Site Suitability Evaluation for New Health Facilities Using Geospatial Technologies in Hadith Zone, Ethiopia

Abstract

Healthcare facilities in developing countries are mostly located in urban and semi-urban areas. Ethiopia's health development has been significant, but the country still faces high morbidity and mortality rates, leading to a relatively poor health status. The study aimed to evaluate the accessibility of healthcare facilities in the Hadiya Zone using geospatial technologies. The road network, existing healthcare center, population data, slope, and land use land cover factors were used from different sources. The health services suitability evaluation was conducted by using geospatial techniques (Arc GIS 10.8 and Erdas Imagine 2014 software and analytic hierarchy process approach). The findings show that the relative accessibility reveals that from 0.0028 to 0.0154 values indicated very low access to health services. 0.79% of the study area was found as permanently unsuitable, while 41.68% of the study area was highly suitable and had potential for a new Healthcare facility site. The result reveals that spatial discrepancy exists in the case of access to healthcare facilities and the location of existing healthcare is largely clustered around the town's area. While there is poor planning of healthcare center distribution, the concerned body should identify the potential sites and allocation of new healthcare to reduce the spatial disparity of the health services.

Keywords: Accessibility index, Analytical hierarchy process, spatial accessibility, three-step floating catchment area, suitability analysis.

1. Introduction

Unreliable spatial distribution of population, healthcare services, and transportation roads can lead to spatial disparities and poor accessibility to required healthcare facilities (Ahmad, 2012). WHO (2017) reports that half of the world's population struggles to access health services, leading to 100 million people experiencing extreme poverty annually due to high health costs and inadequate accessibility. 11 million people in Africa are living in poverty due to insufficient household income for essential healthcare services, with significant disparities in access and availability in Sub-Saharan Africa and Southern Asia (Tessema et al., 2022).

Ethiopia's main health issues are preventable communicable diseases, reproductive health-related issues, and nutritional disorders. Despite significant improvements in recent decades, the population still experiences high morbidity and mortality rates, and the health status remains relatively poor, according to the Ethiopian Public Health Institute (EPHI, 2014).

Factors influence healthcare accessibility, affecting the success rate of people receiving appropriate health services to manage diseases and maintain health (Qiang Pu, 2020). Geospatial technology analysis aids in understanding the evolving spatial arrangement of healthcare services, their connection to access and health outcomes, and exploring ways to modify medical service delivery (Luqman & Khan, 2021).

This study aims to fill methodological gaps in previous research by examining healthcare facility access in rural and urban areas, including distance, time, and suitable site selection criteria. It also explores new sites for healthcare facilities in the Hadiya Zone, focusing on the development of geospatial technologies to measure facility distribution and accessibility. The analysis of service areas revealed that there is no planned distribution of healthcare centers in the community's demanding environment, leading to a high concentration of centers in infrastructure and utility-filled areas, with few in other areas. This situation has resulted in some areas remaining unreachable while others are accessible for coverage and accessibility.

2. Materials and Methodology

2.1 Data Types and Sources

For this study, experimental research design, mainly spatial data processing conducted by using the geospatial technologies-based analysis was used. Land sat OLI 8 /2022 with Path 169 and Row 055 and 30m spatial resolution and DEM was obtained from Earth Explorer for producing LULC map and slope map, respectively. Google Earth was utilized to digitize a road network, create a network dataset, and calculate travel time and distance. The available point-based recorded healthcare center location and Gridded Population data were also obtained from the Hadiya Zone Healthcare Office and statistical plan and socio-economic department, respectively.

To evaluate the site of new healthcare centers five factors (the LULC map, gridded population data, location of the existing healthcare centers, road network, and slope map) were used. The software (Erdas Imagine 2014 software for image processing and classification, ArcGIS 10.8.1 for data analysis and mapping, GPS, and Google Earth to obtain control points, to locate and determine the proximity zone of healthcare services were applied. The researcher obtained 156 ground truth points to validate the classification of land use data analysis.

2.2 Image Pre-processing and classification

The researcher utilized image pre-processing techniques in ERDAS Imagine 2014, including layer stacking, radiometric and geometric correction, atmospheric correction, haze, and noise reduction, to classify Landsat images into six classes. They used a maximum likelihood classification algorithm, assuming a normal distribution of statistics for each class in each band.

2.2.1 **Land Use Land Cover Factor Analysis**

The OLI/2022 Landsat image was classified into six major classes and five suitability ranges based on the FAO's (2006) land suitability classification. 156 ground truth points were used to validate the image from Google Earth and GPS, and accuracy assessment was evaluated using an error matrix involving user, producer, overall accuracy, and kappa coefficient results.

2.3 Road Network Factor Analysis

Network analysis is the ideal technique for managing routing and transport problems by providing correct and short solutions (Akay & Aziz, 2016). For this study, the road community datasets were acquired from Open Street Map and digitized from Google Earth. District and national roads are reclassified into three main road classes: National (Primary), Gravel (Secondary), and Local (Local). These classifications help locate the nearest facilities, calculate service areas, create an OD cost matrix, and identify new facilities with satisfactory response times for the community. The classification helps determine the cost of accessing these locations from every origin. ArcGIS Network Analyst was used for processing and analyzing the proximity of healthcare facilities.

Getu Desalegn, (2020), and (Jalil et al., 2018) based on World Health Organization standards, suggest that healthcare facilities are more suitable when they are located near accessible transportation roads. The study analyzed the suitability level of healthcare facilities in the study area based on their distance from major roads and suitability level from 0.1 to 0.7km in five default breaks.

