determining accessibility. The chosen mode of transportation is walking; an appropriate walking distance is required to be counted as an accessibility characteristic (Assefa, 2008).

Using the collected primary and secondary data, all the data used in this analysis have been extracted and verified with their dataset. An ArcGIS personal Geodatabase has been created (Table 2) for this study.

Table 2. Dataset created in the ArcCatalog window.

Name of the Dataset	Explanation	Forms of the dataset	Feature
Healthcare Center	Geodatabase feature class	Vector	• The point represents the Healthcare Center location
Street Network	Geodatabase feature class	Vector	• Polyline represents streets
Demand Point	Geodatabase feature class	Vector	• The point represents the population for each parcel

Adama Street was used to generate a network dataset in a geodatabase. ArcMap was used to determine the impendence values of service areas for each healthcare center individually using service area analysis settings for healthcare centers after building a network dataset and extracting the point dataset to a geodatabase in ArcCatalog (table 3).

Service areas calculation analysis and location-allocation analysis were employed in this paper. A service area and location-allocation analysis have been calculated based on the parameters and values set in ArcCatalog. Then, utilizing the norms and criteria of these facilities, a service area map for each healthcare center was constructed. These maps show the city's healthcare centers' spatial distribution and accessibility.

Table 3 Service area analysis settings for healthcare centers

Facility	Impedance	Default Breaks	Direction	Allow U-Turn	Restriction
Healthcare center	Distance	500, 1000, 2000	From the Facility	Everywhere	One way

IV. RESULTS AND DISCUSSION

In this study, suitability analysis in ArcGIS10.4 was carried out to find suitable new healthcare locations. Site appropriateness is allocating new and relevant sites by examining existing sites' structure, pattern, and condition using a set of criteria. The current study created a model that integrated multiple theme layers such as existing health centers, road networks, land use land cover (Figure 3), and population density to determine the optimum location. Then, overlaying these theme layers in ArcGIS10.4, new locations for health centers were identified.

