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RESEARCH ARTICLE

OPTIMIZING NEW SCHOOL SITE SELECTION IN BULE HORA TOWN, WEST GUJI ZONE, SOUTHERN ETHIOPIA USING GIS-BASED MULTI-CRITERIA ANALYSIS

Jisan Kebede[a], Paramasivam Chellamuthu Ranganathan[b]*

[a] Bule Hora University, College of Natural Sciences, Bule Hora, Ethiopia.
[b] Q-Gate Infotech Pvt Ltd, Bengaluru, India.
**Corresponding author Email: pusivam@gmail.com*

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ABSTRACT

This study employs GIS-based multi-criteria analysis (MCA) to identify optimal locations for new school sites in Bule Hora, West Guji Zone, Southern Ethiopia. The analysis incorporates five criteria: land cover, slope, proximity to roads, existing schools, and vegetation. Each criterion plays a crucial role in determining the suitability of potential school sites. The methodology prioritizes accessibility, with sites near major roads receiving higher scores due to their ease of service. Specifically, the study excludes areas with steep slopes (5.93°–15.91°) as they scored poorly, focusing instead on flat or gently sloped lands. The final selection identifies a site of approximately 11.13 hectares, representing 0.11% of the study area, as the most suitable location for a new school. This site is located on bare land near the western roads of Bule Hora, offering both accessibility to transportation and distance from existing settlements. The weighted criteria show that bare land and proximity to roads are most influential, whereas steep slopes, dense vegetation, and built-up areas are less favorable. This approach ensures that the selected site is optimal in terms of both accessibility and land suitability, addressing the educational infrastructure needs of the community.

KEYWORDS

GIS-based analysis, Multi-Criteria Analysis (MCA), school site selection, Bule Hora, West Guji Zone, land suitability, accessibility, Ethiopia.

1. INTRODUCTION

Effective site selection for new schools is a multifaceted process that significantly impacts educational outcomes, resource management, and community well-being. The integration of Geographic Information Systems (GIS) into this process represents a significant advancement in planning and decision-making. GIS provides a powerful tool for analyzing spatial data, allowing for a more informed and systematic approach to identifying optimal locations for new educational facilities. However, exploiting GIS effectively requires a comprehensive understanding of both historical context and current challenges in school development.

The history of school site selection reveals a range of traditional practices that often lacked the sophistication provided by modern GIS technology. Historically, site selection decisions were made based on basic criteria such as land availability, cost, and proximity to existing infrastructure. These decisions were frequently influenced by political, economic, and social factors rather than a detailed analysis of spatial data. As educational needs and urban development have evolved, the limitations of these traditional methods have become more apparent. Inadequate site selection can result in a host of problems, including overcrowded classrooms, poor accessibility, and suboptimal learning environments (Seredovych et al., 2008).

The advent of GIS has revolutionized the site selection process by introducing a spatial dimension to planning and decision-making. GIS enables the integration and analysis of various types of data, including geographic, demographic, and environmental information. This capability allows planners to evaluate potential school sites more comprehensively, considering a wide range of factors such as land use, transportation access, environmental conditions, and proximity to other schools and amenities. By incorporating GIS into the site selection process, decision-makers can achieve a more balanced and data-driven approach, leading to more effective and sustainable outcomes (Kholoshyn et al., 2020).

One of the primary benefits of GIS in school site selection is its ability to handle large volumes of spatial data from diverse sources. GIS facilitates the analysis of complex spatial relationships and the identification of suitable sites based on multiple criteria. This capability is particularly valuable in urban planning, where the interaction between land use, infrastructure, and social factors can be intricate and dynamic. By using GIS to analyze these interactions, planners can identify sites that not only meet educational needs but also align with broader community goals and constraints.

In addition to its technical capabilities, GIS offers a range of advantages for educational planning. For example, GIS can support effective education planning by providing detailed maps and spatial analyses that inform the decision-making process. This includes estimating the number of schools needed based on population projections, identifying areas with high demand for educational services, and evaluating the suitability of potential sites based on various criteria. By incorporating GIS into the planning process, educational authorities can make more informed decisions that optimize resource allocation and address the needs of the community (Elsheikh, 2017).

The integration of GIS with Multi-Criteria Decision Analysis (MCDA) further enhances the site selection process by providing a structured framework for evaluating and comparing potential sites. MCDA is a decision-making approach that considers multiple criteria to identify the most suitable option among various alternatives. By integrating MCDA with GIS, a more detailed and systematic assessment of potential school sites can be achieved, considering factors like land availability, environmental impact, transportation access, and proximity to existing

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infrastructure.

In developing countries like Ethiopia, where the educational infrastructure is often underdeveloped and rapidly expanding, the application of GIS and MCDA in school site selection is particularly valuable. The Ethiopian government has made significant steps in improving access to education, but challenges remain in ensuring that new schools are located in optimal positions to serve the growing population. The use of GIS and MCDA provides a means to address these challenges by offering a data-driven approach to site selection that considers both qualitative and quantitative factors (Jayaweera et al., 2016).

For instance, in Bule Hora, a town in the West Guji Zone of Southern Ethiopia, the historical approach to school site selection has led to several issues. Many schools were established without the benefit of GIS-based analysis, resulting in locations that are less than ideal for supporting effective education. Schools such as Sinaye Elementary and St. Maryam Elementary have faced challenges due to their proximity to busy areas and inadequate infrastructure. Additionally, the Bariso Dukale High School's proximity to Bule Hora University has introduced issues related to student behavior and safety. These problems highlight the need for a more systematic approach to site selection that considers various factors and using GIS technology (Daneshvar et al., 2017).