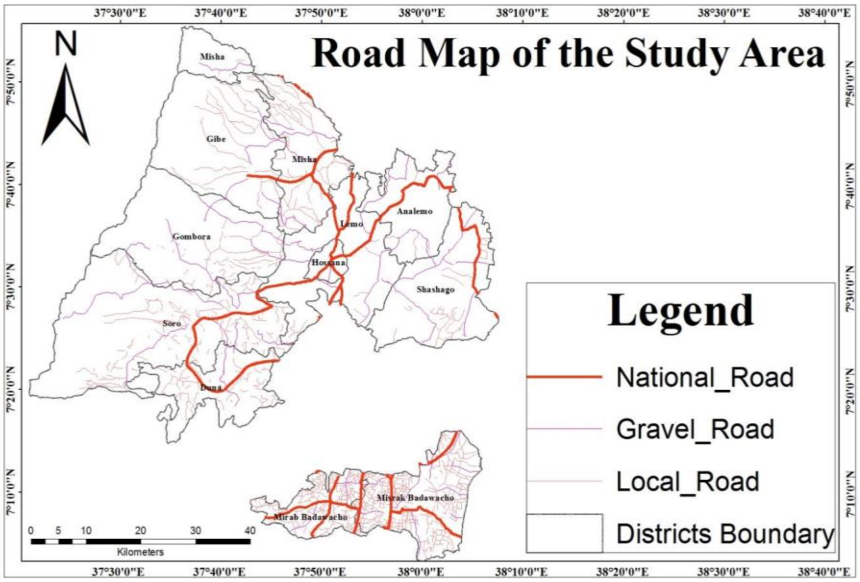

Figure 1 Location Map of Study Area.

2.4 Slope Factor Analysis

Researchers suggest that low-slope areas are ideal for developing healthcare services, (EFMHACA, 2012 and Gelan, 2021) as they create a common space for all societal sectors, including children and the elderly, making necessary measures crucial for their successful implementation. This study, considered values based on FAO, (2006) slope factor suitability ranged from 0^0 to 5^0 (S1), 5^0 to 10^0 (S2), 10^0 to 15^0 (S3), 15^0 to 30^0 (N1), and above 30^0 are (N2). Steep slope areas are more susceptible to erosion due to high surface water rushing, which significantly impacts healthcare facility sites.

2.5 Existing Healthcare Facility Suitability Factor Analysis

The study analyzed the suitability of health services from existing facilities in the study area using a buffer zone (distance) from 5 to 25km, using five suitability classes Kanga et al., (2021), (S1) for distances under 5km, (S2) for distances between 6-10km, (S3) for distances between 11-15km, (N1) for distances between 16-20km, and (N2) for distances over 25km.

2.6 Population Density Suitability Factor Analysis

Population density is a crucial factor in determining the most suitable site for healthcare distribution and accessibility. Researchers (Abebe, 2016, Mandell 1991, Gigantesco & Giuliani 2011, Oppio, 2016 Almansi et al., 2022) indicate that populated areas are ideal for healthcare service distribution, with neighborhood population being a key factor in site selection. The suitability of facilities is analyzed based on population density, with levels ranging from 80 to 20. The study suggests that density >80 is the most suitable (S1), followed by 50-80 (S2), 20-50 (S3), 5-20 (N1), and <5 (N2).

2.7 The process of determining criteria weights using the AHP method.

The Analytic Hierarchy Process (AHP), developed by Saaty in 1980, is a decision-making tool used for organizing and analyzing complex problems using multiple criteria.

Table 1 provides a comprehensive overview of the fundamental scale preferences in AHP.

The strength of significance	Definition	Explanation
1	Equal significance	Two activities give equally to the objective
3	Moderate significance	Judgment strongly favors one activity over another
5	strong significance	Decisions intensely favor one activity over another
7	Very strong significance	The activity is highly favored and its dominance is evident in practice.
9	Extreme significance	The evidence supporting one activity over another is of the highest possible affirmation.
2, 4, 6, 8	Transitional values	When compromise is necessary
1/3, 1/5, 1/7, 1/9,	value for inverse comparison	

The table is based on Saaty's 1980 work.

The AHP procedure calculates a consistency ratio (CR) based on the opinions of experts and questioners. The first step involves pairwise comparisons between each criterion. Mathew et al., (2017) emphasize the importance of proximity to roads and land use in healthcare site suitability analysis. Rahaman, (2018) suggests that hospitals should be located near major roads, as they are the main communication system in the city, and in proper land use, mainly in residential areas. Qualitative data and analyses are used to make the site more reliable, considering population concentration and employment concentration. The hospital is needed in high-population concentration areas and less employment-focused areas, as these areas have poorer populations who use public hospitals.

Table 2 presents a pair-wise comparison matrix of criteria.

Criteria (C)	Di.road	LULC	Pop. den	Exist. HF	Slope
Di.road (C1)	1	3	5	3	7
LULC (C2)	1/3	1	3	2	2
Pop. den (C3)	1/5	1/3	1	1/2	2
Exist.HF(C4)	1/3	1/2	2	1	3
Slope (C5)	1/7	1/2	1/2	1/3	1

Criteria value

Criteria	C1	C2	C3	C4	C5
C1	1	2	3	2	7
C2	0.5	1	2	2	2
C3	0.33	0.5	1	2	3
C4	0.5	0.5	0.5	1	2
C5	0.14	0.5	0.33	0.5	1

The process involves converting fraction values to decimals for subsequent calculations. The matrix is then normalized and the criteria weight is calculated. Each column value in the evaluation matrix is divided using the column sum to obtain its normalized score. The criteria weight is calculated by dividing the sum of each normalized value row by the number of criteria for the given output, as shown in Table 2.

