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Urban green space development using GIS-based multi-criteria analysis in Addis Ababa metropolis

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Abstract Land suitability analysis is becoming critical in determining the land resource which is suitable for some specific uses. The city administrators and planners are faced with difficulties in supplying facilities like availing of green space due to the dynamic urban growth trends. The paper assesses suitable sites for urban green space using geographic information system (GIS) multi-criteria analysis methods. Numerous spatial and non-spatial datasets were obtained from different organizations and processed using GIS tools and remote sensing techniques for suitable site selection process. The suitability analysis was done in GIS-based multi-criteria decision analysis steps. Analytical hierarchy process of a pairwise comparison matrix was created and criteria weights were calculated for each factor. Based on GIS-based MCA, 49.76, 4.15, and 24.04% of the study area identified as less suitable, highly suitable and moderately suitable for green space development, respectively.

Keywords Urban green space · Remote sensing · Geographic information systems · Multi-criteria analysis · Addis Ababa, Ethiopia

Introduction

Due to rapid urbanization in developing world, city administrators and urban planners are challenged with problems in delivering basic services like green space, sanitation, water supply, transportation, and primary health center. The urban green spaces' coverage is not adequate to meet people's needs due to population pressure, expansion of industry, and construction in the process of urbanization (Cetin 2015a, b, c). Urban planners have to visualize such growth during planning, policy, and decision-making. Impulsive construction of unplanned informal houses in and outside the administrative boundaries of towns and cities is common in developing countries. These insightful changes cause a change in land use type which makes urban planning foreseeable (Zewdu 2011).

Urban planning does not only cover matters of the built environment such as housing and transportation network, but also the integration of green spaces into the physical urban landscape. The main indicators of planned urbanization expecting physical and socioeconomic development in terms of the suitable areas for health, where bioclimatic comfort arises as one of the most significant factors (Cetin 2015a, b, c). The bioclimatic comfort situations can be established with the design criteria of landscape architecture and planning (Cetin et al. 2016).

In recent years, Addis Ababa and its surroundings have observed unprecedented land degradation as a consequence of deforestation for firewood supply and human settlement. Big tracts of the city's vegetation area are transformed to permanent structures at a rate of 6.65 km^2/year (Tamiru et al. 2005). About 10,000 ha of land initially reserved for green spaces have been allocated for other uses (Tadesse 2010). Over the years, Addis Ababa witnessed ecosystem degradation and vegetation cover is estimated at 14.6% (AAEPA 2005). In the city, 382 ha of riparian area is being cultivated by vegetable growing farmers, which cover up to 7.1% of the city's vegetable demand (Azeb 2007).

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Table 1 Data sources

Dataset	Source	Resolution	Purpose	Type	year
Landsat ETM+	http://libra.developmentseed.org	15 × 15 (m)	Classification	Raster	14/12/2015
Land use plan	Integrated land Information center		Reference		2012
ASTER Global Digital Elevation Models version 2	The US National Aeronautics and Space Administration (https://earthdata.nasa.gov/)	30 m	To drive slope	Raster	2011
GPS field survey	Survey	–	Point data for proximity analysis	Vector	2015/16
Soil data	Ministry of Agriculture		For suitability analysis	Vector	2013
Population	CSA	–	For suitability analysis	Excel	2007 & 2014 (projected)
Road network	Ethiopian Roads Authority and OSM		For proximity analysis	Vector	2012 & 2014
Stream	OSM		For proximity analysis	Vector	2014
Bole boundary	CSA		For delineated	vector	2007
Topographic maps: sheet no. 0838B2, 0838B1, & 0938D4	EMA	1:50,000	Reference	vector	1973/1982
City map of Addis Ababa	EMA	1:15,000 & 1: 25,000	Reference	Raster	1986 & 2000

Land suitability analysis is the process to determine whether the land resource is appropriate for some specific uses and to determine the suitability level by considering different factors such as LULC (land use and land cover) type, landscape, and road infrastructure (Manlun 2003). Suitability analysis of different LULC patterns and dynamics is important to determine the most desirable site for future development. Identifying appropriate suitability parameters are the foundation of construction of suitability analysis.

Green spaces are land uses that are covered with natural or man-made vegetation in the built-up areas and planning areas (Manlun 2003). The meaning of the green space system has also been continuously emerging with the development of city theory, which mainly encompasses horticultural, ecological, and spatial meanings. GIS has the main role in land-use suitability analysis for green space. In the tourism sector also, maps have vital role to protect natural and cultural value in terms of time and cost efficiency and deliver very accurate and up-to-date data (Cetin 2015a, b, c).

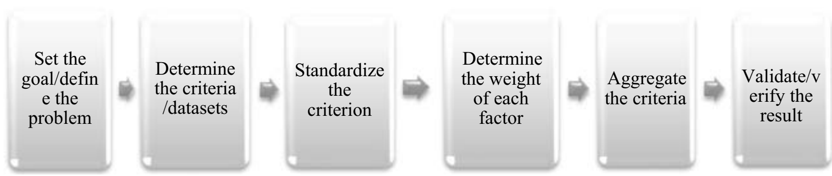

Fig. 1 Methods of multi-criteria evaluation (MCE) steps (modified from Eastman 2006)