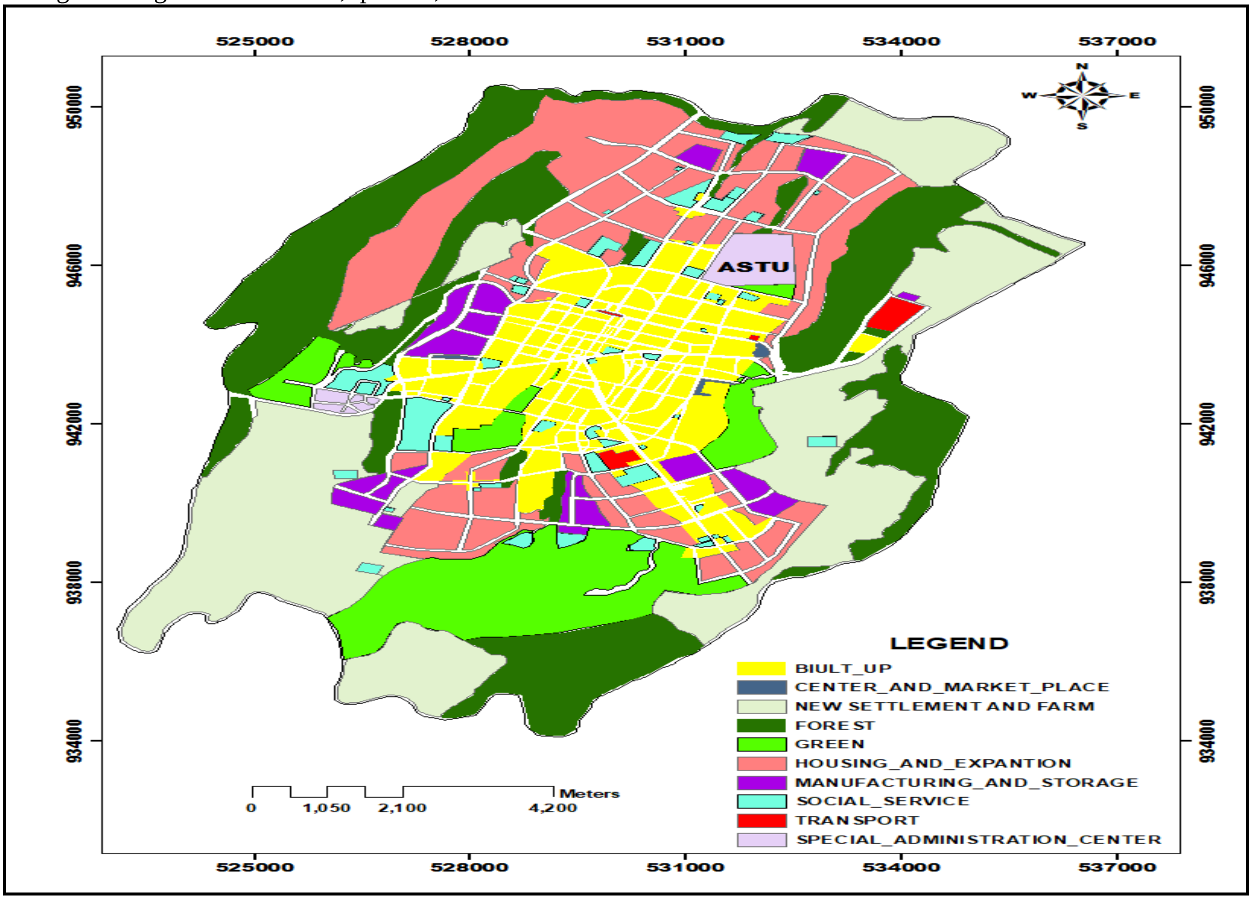

Figure 3. Land Use/cover Classes of Adama City based on Landsat 7 data

From the existing health centers distribution, using service area analysis, the accessibility level of the population for the years 2020 and 2021 is 64.50%, and projected to 2030 is around 66.80%. Therefore, to increase the healthcare center accessibility level of the population by the year 2030, the researcher conducted a location-allocation analysis.

Proposing additional new health centers in under-served areas improves the current problem by making better distribution to optimally serve people in the city. Accordingly, three scenes were generated to adjust the current plan for the city healthcare center (figure 4, 5, and 6).

Scene 1: Locating four additional health centers in underserved areas. These four healthcare facilities are strategically placed in underserved communities. Again, Location-allocation network analysis is used to do this.

Retrieval Number: 100.1/ijrte.C64770910321
DOI: 10.35940/ijrte.C6477.0910321
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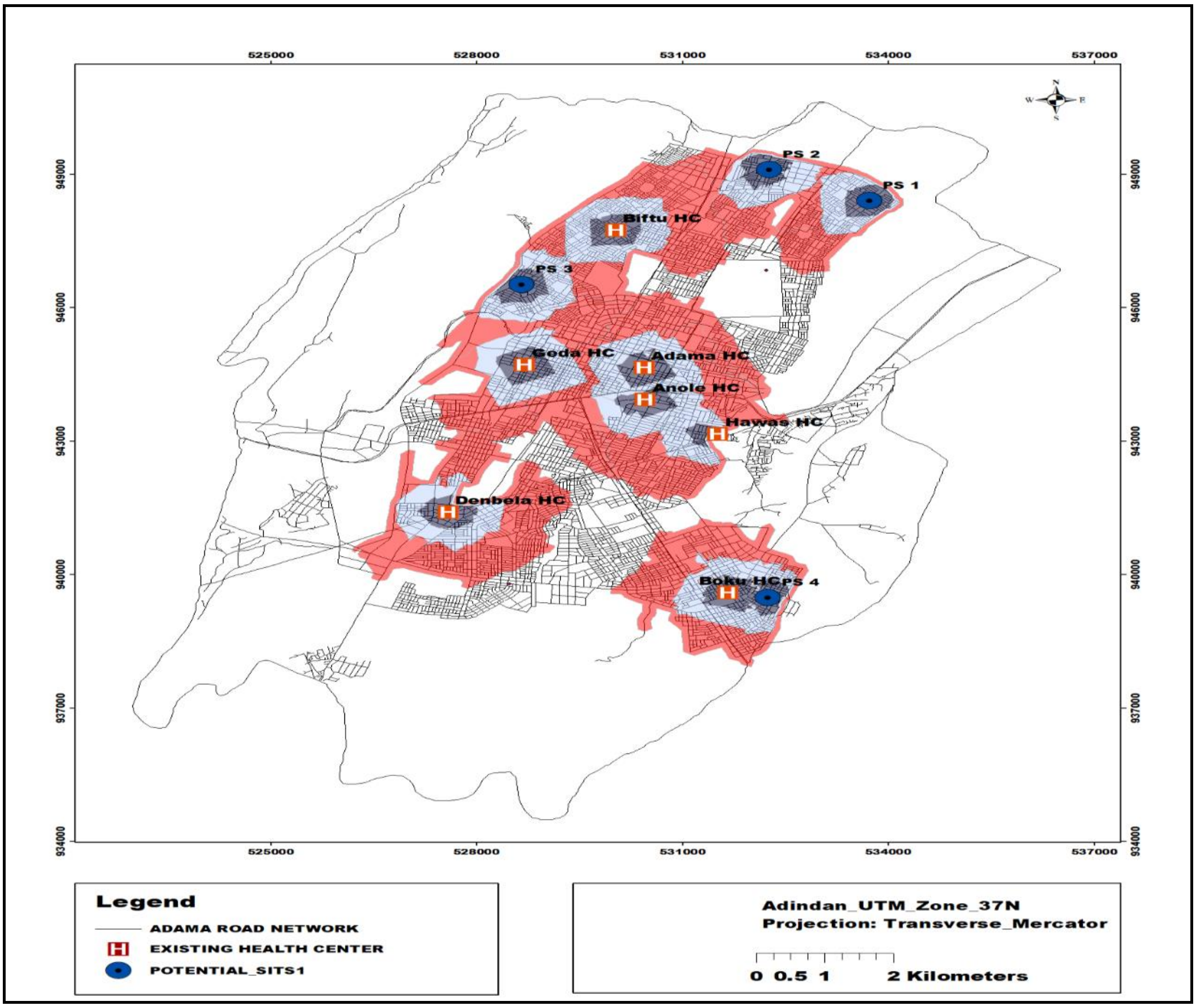