Table 0 Normalized Pair-Wise Comparison Matrix and Criteria Weight

Criteria	Di.road	LULC	Pop. den	Exist. HF	Slope	Criteria weight	Weighted Sum value	CR=WSv/Cw
Di.road (C1)	0.50	0.56	0.43	0.44	0.47	0.48	2.460	5.13
LULC (C2)	0.17	0.19	0.26	0.29	0.13	0.21	1.078	5.14
Pop.den (C3)	0.10	0.06	0.09	0.07	0.13	0.09	0.455	5.06
Exist.HF(C4)	0.17	0.09	0.17	0.15	0.20	0.16	0.783	4.91
Slope (C5)	0.07	0.09	0.04	0.05	0.07	0.06	0.330	5.50
Weighted average								5.15

The next step involves calculating consistency by multiplying each matrix value of the criteria by the criteria weight, obtaining the weighted sum value by summing each row of consistency values, and then dividing the weighted sum by the criteria weight to calculate the weighted average.

The consistency of judgments is determined by the Consistency Ratio (CR) = C.I. / RI, where CR is the consistency ratio and CI = (λmax –n)/n – 1 the consistency index is calculated by dividing the □weighted average by the number of criteria (n), denoted by λmax. The random index value of the criteria RI is obtained from the Saty table. A score below 1 is considered acceptable.

Table 4 presents the Random Consistency Index (RI) as per Saaty's 1980 research.

Matrix size	1	2	3	4	**5**	6	7	8	9
Random Consistency Index (RI)	0.00	0.00	0.58	0.90	**1.12**	1.24	1.32	1.41	1.45

The final outputs showed λmax=5.14, CI = 0.037, RI = 1.12, CR = 0.033, C.R = 0.033 < 0.1 Saaty suggested that inconsistency is acceptable if the CR is less than or equal to 0.1.

Table 5 Calculated Weights for Criteria

Criteria's	Weight	
C1, Distance to Road	W1= 48	Total = 100
C2, Land use land cover	W2= 21	
C3, Population Density	W3= 9	
C4, Existing Healthcare Facilities	W3= 16	
C5, Slope	W4= 6	

2.7.1 Weighted Overlay and Site Suitable

A comparison matrix was created and criteria weights were calculated for each factor using a scale from 9 to 1/9. The reclassified input datasets were assigned weight values to express the importance of each criterion to other criteria for suitable site selection for healthcare services (Abebe, 2016, Ahmed et al., 2016, Almansi et al., 2022). All datasets were overlaid using a weighted overlay tool or a raster calculator in ArcGIS.

The decision approach suggests suitable sites for allocating new healthcare facilities in inaccessible areas. AHP analysis was used to determine the best site and required area. The healthcare facility site suitability map (HFSSM) was produced using a logical formula from Malczewski (2006) and developed in a Geo-processing model builder using ArcMap10.8 spatial analyst weighted overlay extension tool.

$$Sm = \sum n \; i=1 Wi * Ci$$

The study uses a suitability map, criteria weights, and factor reclassified criteria map (HFSSM) to determine the suitable site for a healthcare facility. The road is the most important factor, with a weight of 48%, followed by land use with a weight of 21%. The least important criteria are distance from the existing health facility, population density, and slope, with weights of 16%, 9%, and 6%, respectively. The study aims to identify the most suitable healthcare facility site in the study area.

Saaty (1980) suggests that a CR < 0.1 indicates consistency, while above 0.1 indicates out of it. If the pairwise values/weights are out of the consistency limit, they need to be reconsidered and repeated until the desired CR < 0.10 is reached. In this case, the calculated CR was 0.033/3.3%, indicating consistency.

Table 6 presents the suitability level based on the criteria for healthcare site selection.

Criteria Extent units		Suitability rank					Weights (%)
		5 S1	4 S2	3 S3	2 N1	1 N2	
Criteria	Units						
LULC	Class	BL&Os	CL	-	Bu &FL	WB	21
Distance. to road	Km	<5	5-10	10-15	15-20	>25	48
Dist. Existing HF	Km	<0.1	0.1-0.3	0.3-0.5	0.5-0.7	>0.7	16
Slope	Degree	<5	5-10	10-15	15-30	>30	6
Pop. den.	Per/ha	>80	50-80	20-50	5-20	<5	9

Note: the table explains the concept of barren land(BL), open space(Os), forestland(FL), built-up area(Bu), water body(WB), population density(Pop. den), and cropland(CL).

Site suitability is a method of determining the best locations for new or ideal healthcare facilities by analyzing their structure, model, and condition, using factors like road, slope, LULC, existing healthcare facilities, and population density. Thematic maps were converted into raster format and reclassified into five suitability classes (unsuitable, not suitable, moderately suitable, suitable, and highly suitable) for selecting potential healthcare service sites. Each category was assigned a score on a 1-5 to 1/9 point scale, with 1 assigned to the least suitable and 5 to the most suitable, as per Saaty's 1980 guidelines.