The objective of this study is to develop a GIS-based public-school site selection model using a Multi-Criteria Decision Analysis approach. This model aims to address the limitations of previous site selection practices by incorporating a range of factors into the decision-making process. By integrating GIS with MCDA, the study seeks to identify suitable locations for new schools in Bule Hora that will support effective educational environments and address the issues faced by existing schools. The proposed model will evaluate potential school sites based on criteria such as land cover, slope, proximity to roads, existing schools, and vegetation. These criteria were selected to reflect the diverse factors that impact the suitability of a site for a new school. For example, land cover and vegetation affect the environmental suitability of a site, while proximity to roads and existing schools influences accessibility and potential interactions with other educational facilities. The model will use GIS to analyze spatial data related to these criteria, providing a comprehensive assessment of potential sites and facilitating the selection of the most appropriate location for a new school.

The present study concentrates on the integration of GIS and MCDA, which represents a significant advancement in the site selection process for new schools. By manipulating the capabilities of GIS and the structured approach of MCDA, decision-makers can address the complex factors involved in site selection and identify locations that best meet the community's needs. This approach has the potential to improve educational outcomes, optimize resource allocation, and support sustainable development in rapidly growing areas like Bule Hora town in Ethiopia.

2. Materials and Methods

2.1 Study Area

The study area is located in the West Guji Zone, serving as the administrative city of the zone (Figure 1). Geographically, it is positioned between 5º 35' 50" and 5º 40' 50" North latitude, and 38º 12' 30" and 38º 19'10" East longitude, in the southern region of Ethiopia, within southern Oromia. The area is bounded by Baridaye Chabiti to the south, Kelelitu to the southeast, Sarji Ela Bedessa to the east, Meretur Kuma to the north, Donibel Hara to the west, and Motokoma Hara Kebele to the southwest.

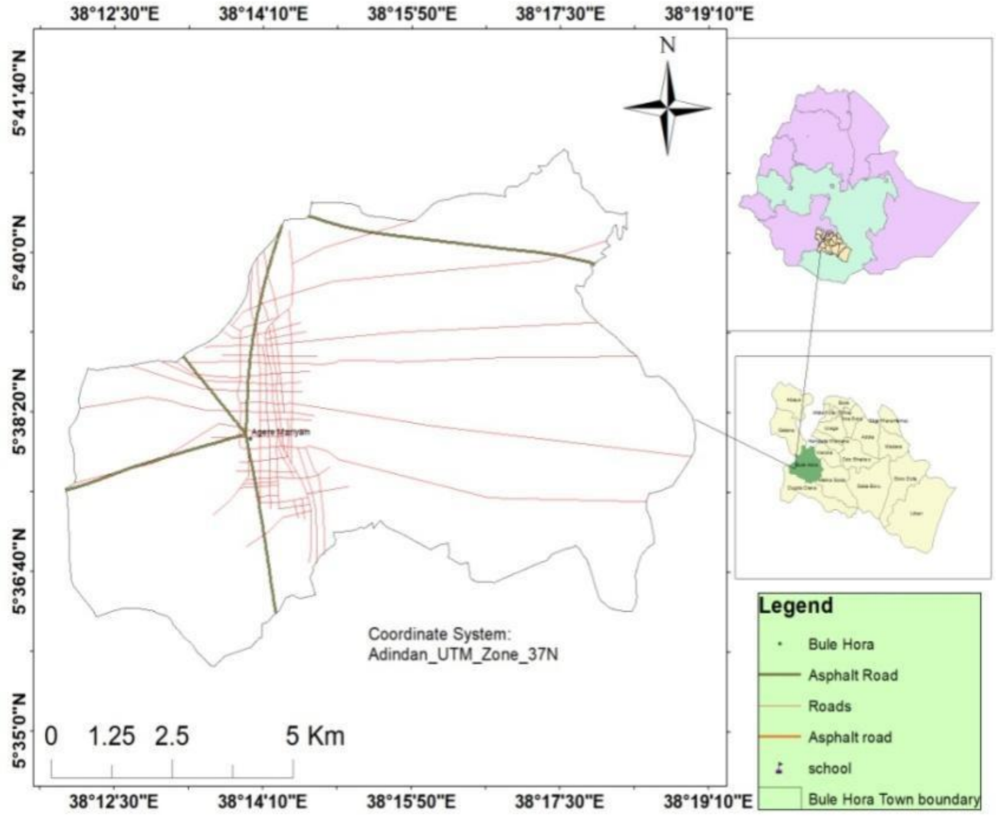

Figure 1: Location Map of the study region.

2.2 Software and Data

The GIS software used in this study was Arc GIS 10.8 and Q-GIS 3.24. The boundary maps were delineated from the Shapefile of Oromia Kebele. The satellite image for land use classification of the study area was downloaded through the USGS web site and classified by Q-GIS software. MapInfo Pro allows exploring spatial data within a dataset, symbolizing features, and creating maps. Data processing and modelling were performed mainly with ArcGIS 10.8, while MapInfo Professional was used for standardizing the input format.

The work was carried out by GIS software and the Remote Sensing platform through a knowledge-based factor analysis using elevation, roads, slope, recreation sites, existing school sites, and land use and land cover. Satellite images have been used for the delineation of thematic layers. The acquisition date of the satellite image was January 15, 2021, to January 31, 2021, in which the climatic condition is very good in Ethiopia. Thus, no more atmospheric error is present in the image. Seven bands (B1–B7) were downloaded and stacked together. Their false colour composite image was also prepared through the property on the stacked image, and bands 5, 4, and 3 were used since the satellite image is land sat 8 (Figure 2). The downloaded image was clipped by a mask in Q-GIS within the study area boundary, i.e., Bule Hora town area.