Figure 4: New healthcare facilities resulted from location-allocation analysis (Scene 1)

Table 4: Distance Calculation to New Health Care Facilities within 2000m (scene 1)

ID	Name of Health Center	Approximate Serving Population	Approximate Serving Population in %	Total distance in meters	Total Weighted Distance (meter)
1	Adama Health Center	47160	7.53	6709508.166	53676065.33
2	Anole Health Center	11720	1.87	1648310.441	13186483.53
3	Biftu Health Center	56408	9.01	8093120.2	64744961.6
4	Boku Health Center	58016	9.27	7592501.839	60740014.71
5	Denbela Health Center	77120	12.32	13024487.2	104195897.6
6	Geda Health Center	54272	8.67	6812466.384	54499731.07
7	Hawas Health Center	33168	5.30	5271057.328	42168458.62
8	Potential Site1	31384	5.01	3253064.898	26024519.18
9	Potential Site 2	28040	4.48	4069192.42	32553539.36
10	Potential Site 3	55344	8.84	5527757.014	44222056.11
11	Potential Site 4	25416	4.06	2328021.293	18624170.35
Total Number of Population		**478048**	**76.37**		

From the above figure 4, four potential new health centers sites to the existing health facility in the study area. But still, there is approximately 216,328 population overloaded due to limited health centers and 147,952 beyond the standard conditions; a total of 364,280 population will have no access to these health services.

Scene 2: Locating two additional health centers in underserved areas on top of scene 1. One of the current plan's recommendations is to establish two more health facilities with different location configurations. These six health centers are strategically placed in underserved communities. This is accomplished through the use of location-allocation network analysis.