Methodological Flow Charts

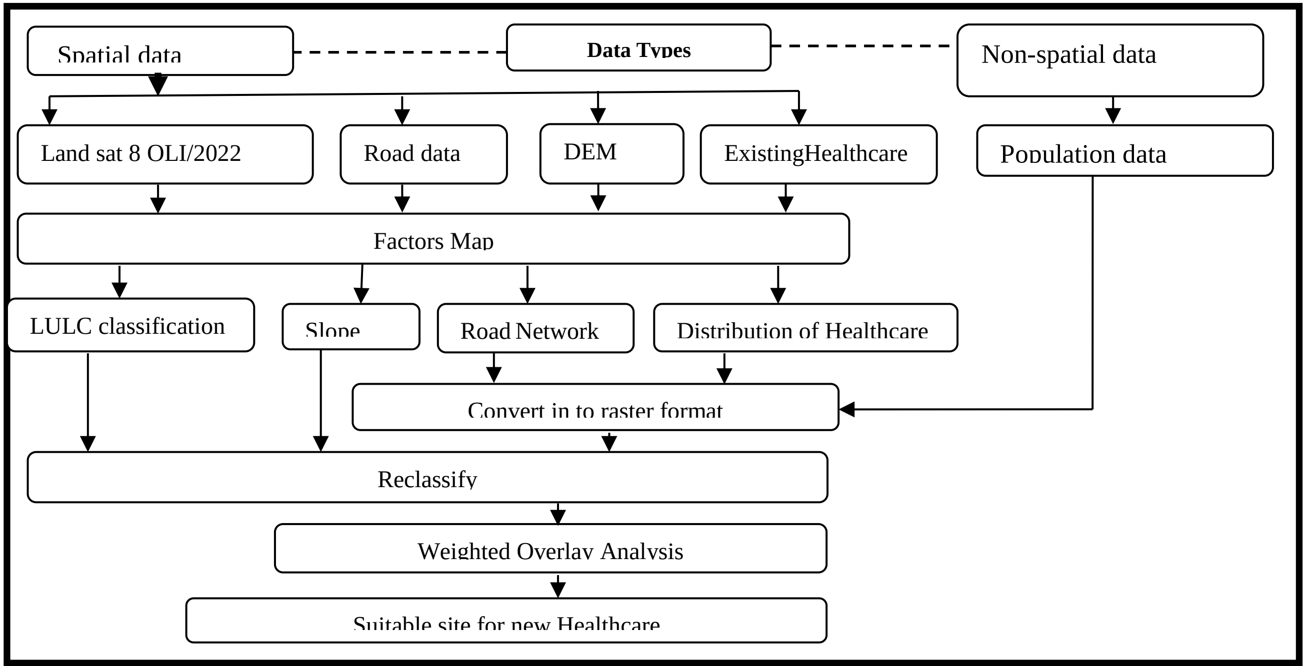

Figure 2 The text provides an overview of the integrated research design and methodology.

4.1 Site Suitability Analysis of Healthcare Facility

Spatial analysis methods involve converting input data into a valid format, such as vector or raster, for decision-making purposes. In the Hadiya zone study area, the criteria for site selection included existing healthcare facility centers, roads, population, slope, and land use land cover. The Euclidean distance toolset from spatial analyst tools converts these into raster format, calculating the proximity for each pixel in the output raster from the existing source data within the study area.

4.2 Suitability Analysis of Land Use Land Cover

Parvin (2021) suggests that barren land, low economic land, and less resourceful land are highly suitable for new healthcare facilities. The reclassification was performed using Arc GIS tools and FAO's 2010 global forest assessment standard. Open space and barren land are most valuable, while water bodies are less valuable. Forests, and built-up areas, are moderately suitable and croplands are suitable for new healthcare centers. Table 7 shows land use suitability classes and area coverage in hectares and percentages.

Table 7 presents the classifications of land use suitability classes and their area coverage.

LULC_Class 2022	Suitability level	Area (hac)	Area (%)
Waterbody	N2	5046.51	1.37
Built-up and Forest land	N1	156459.53	42.49
Cropland	S2	139198.55	37.80
Barren land and Open space	S1	67497.98	18.33

Source: Reclassified land use map attribute table.

The study found that 42.49% of the study area was not suitable for healthcare facility sites, while 18.33% and 37.80% were highly suitable and suitable, respectively. The remaining 1.37% was permanently unsuitable. The data was extracted from a reclassified map of the attribute table and converted into respective units of measurement.

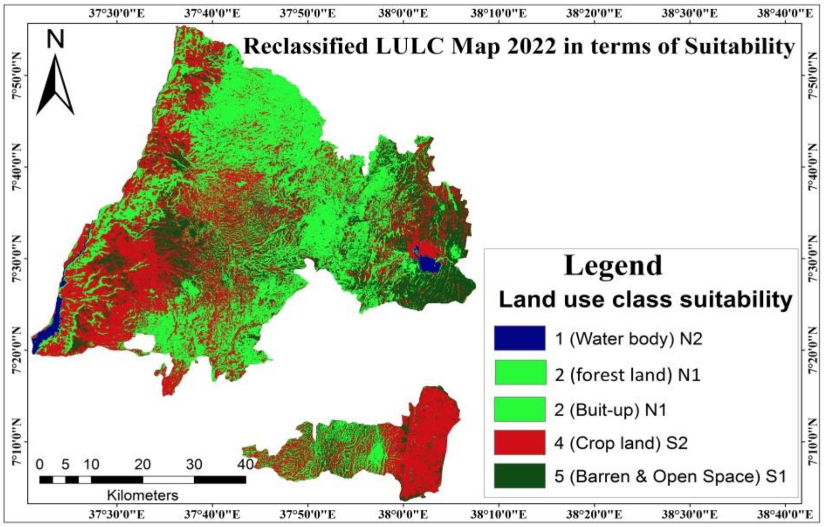

Figure 3 The study area's land use/cover suitability map,

4.3 Suitability Analysis of Distance to Main Road

Getu Desalegn 2020, and Jalil et al.,'s 2018 study on District Health Facilities by World Health Organization standards suggest that healthcare facilities are better located near roads for transportation access. The line feature map was converted into a raster feature and reclassified into five classes based on road distance. Highly suitable areas are within a 0.1 km buffer, moderately suitable areas are within 0.3-0.5 km, and low suitable areas are within 0.5-0.7 km. All roads outside these buffers are deemed not suitable for healthcare facilities. The study highlights the need for better road connectivity for healthcare facilities.

Table 8 presents road suitability classes and their area coverage in the study area.