3. Methodology

The study begins with the acquisition of various datasets including Google Earth, conventional data, and satellite imagery data. Key features such as roads, recreation sites, and existing schools are extracted. Additionally, SRTM (Shuttle Radar Topography Mission) data and Landsat8 satellite images are utilized to derive important geographical parameters like slope. Following the acquisition, the boundary of the study area is established, and pre-processing steps are applied to the data. Land use/land cover information is obtained and classified using maximum likelihood classification to ensure accurate representation of the area's features.

A multi-factor selection approach is adopted, where the relevant factors are identified, and a geospatial dataset is created and reclassified as needed. These factors are used to generate thematic layers in GIS, forming the basis for further analysis. The AHP (Analytic Hierarchy Process) Model is employed to ensure consistency in the decision-making process. The model helps in determining whether the factors are consistent. If inconsistencies are found, adjustments are made; otherwise, factors weighting and ranking are performed to prioritize the factors based on their importance. An overlay analysis is then conducted using a raster calculator, allowing for the integration of the thematic layers. This integration leads to the identification of optimal areas by raster, which are subsequently converted to polygon format for more precise mapping. The analysis also considers best areas from road distance to ensure accessibility (Figure 3)

The new school site was obtained by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in Arc GIS 10.8. During weighted overlay analysis, the ranking was given for each individual parameter of each thematic map, and weights were assigned according to the multi influencing factor (MIF) of that particular feature on the appropriate site of the study area. For instance, one good site was

selected for new school. A factor with a value of higher weight shows a larger impact and a factor with a lower weight value shows a smaller impact on new school site. Integration of these factors with their site weights is analyzed through weighted overlay analysis in Arc GIS software.

3.1 Multi-influencing factors, thematic layers, and data collection

This research initiated with a review of previous observation, investigation, and comparison of guidelines used by many authors to find a complete and reliable list of criteria for school site selection focusing on safe location. The whole process of site selection incorporates the Analytic Hierarchy Process (AHP) as a Multi Criteria Decision Analysis (MCDA) technique, which was used to organize the identified criteria into a hierarchy structure before obtaining judgement expertise in weighting land suitability factors.

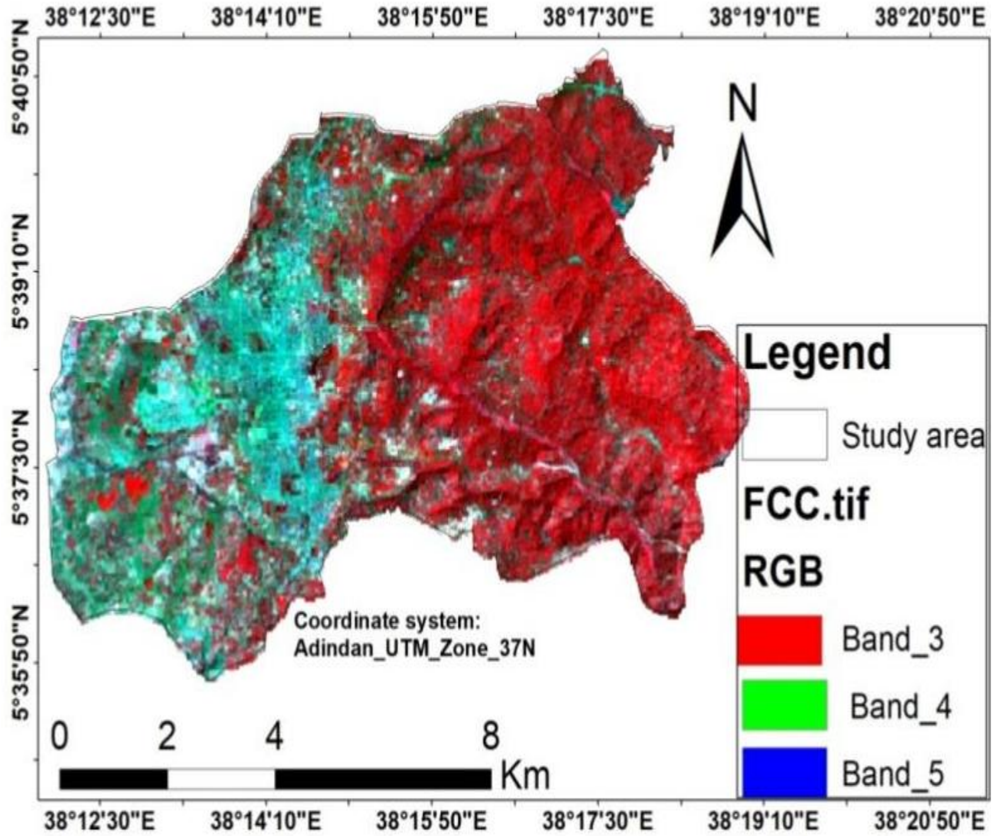

Figure 2: Study area False Colour Composite map (Bands 5,4 and 3)

The criteria analyzed were based on environmental suitability (slope, land cover, distance from the existing school and recreation site), safety, and accessibility (like distance from roads). Five influencing factors, such as the existing schools, recreation sites, slope, roads, and land use and land cover, were identified to delineate the suitable new school site. The collected data includes high-resolution satellite images of the of the Bule Hora area, GPS measurements of existing schools (Table 1) from direct fieldwork, and recreation sites from a land cover classification map.