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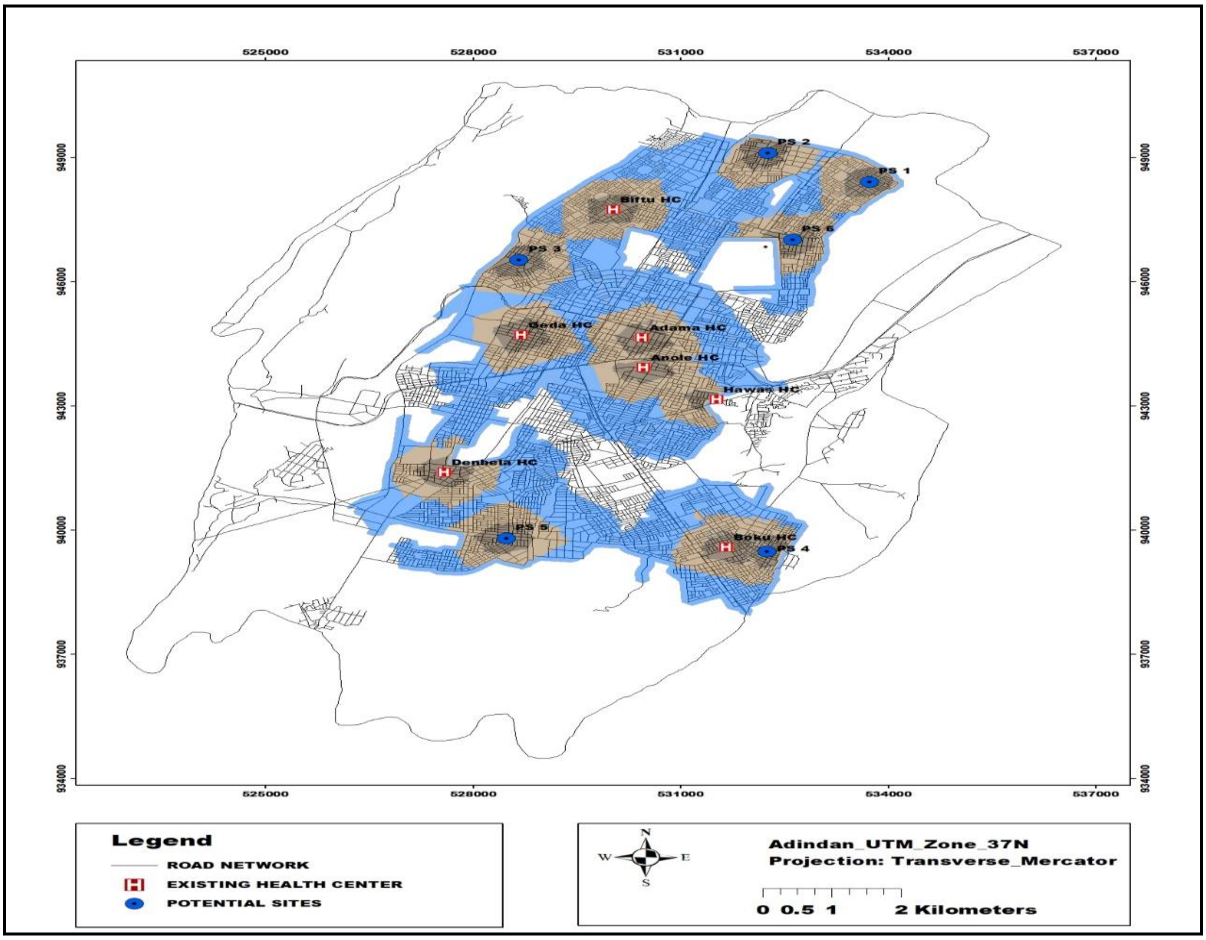

Figure 5: New health centers resulted from location-allocation analysis (scene 2)

Table 5: Distance Calculation to Proposed Health Care Facilities Within the City Limits (Scene2)

ID	Name of Health Center	Approximate Serving Population	Approximate Serving Population in %	Total distance in meters	Total Weighted Distance (meter)
1	Adama Health Center	47152	7.53	6707509.367	53660074.94
2	Anole Health Center	11720	1.87	1648310.441	13186483.53
3	Biftu Health Center	52448	8.38	7195859.151	57566873.21
4	Boku Health Center	57424	9.17	7450560.053	59604480.43
5	Denbela Health Center	44248	7.07	6170680.355	49365442.84
6	Geda Health Center	54272	8.67	6812466.384	54499731.07
7	Hawas Health Center	33168	5.30	5271057.328	42168458.62
8	Suitable Site 1	26432	4.22	2299662.305	18397298.44
9	Suitable Site 2	22416	3.58	2867820.881	22942567.05
10	Suitable Site 3	55344	8.84	5527757.014	44222056.11
11	Suitable Site 4	25416	4.06	2328021.293	18624170.35
12	Suitable Site 5	81672	13.05	11315623.84	90524990.7
13	Suitable Site 6	25216	4.03	3815768.373	30526146.99
Total Number of Population		**536928**	**85.77**		

As shown in Figure 5, two additional prospective sites have been added, bringing the total number of future locations in the research area to six. However, roughly 227,792 population denied access to these health services owing to overcrowding, and 89072 will be denied access due to exceeding the standard, for a total of 316864 persons.