Distance (km)	Suitability level	Area (hac)	Area (%)
>0.7	N2	11920.42	3.27
0.5-0.7	N1	21096.09	5.78
0.3-0.5	S3	50865.02	13.95
0.1-0.3	S2	113034.22	30.99
<0.1	S1	167810.81	46.01

The source was obtained from the reclassified road map attribute table.

The study area's road proximity suitability was assessed, finding 46.01% and 30.99% of the area highly suitable and suitable, respectively, while 5.78% and 3.27% were not suitable and unsuitable. The remaining 13.95% of the area was moderately suitable for potential healthcare facility sites. The road network proximity suitability map is provided.

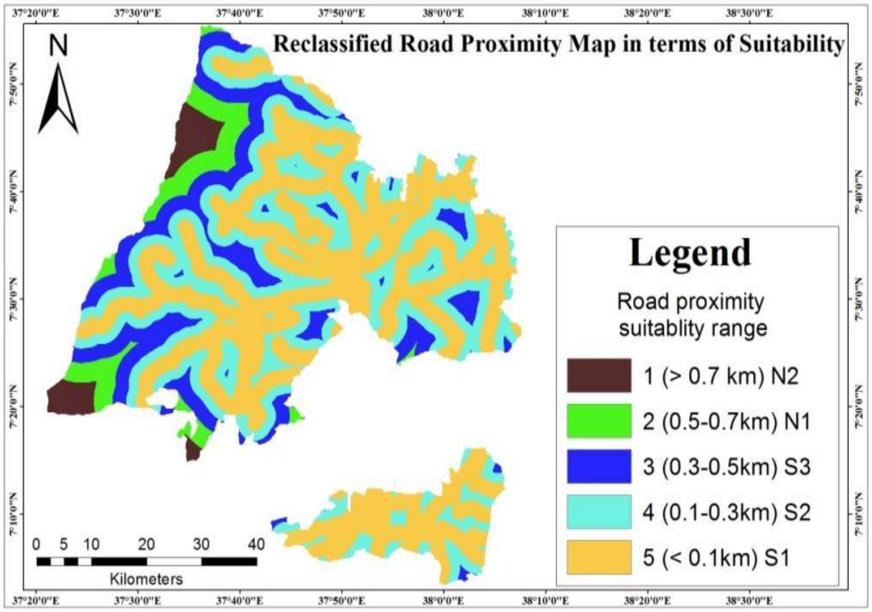

Figure 4 Road Suitability Map

4.4 Suitability Analysis of Slope

The study area's slope suitability index was calculated using Arc GIS. The EFMHACA(2012) and (FAO (2006) standards indicate that Areas with a slope (0^0-5^0%) and (5^0-10^0%) were highly suitable for healthcare facility sites, while those with a slope (10^0-15^0%) were moderately suitable. Areas with a slope (15^0-30^0 and > 30^0%) were considered less suitable and unsuitable due to the steepness of the topography. Steep slope areas are more susceptible to erosion due to high surface water rushing, which significantly impacts healthcare facility sites.

Table 9 provides information on slope suitability and area coverage.

Slope degree	Suitability level	Area (hac)	Area (%)
$<5^0$	S1	179588.20	49.60
5^0-10^0	S2	115715.04	31.96
10^0-15^0	S3	40277.97	11.12
15^0-30^0	N1	21771.79	6.01
$>30^0$	N2	4700.40	1.30

The source was obtained from the reclassified slope map attribute table.

Table 9 shows that land with a 0^o-5^o slope covers 49.60% of the total area, classified as highly suitable (S1). The remaining land with a 5^0-10^0 slope covers 31.96%, classified as suitable (S2). The land with a 10^0-15^0 slope covers 11.12%, classified as moderately suitable (S3). Less-suitable and unsuitable classes account for 6.01 and 1.30%, respectively.

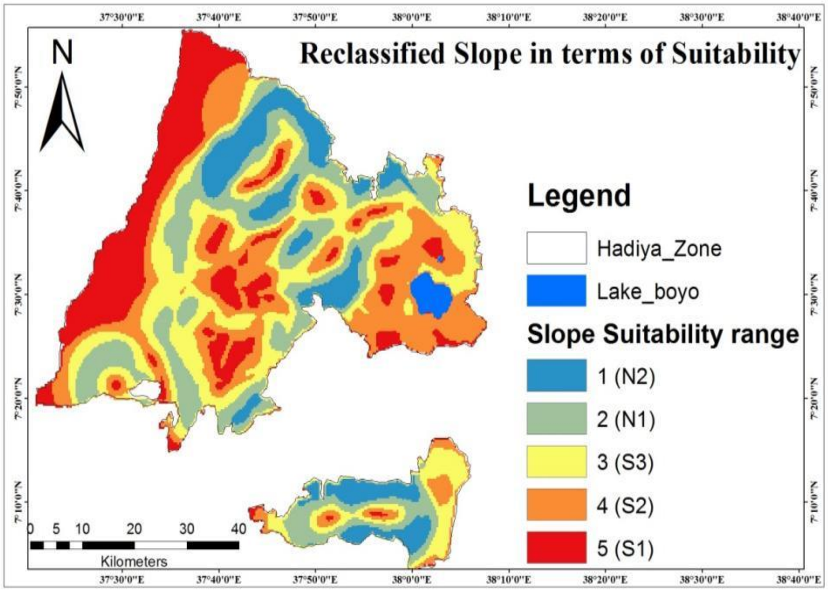

Figure 5 Reclassified Slope Map

Figure 4 shows that suitability ranges from unsuitable to very high from (N2 to S1). The range of slopes between 0^0 and 10^0 is highly suitable for selecting healthcare service sites.