Table 1: Existing schools in Bule Hora town

Probable Name of School	Easting (X)	Northing (Y)	Elevation (in m)
Bariso Dukale preparatory	414476	623507	1866
government primary	415838	623299	1893
Sinaye primary	416166	623272	1894
St. Mariam school	416172	623659	1924
KG	415581	622267	1918
KG	415746	622254	1933
Preparatory	415184	624771	1950
Preparatory	415915	624572	1944

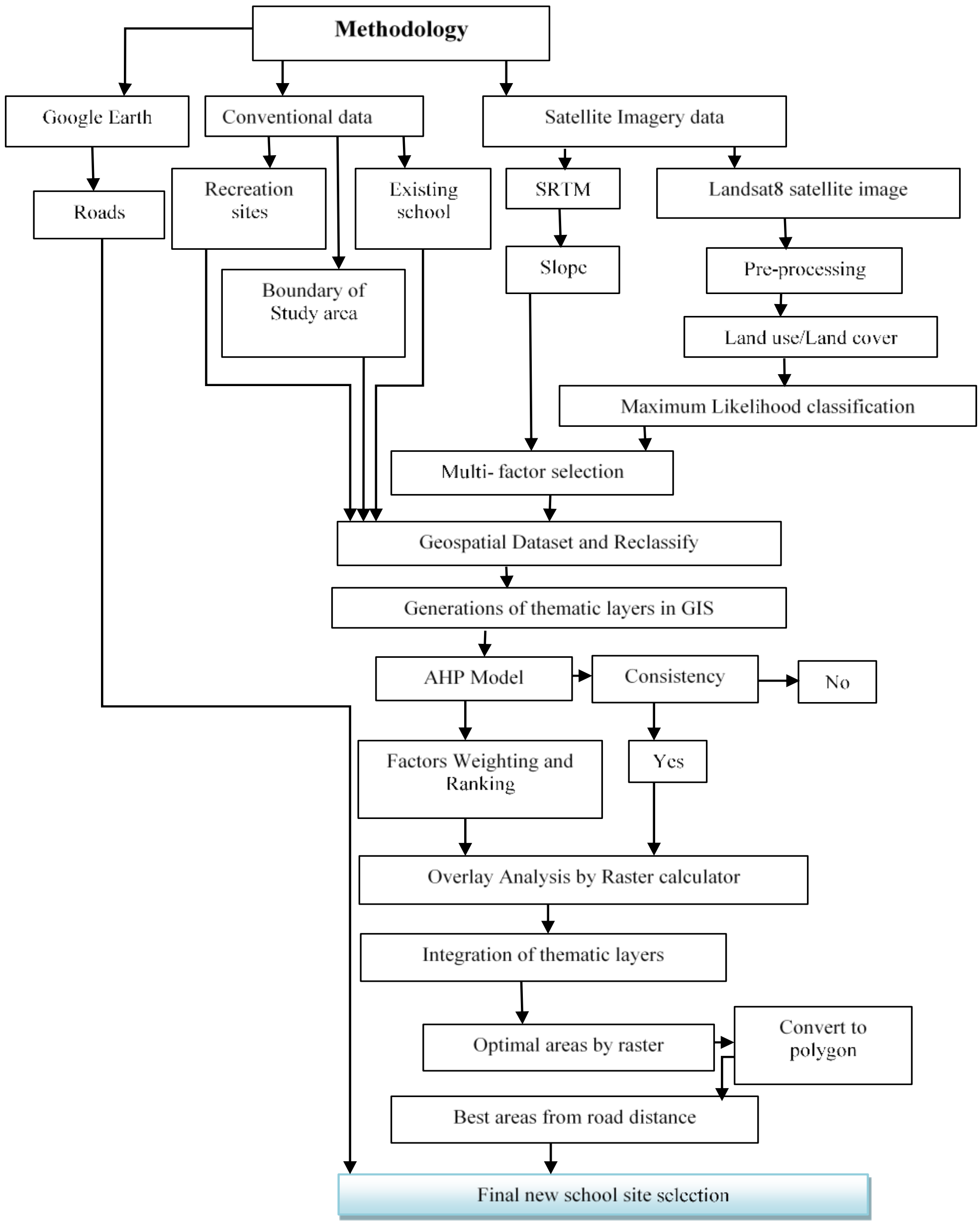

Figure 3: Methodology Flow chart for new school site selection

4. Result and Discussion

4.1 Multi Criteria used in GIS-AHP

The multi influencing factors for new school site selection namely slope; recreation site, existing school, roads and land use/land cover were analyzed in Arc GIS software using AHP weightage method. The results obtained on various thematic layers are discussed below.

4.2 Distance to Recreation site

The recreation site indicates that the refreshment area out of classes. Students benefit when complimentary park and recreation resources are located near public schools. Recreation and nature areas available by walking provide opportunities to use the outdoors as an extension of the classroom. The distance to recreation site was reclassified into 10 classes (Table 2) using equal interval method and reversed, because if the recreation site distance is nearest to the new school, it is preferable for students' refreshment at their rest time. Thus way the nearest got high value (10) and vice versa (Figure 4 and Table 2). Accordingly for new school site selection, the nearest distance to recreation area was used.

Table 2: Distance to recreation site score evaluation

Distance to recreation site	Score	Suitability
0 - 872.6668945	10	Very suitable
872.6668946 - 1,745.333789	9	Excellent
1,745.33379 - 2,618.000684	8	high
2,618.000685 - 3,490.667578	7	good
3,490.667579 - 4,363.334473	6	Moderate
4,363.334474 - 5,236.001367	5	Fair suitable
5,236.001368-6,108.668262	4	Less suitable
6,108.668262 - 6,981.335157	3	Very low
6,981.335157 - 7,854.002051	2	Un-suitable
7,854.002052 - 8,726.668945	1	Un-suitable