Scene 3: Locating two new health centers on top of scene 2, which cover more than 85% of under-served Service Areas

Another plan adjustment recommendation is to propose a location design covering more than 85% of all underserved locations.

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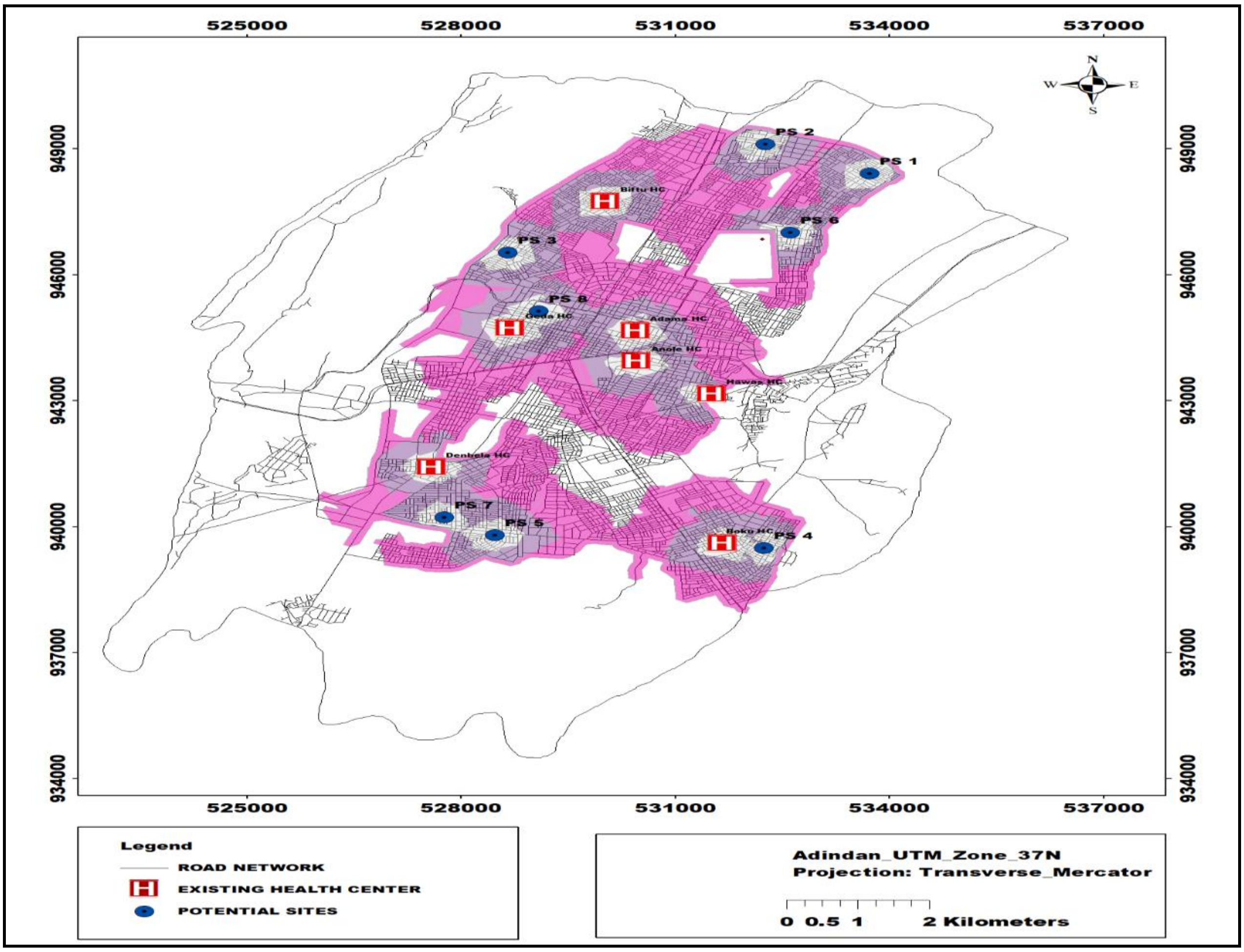

Figure 6: Location identified for health centers resulted from Scene 3.