4.5 Suitability Analysis of Existing Healthcare Facilities

The study developed a hybrid decision model to identify suitable healthcare service locations using existing facilities. Factor and constraint criteria were considered, and sites were selected based on factors such as residential accessibility. A 5 km buffer with a high population was chosen as a preferred site, as per Parvin et al., (2021).

Table 10 presents the terms of suitability for distance from existing health centers.

Distance from an existing healthcare facility (km)	Suitability level	Area in (hac)	Area in (%)
<5 & >25	N1	219839.74	60.44
5-10 & 20-25	S3	109650.20	30.15
15-20	S1	34236.53	9.41

The source was derived from the reclassified existing health facility map attribute table.

Table 10 shows that 60.44% of the study area, covering <5 and >25km, is unsuitable for healthcare facilities. The remaining 5-10, 15-20km, and 15-20km proximity land, with 30.15 and 9.41% road proximity, are moderately suitable and highly suitable for potential healthcare facility sites.

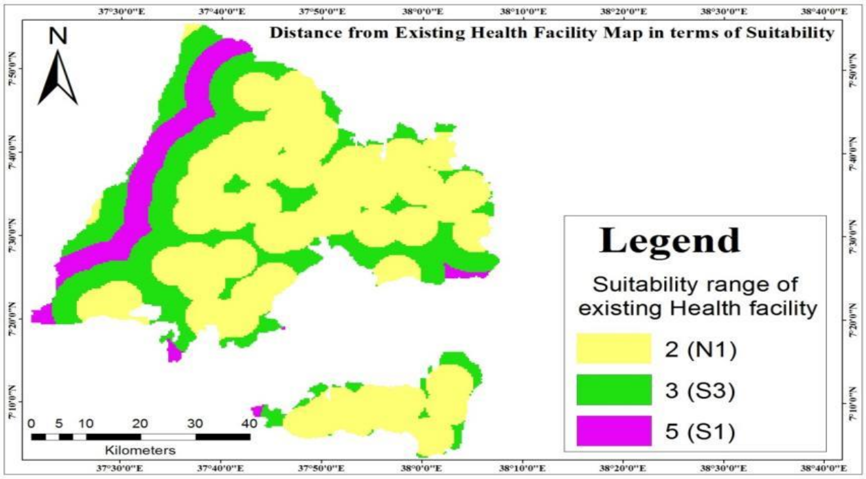

Figure 6 Reclassified Distance from Existing Health Center

4.6 Suitability Analysis of Population Density

According to Hierink et al., (2022), the use of a single population dataset can significantly impact policy-making and decision-making. With global targets for improving healthcare access, accurate indicators must be based on realistic input parameter values. The World Health Organization's Ending Preventable Maternal Mortality (EPMM) strategies aim for 60% of the global population to access the nearest functional emergency obstetric care facility within two hours, and 80% of countries to have 2-hour accessibility coverage greater than 50% by 2025.

Based on the standard used (Dell et al., 2018;), Mandell, 1991); Gigantesco & Giuliani, 2011) and Almansi et al., 2022) population density of Gibe and Gombora districts which accounts for about 24.95% (90994.26hac) which are classed as highly suitable (S1). Analemo and Soro districts and Lemo, Shashogo, and Misha districts are as classed suitable and moderately suitable (S2) and (S3) with 26.15 and 29.42% (95367.44 and 107293.84hac) respectively. The remaining three districts Misrak, Mirab Badawacho, and Duna are less suitable (N1) and account for 18.38% (67032.31hac) of potential healthcare services. Hossana town 1.11% (4046.79hac) which is as classed unsuitable (N2).

Table 11 Population Density Suitability Ranges and Areal Coverage

District Name	Suitability level	Population	Area in (hac)	Area in (%)
Hossana town	N1	145399	4046.79	1.11
Misrak,Mirab Badawacho and Duna	N1	572925	67032.31	18.38
Lemo, Shashogo, and Misha	S3	557860	107293.84	29.42
Analemo and Soro	S2	405419	95367.44	26.15
Gibe and Gombora	S1	288262	90994.26	24.95

Source: Extracted from reclassified population density map attribute table.

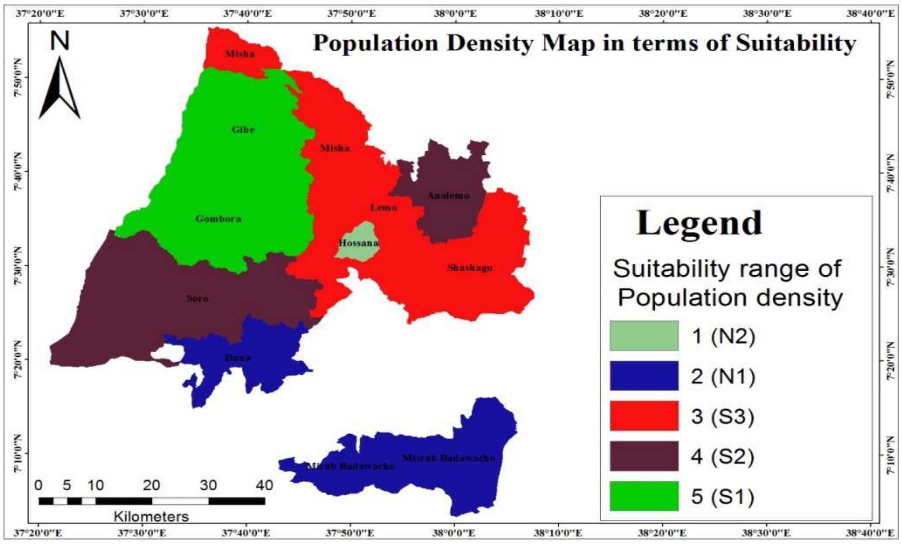

Figure 7 Population Density Map.