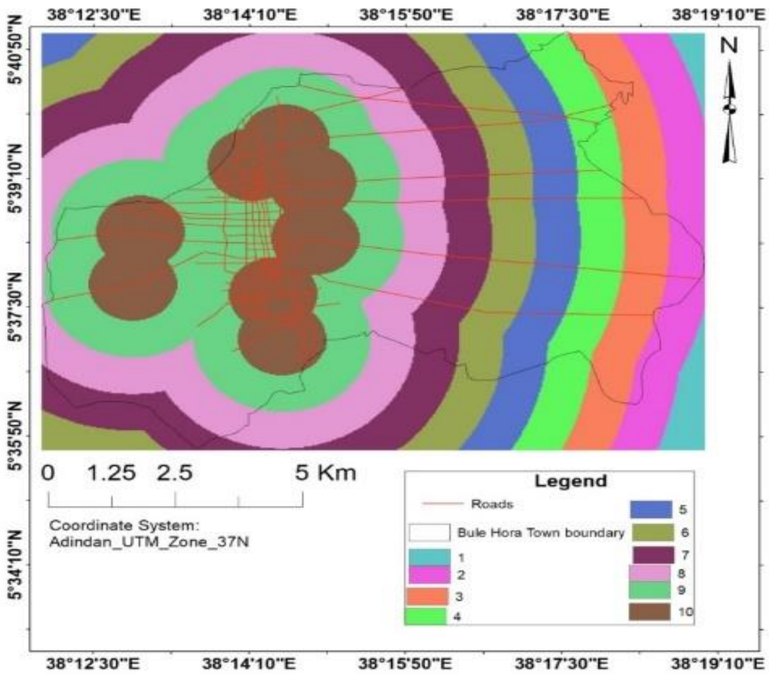

Figure 4: Reclassified distance to recreation site map.

4.3 Distance to Existing School

To select the new school site the existing school measurement should be mandatory. For instance, the new school site was selected far from the existing school. The new school was classified using equal interval method. The distance to existing school has taken as a parameter (Figure 5 and Table 3).

Table 3: Distance to school score evaluation

Distance to recreation site	Score	Suitability
0 - 942.7431641	1	Very suitable
942.7431642 - 1,885.486328	2	Excellent
1,885.486329 - 2,828.229492	3	high
2,828.229493 - 3,770.972656	4	good
3,770.972657 - 4,713.71582	5	Moderate
4,713.715821 - 5,656.458984	6	Fair suitable
5,656.458985 - 6,599.202148	7	Less suitable
6,599.202149 - 7,541.945313	8	Very low
7,541.945314 - 8,484.688477	9	Un-suitable
8,484.688478 - 9,427.431641	10	Un-suitable

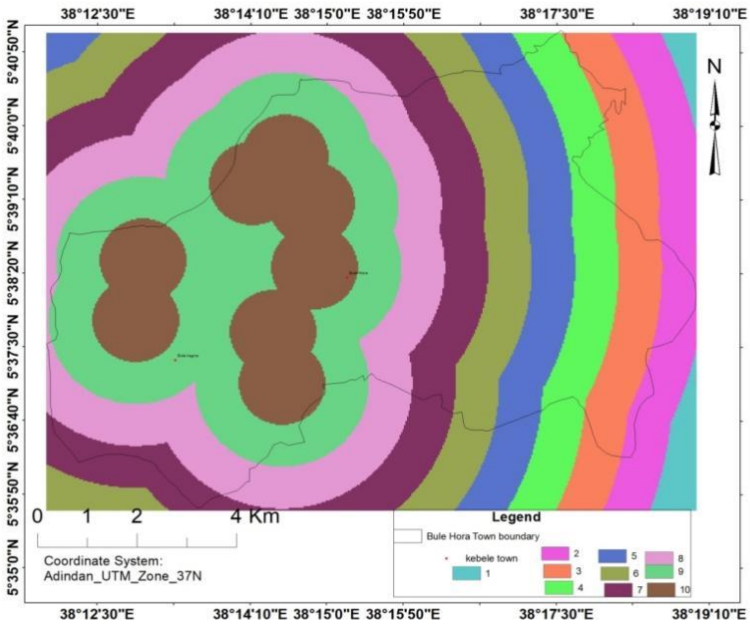

Figure 5: Reclassed distance to school map

4.4 Slope

The slope were classified in range first from the elevation map and reclassified into 10 sub classes (1 to 10) using equal interval method as mentioned in Table 4 and Figure 6. The 10 value represents very steep slope and 1 shows the gentle area. During reclassification, the value was reversed, because the steep slope does not suitable for school site selection. The slope of 1 up to 3 was restricted and that of 4 up to 10 values was considered as low suitable to highly suitable areas respectively.

Table 4: Slope evaluation and their score

Distance to recreation site	Score	Suitability
0 - 1.123219232	10	Excellent
1.123219233 - 1.934433122	9	high
1.934433123 - 2.683245943	8	good
2.683245944 - 3.432058764	7	Moderate
3.432058765 - 4.180871586	6	Fair suitable
4.180871587 - 4.992085476	5	Less suitable
4.992085477 - 5.928101502	4	Very low
5.928101503 - 7.051320734	3	Restricted
7.051320735 - 8.736149582	2	Restricted
8.736149583 - 15.91227245	1	Restricted