A percentage greater than 85 percent is used because it is assumed that if 85 percent of underserved areas are served, the majority of the population is served. The number of health centers to be offered and their spatial arrangement is proposed in this model (Table 6).

Table 6: Distance Calculation to Proposed Health Care Facilities within 2000m (Scene 3)

ID	Name of Health Center	Approximate Serving Population	Approximate Serving Population in %	Total distance in meters	Total Weighted Distance (meter)
1	Adama Health Center	42496	6.79	5980691.317	47845530.54
2	Anole Health Center	11720	1.87	1648310.441	13186483.53
3	Biftu Health Center	52448	8.38	7195859.151	57566873.21
4	Boku Health Center	57424	9.17	7450560.053	59604480.43
5	Denbela Health Center	32280	5.16	4456724.912	35653799.29
6	Geda Health Center	43760	6.99	5658621.589	45268972.71
7	Hawas Health Center	33168	5.30	5271057.328	42168458.62
8	Potential Site 1	26432	4.22	2299662.305	18397298.44
9	Potential Site 2	22416	3.58	2867820.881	22942567.05
10	Potential Site 3	47080	7.52	4206017.825	33648142.6
11	Potential Site 4	25416	4.06	2328021.293	18624170.35
12	Potential Site 5	65008	10.38	8964394.29	71715154.32
13	Potential Site 6	25216	4.03	3815768.373	30526146.99
14	Potential Site 7	28760	4.59	2311116.661	18488933.29
15	Potential Site 8	23432	3.74	2269763.529	18158108.23
Total Number of Population		**537056**	**85.79**		

Two more new sites have been added to the study area, as indicated in Figure 6, bringing the total number of prospective sites in the study region to eight. However, about 268,432 population do not have access to these health services due to excess population, with 179,488 denied access due to overcrowding and 88,944 denied access due to exceeding the standard.

In general, according to the location-allocation model, more than eight new facilities are required to service the population optimally within the allowable travel distance. However, for the time being, the researcher suggests that eight new facilities be built because calculating all of the amounts from demand could lead to overpopulation and facilities being too close to one another.

V. CONCLUSIONS AND RECOMMENDATION

Conclusions

The p-median problems have been used to create the location-allocation models and approaches discussed in this study. The goal of the p-median problem is to position a set of facilities so that the total travel distance between facilities and demand points is minimized. In underdeveloped nations, location analysis utilizing p-median formulations appears to be one of the most preferred healthcare service location planning techniques.

The location-allocation analysis is one of the methods that may be used to plan the provision of social infrastructure. With reliable data on distance and demand, a location-allocation model can determine the best locations. In addition, these models can be used to find new ideal placements for new facilities in a study region with various constraints. This research has shown that using a location-allocation strategy for social infrastructure development can recommend the best locations, resulting in enhanced geographic accessibility for people.

This facility siting challenge can be solved with the use of a location-allocation model. This methodology has the potential to produce highly beneficial outcomes. Based on this strategy, the plan was suggested to be improved by providing a new location for healthcare services. This was done using three scenes; 76.37 percent of the demand was met in the first scenes. In the second and third scenes, 85.77 and 85.79 percent of the demand were met. More than eight additional health centers and redistribution of the existing health centers are required to serve all populations.

Even if the final decision to develop social infrastructures rests with politicians or decision-makers, this outcome can serve as an essential input for them to make that decision.

Recommendation

This study used location-allocation analysis to select appropriate suitable new sites to improve health facilities.

Thus, at the end of this research, the researcher has specific recommendations that may help the application of the result of this research indicated hereunder:

- The institution in charge of using the findings of this study is currently and, in the future, doing development planning in the city.
- Authorities of the City should form a GIS group together with other experts in this area; the city's municipality would monitor the entire activity.
- City authorities must reserve areas for health facilities as suggested in this study.
- Planners must use GIS to evaluate the concepts of safety, cost, and speed when conducting city planning exercises.

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Retrieval Number: 100.1/ijrte.C64770910321
DOI: 10.35940/ijrte.C6477.0910321
Journal Website: www.ijrte.org

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