4.7 The Weighted Overlay Analysis

The weighted overlay analysis was used to determine potential healthcare facility sites in a study area. The western, southwestern, southeastern, and eastern parts of the area were found to be highly suitable, while the rest were deemed unsuitable. The most suitable areas were open and barren lands, with the rest being unsuitable for healthcare facilities. The analysis resulted in a more accurate selection of suitable sites.

Table 12 discusses the suitability of weighted overlay results for different classes and areas.

CODE	Suitability level	Area (hac)	Area (%)
2	S1	162221.11	41.68
3	S2	47183.66	19.76
4	S3	18829.05	9.19
5	N1	127682.75	29.37

The source was obtained from the reclassified Weighted overlay result map attribute table.

The study found 29.37% of the total study area as low-suitable for healthcare facility potential sites, as they failed to meet the criteria and standards formulated by various organizations, including EFMHACA (2012), FAO (2006), Kanga et al. (2021), Getu Desalegn (2020) and Parvin (2021). These standards require healthcare facility sites to be within 5 and above 25kilo meters from existing facilities. However, 41.68% of the area was found to be highly suitable, meeting accessibility, environmental, and topography criteria. Although moderately suitable and suitable sites in the study area may not meet the most suitable class standards, they can still be used as alternative potential sites for healthcare facility service areas.

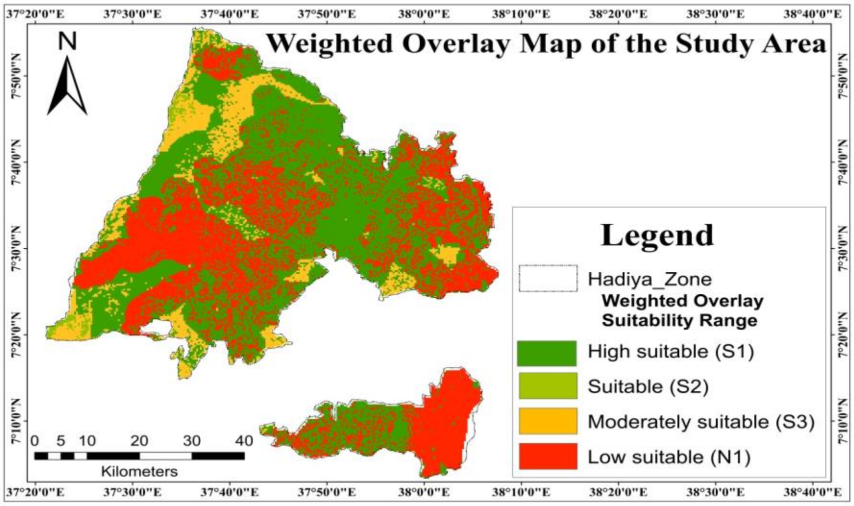

Figure 8 The study area is depicted through a weighted overlay result map.

4 .7.1 The Final Suitable Map

The study identifies areas suitable for healthcare facilities based on factors such as slope, land use type, distance from existing facilities, main road, and population density. Each raster output is reclassified into common measurement scale values, ensuring equal influence from each participant. In this case, a common measurement scale of 5 is assigned for all inputs. Overlay analysis is used to combine factors, resulting in the final output, which is considered suitable for healthcare facilities. The final output is displayed in Figure 8.

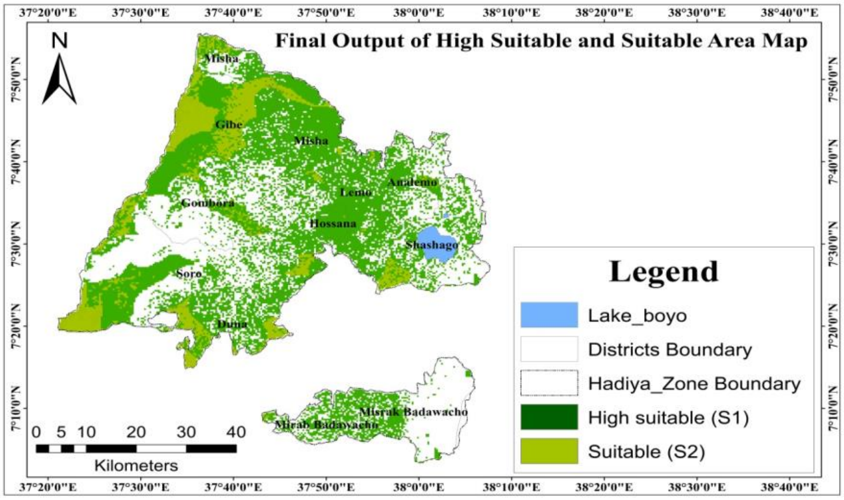

Figure 9 displays the final outputs of suitable areas for a new health facility.

The study reveals that almost all locations are considered optimal for healthcare facility locations, despite some sites being more stable. The optimality of these sites is based on a general set of zonal demand data, not the true underlying demand structure. This suggests that spatial analysis techniques can be used to find the most reliable sites for healthcare facilities based on optimized sites from service area analyses.

5. Conclusion

The study uses a geospatial-based decision-making approach to analyze healthcare accessibility and distribution in geographical locations, highlighting that this method is the most suitable method for finding suitable locations for new healthcare center sites and related public services. The study indicates a spatial inconsistency in healthcare access, with existing facilities primarily located in the town's specific areas. The study aimed to allocate new healthcare facilities based on factors such as land use, road proximity, existing facilities, population density, slope, and residential distance to ensure equal access and reduce spatial disparity in healthcare facilities. The service area analysis reveals that there is no planned distribution of healthcare centers in the community's demanding environment, leading to a high concentration of centers in infrastructure and utility-filled areas. This situation makes some areas unreachable, while others are accessible. Additional healthcare center facilities are needed in the western, southwestern, and southern parts of the study area, which have distance and time values beyond recommended standards. The road network availability in the area is irregular and low standard, negatively affecting the service area analysis and creating a disorder in locating the nearest facilities.