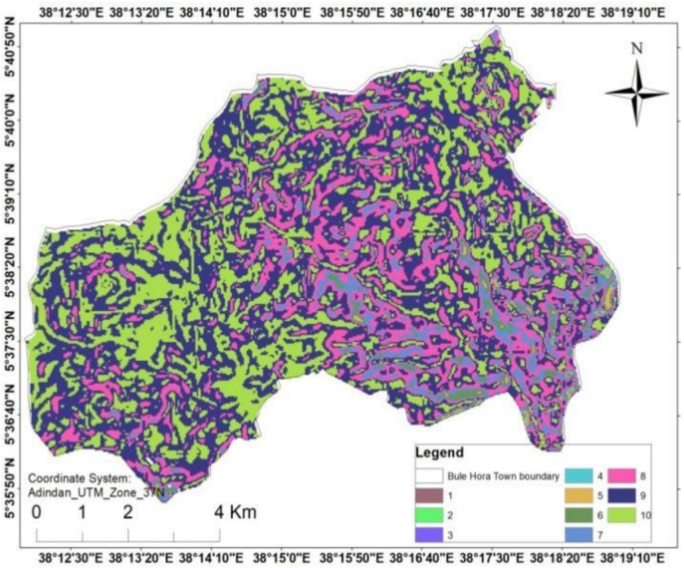

Figure 6: Reclassified slope

4.5 Land use/ land cover

Land cover/land use has effects on new school site selection. For instance, the bare land is suitable area and vegetation as low weightage for new school site selection. The land use/land cover patterns in the study area are builtup, vegetation, bareland, and farmland (Figure 7). The classification was using Maximum likelihood supervised classification method. Since MLH algorithm has the ability to consider both mean and covariance of pixels as the same time preferred it for land use/ land cover classification. Vegetation dominates the area covering 74% and farmland is the list covering only 0.1% of the area (Table 5 & Figure 8, Figure 9 and Figure 10).

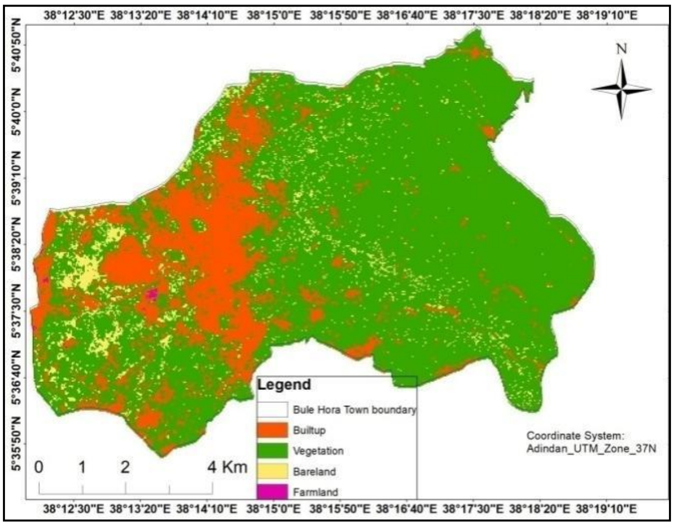

Figure 7: Land use/ Land cover map

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Table 5: Land use/Land cover area coverage

LU/LC category	Percentage (%)	Area (in m)	Suitability
Built-up	20.6	1567.0	Low
Vegetation	74.0	5644.0	Moderate
Bare land	5.3	404.0	excellent
Farm land	0.1	8.0	High

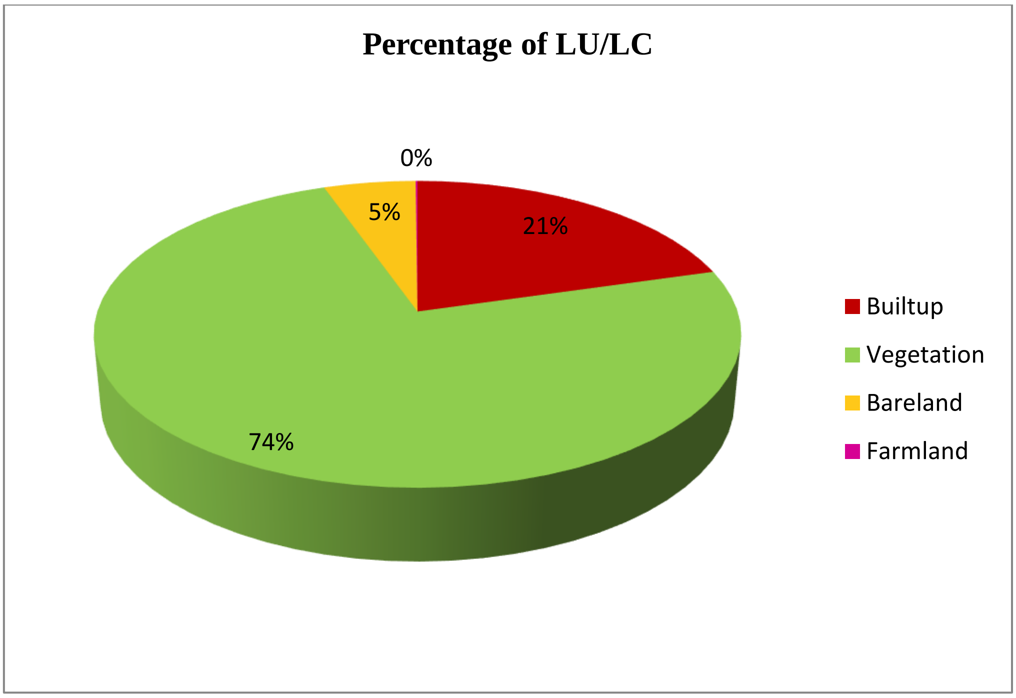

Figure 8: Pie chart for percentage of LU/LC category

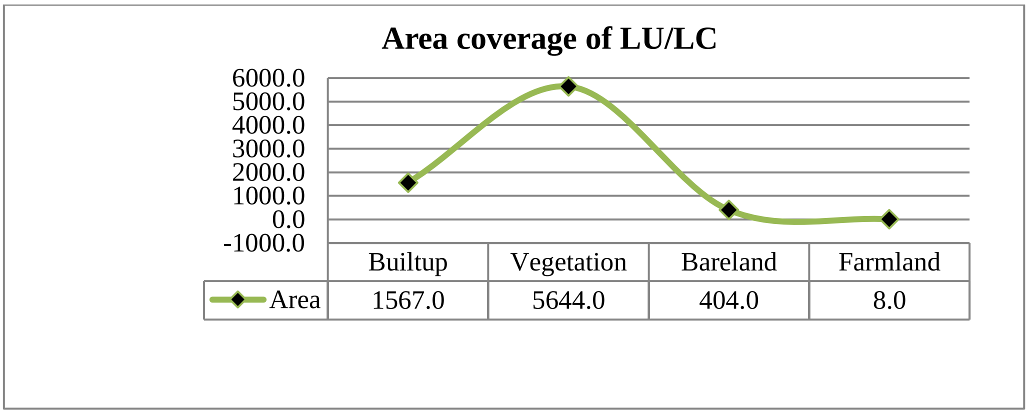

Figure 9: Line chart indicating area coverage of LU/LC

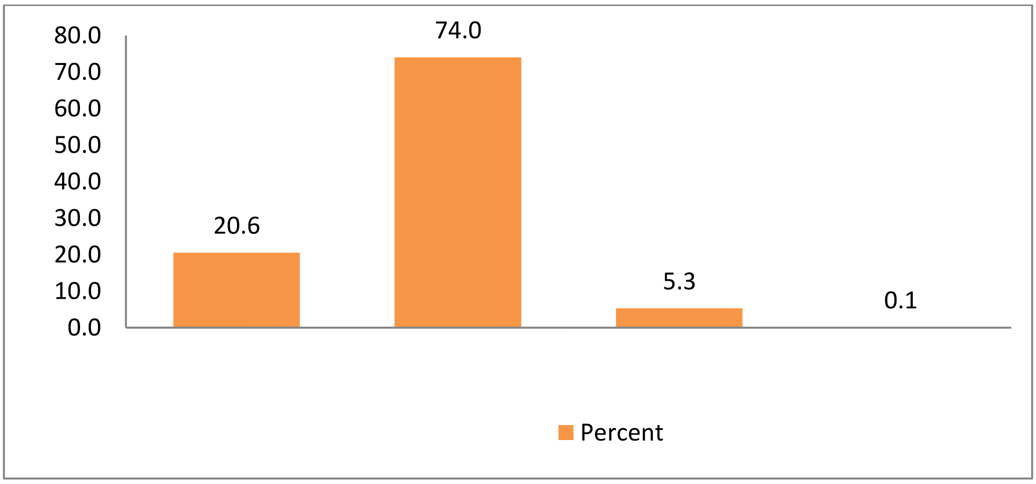

Figure 10: Bar chart indicating percent of each feature

Since the building affects the school site for its future growth, the new school site is selected with respect to intermediate distance from built up, even from all land use/land cover built up has the least (3) weightage value. Their weightage scale value in descending order is Bareland (10), Farmland (9), Vegetation (4) and Built up (3) (Table 6).

4.6 Weightage calculation

After identifying the site selection elements (multifactor), the next step is to assign weighting factors to each element. Assignment of the weighting factors is the district/community's opportunity to apply its values to the evaluation process so that the final scores for each site reflect issues involved at the local level. The weightage of each parameter factor were calculated based on their relationship degree with school. The overall weightage ranged from 1 to 10 values for each factor. For instance vegetation and school has negative correlation. This means if we cut trees to build new schools deforestation will come and it brings drought. So Bareland is more positively correlated to school. In this project Bareland got 10 values, 9 values for farmland. The distance to recreation site has high (50%) Influence factor, Landuse land cover has 25 %, Distance to school has 13% and Slope has 12% of influencing factor (Table 6).

Table 6: Overall Weightage of Multi-factor and their rank

Multi-factor	Percentage of influence	Field value	Scale value	Suitability
Distance to schools	13	1	1	Un-suitable
		2	2	Un-suitable
		3	3	Very low
		4	4	Less suitable
		5	5	Fair suitable
		6	6	Moderate
		7	7	good
		8	8	high
		9	9	Excellent
		10	10	Very suitable
Distance to recreation sites	50	1	1	Un-suitable
		2	2	Un-suitable
		3	3	Very low
		4	4	Less suitable
		5	5	Fair suitable
		6	6	Moderate
		7	7	good
		8	8	high
		9	9	Excellent
		10	10	Very suitable
Slope	12	1	Restricted	Restricted
		2	Restricted	Restricted
		3	Restricted	Restricted
		4	4	Very low
		5	5	Less suitable
		6	6	Fair suitable
		7	7	Moderate
		8	8	good
		9	9	high
		10	10	Excellent
Land use/ Land cover	25	Builtup	3	Low
		Vegetation	4	Moderate
		Bareland	10	excellent
		Farmland	9	High

Following the assignment of the weighting factors, each selection element is evaluated according to established criteria and ranked on the simple ten-point scale from 0 to 9 (Figure 11). For instance, the criteria ranking scores represents as the area ranges from unacceptable to excellent site.

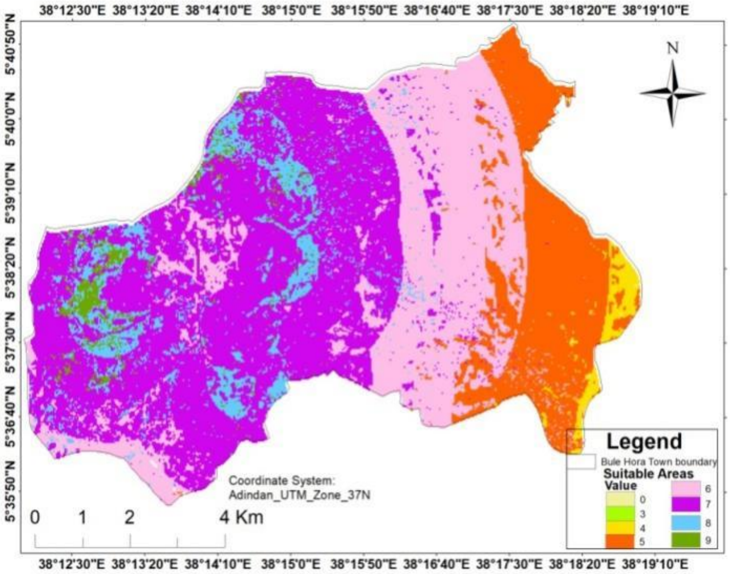

Figure 11: Suitable areas with their ranking scores of 0-9 values.