References

Abebe, M. T. (2016). *Remote Sensing and Geographic Information System Based Suitability Analysis of Urban Green Space Development in Addis Ababa : A Case Study of Bole Sub-ci*

Ahmad, S. (2012). *A Gis Based Investigation of Spatial Accessibility To Health*.

Ahmed, A. H., Mahmoud, H., & Aly, A. M. M. (2016). *Site Suitability Evaluation for Sustainable Distribution of Hospital Using Spatial Information Technologies and AHP : A Case Study of Upper Egypt, Aswan City*. 578–594. https://doi.org/10.4236/jgis.2016.85048

Akay, A., & Aziz, B. (2016). GIS-Based Forest Road Network Model for Forest Protection Purposes. *38th Annual COFE Meeting: Engineering Solutions for Non-Industrial Private Forest Operations*,

Almansi, K. Y., Rashid, A., Shariff, M., Kalantar, B., Abdullah, A. F., Norkhadijah, S., Ismail, S., & Ueda, N. (2022). *Performance Evaluation of Hospital Site Suitability Using Multilayer Perceptron (MLP) and Analytical Hierarchy Process (AHP) Models in Malacca, Malaysia*.

Dell, M., Capolongo, S., & Oppio, A. (2018). Land Use Policy Combining spatial analysis with MCDA for the siting of healthcare facilities. *Land Use Policy*, *December 2017*, 0–1. https://doi.org/10.1016/j.landusepol.2018.02.044

EFMHACA. (2012). ETHIOPIAN STANDARD Health Center - Requirements. *Ethiopian Health Center Standard*, 1–126.

FAO. (2006). Food and Agriculture Organization of the United Nations. In *Electronic Publishing Policy and Support Branch Information Division FAO* (Vol. 59).

Hierink, F., Boo, G., Macharia, P. M., Ouma, P. O., Timoner, P., Levy, M., Tschirhart, K., Leyk, S., Oliphant, N., Tatem, A. J., & Ray, N. (2022). Differences between gridded population data impact measures of geographic access to healthcare in sub-Saharan Africa. *Communications Medicine*, *2*(1). https://doi.org/10.1038/s43856-022-00179-4

Jalil, I. A., Rauf, A., Rasam, A., Adnan, N. A., Saraf, N. M., & Idris, A. N. (2018). *Geospatial Network Analysis for Healthcare Facilities Accessibility in Semi-Urban Areas*. *July*. https://doi.org/10.1109/CSPA.2018.8368722

Kanga, S., Kranjčić, N., Singh, S. K., Raja, S., & Durin, B. (2021). A geospatial approach for site suitability and accessibility for healthcare services in Bankura district, West Bengal, India. *Present Environment and Sustainable Development*, *15*(2), 81–91. https://doi.org/10.15551/pesd2021152007

Luqman, M., & Khan, S. U. (2021). Geospatial application to assess the accessibility to health facilities in Egypt. *Egyptian Journal of Remote Sensing and Space Science*, *24*(3), 699–705.

https://doi.org/10.1016/j.ejrs.2021.02.005

Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science*, *20*(7), 703–726.

https://doi.org/10.1080/13658810600661508

Mandell, M. B. (1991). Modeling Effectiveness-Equity Trade-Offs in Public Service Delivery Systems. *Management Science*, *37*(4), 467–482. https://doi.org/10.1287/mnsc.37.4.467

Mathew, S., Rekha, R. S., Wajid, S., & Radhakrishnan, N. (2017). Accessibility Analysis of Health care facility using Geospatial Techniques. *Transportation Research Procedia*, *27*, 1163–1170. https://doi.org/10.1016/j.trpro.2017.12.078

Oppio, et al. (2016). Addressing decisions about new hospitals' siting: a multidimensional evaluation approach. *Ann Ist Super Sanità*, *47*(4), 363–372. https://doi.org/10.4415/ANN

Parvin, F., Ali, S. A., Hashmi, S. N. I., & Khatoon, A. (2021). Accessibility and site suitability for healthcare services using GIS-based hybrid decision-making approach: a study in Murshidabad, India. *Spatial Information Research*, *29*(1), 1–18. https://doi.org/10.1007/s41324-020-00330-0

Qiang Pu, et. (2020). Improving the spatial accessibility of healthcare in North Kivu, Democratic Republic of Congo. *Applied Geography*, *121*(June), 102262.

https://doi.org/10.1016/j.apgeog.2020.102262

Saaty, T., Pressures, S., Resources, W., Interests, V., & Values, C. (1980). The Analytic Hierarchy Process (AHP) for Decision Making By Thomas Saaty Decision Making involves setting priorities and the AHP is the methodology for doing Most Decision Problems are Multicriteria Maximize profits Satisfy customer demands Maximize emp.

Tessema, Z. T., Worku, M. G., Tesema, G. A., Alamneh, T. S., Teshale, A. B., Yeshaw, Y., Alem, A. Z., Ayalew, H. G., & Liyew, A. M. (2022). Determinants of accessing healthcare in Sub-Saharan Africa: A mixed-effect analysis of recent Demographic and Health Surveys from 36 countries. *BMJ Open*, *12*(1), 1–8. https://doi.org/10.1136/bmjopen-2021-054397

WHO. (2010). *Facts/2010.1 Progress Report*.