The optimal selection for new school site was then filtered in raster form and converted to polygon. For instance the option is to ward northwestern and western part of the study area (Figure 12 and 12a). After evaluating the selection criteria based on the distance from roads, the optimal final site is determined to be located in the western part of the study area. This location offers the most suitable characteristics when considering accessibility, proximity to roads, and other relevant factors, making it the ideal choice. Then finally using the selection with respect to distance from roads, the best final site is Western part of the study area (Figure 13). northwestern and western part of the study area.

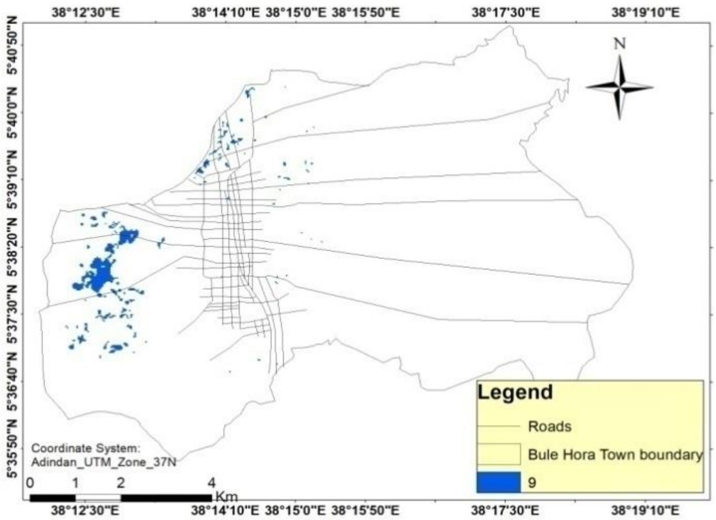

Figure 12: Output Filtered Optimal Areas in raster

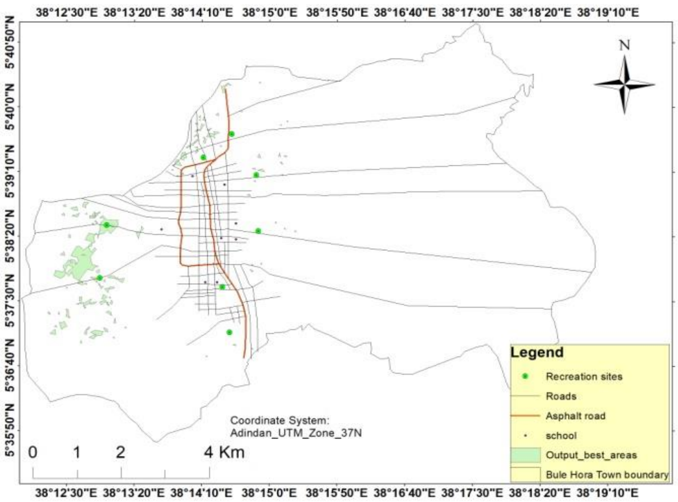

Figure 12a: Output Filtered Optimal Areas in raster and output best areas in polygon

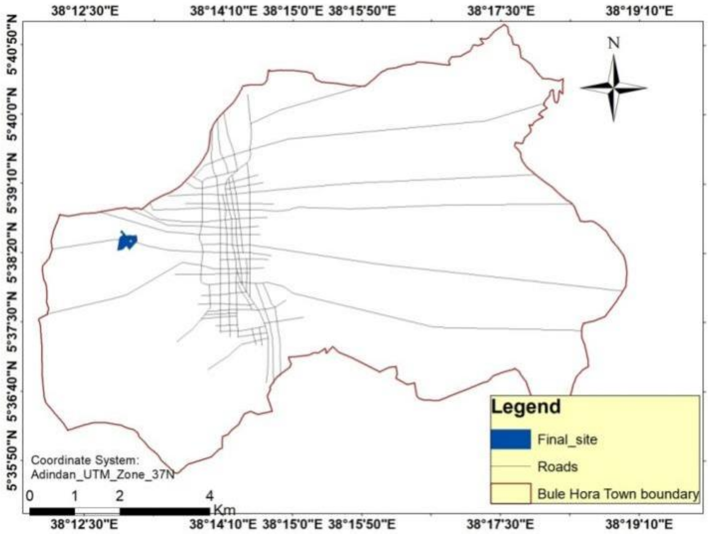

Figure 13: Final suitable new school sites

5. Conclusion

The GIS based multi-criteria analysis method has been utilized to build up the school site selection that is introduced in this study. For new school site selection in Bule Hora area five multi criteria were used. Each of them has their own factor on new school site selection. Additional the site was selected with respect to roads distance. For instance the Final site selected near to western roads of the study area. This is by considering the accessibility of transportation. A site closest to the transportation route is most easily serviced. The steep slope having 5.928101503 - 15.91227245 (6 -16) degrees with 1 – 3 score values have been restricted for site selection. The final suitable site map indicates that the most suitable site covers 11.129244 hectares area which indicates 0.111292 percent. Generally, bare land, recreation sites, and gentle slopes were assigned higher weightage values, whereas steep slopes, vegetation, existing schools, and built-up areas received lower weightage assigned. Consequently, the final site for the new schools was chosen in a bare land area, near the road leading to the western part of the region, approximately midway between settlements, to the west of Bule Hora town.

Conflicts of Interest

The authors declare that there are no conflicts of interest associated with the publication of this Manuscript.

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