Table 2 Pairwise comparison matrix

Criteria	LULC	Population density	Road	River	Historical place	Noise influence	Park	Slope	Soil type	Weight
LULC	1.00	2.00	3.00	7.00	9.00	3.00	7.00	5.00	3.0	0.31
Population density	0.50	1.00	2.00	5.00	7.00	2.00	5.00	3.00	2.0	0.2
Road	0.33	0.50	1.00	3.00	5.00	1.00	3.00	2.00	1.0	0.11
River	0.14	0.20	0.33	1.00	2.00	0.33	1.00	0.50	0.3	0.04
Historical place	0.11	0.14	0.33	0.50	1.00	0.20	0.50	0.33	0.20	0.03
Noise influence	0.33	0.50	1.00	3.00	0.50	1.00	3.00	0.50	1.0	0.09
Park	0.14	0.20	0.33	1.00	2.00	0.33	1.00	0.50	0.33	0.04
Slope	0.20	0.33	0.50	2.00	3.00	0.50	2.00	1.00	0.50	0.07
Soil type	0.33	0.50	1.00	3.00	5.00	1.00	3.00	2.00	1.00	0.11

Table 3 Random consistency index (RI) (Saaty 1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Theoretical framework

Theory, models, and observation are fundamental constituents of land use study. There are three main customs of speculating land use such as urban and regional economics and regional science, sociology and political economy, and nature-society theories culture (Hersperger et al. 2010). Urban and regional economics and regional science are significant for sustainable land management and urban planning. The sociological and political economy method is used for land use study in combination with the economic manner. Nature-society theories refer to a universal outlook of the human cause of environmental change and concerned of the relations between environment, economy, society, technology, and culture (Hersperger et al. 2010).

LULC has three main components such as driving forces, actors, and land itself (Hersperger et al. 2010). The driving forces interact with actors to shape the land change like climate change, human activities, urbanization, and population growth etc. Government policy influences the actors through making decisions (e.g., land use policy, urban utilities planning, resettlement, etc.). Actors may be individuals or groups

Table 4 Reclassified LULC

LULC	Level of suitability	Value	Area (ha)	Percent of total area
Bareland and grassland	S1	5	536.41	4.46
Plantation	S2	4	135.32	1.12
Forest land	S3	3	408.40	3.39
Cultivated land	N1	2	1736.83	14.43
Built-up and transport area	N2	1	9221.19	76.60

S1 highly suitable, *S2* moderate, *S3* less suitable, *N1* not suitable, *N2* permanently unsuitable conditions for green space

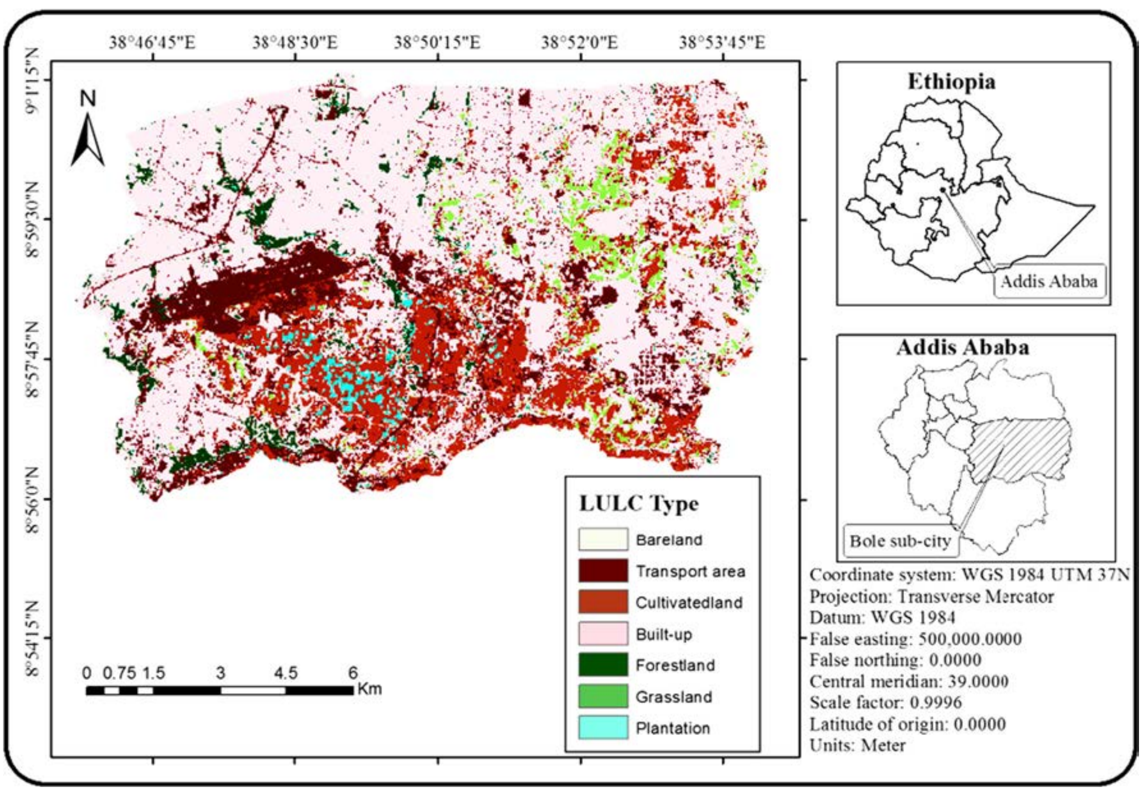

Fig. 2 LULC classification of 2015

Table 5 Reclassified distance from road and area coverage of suitability levels

Distance from road (km)	Level of suitability	Value	Area (ha)	Percent of total area
< 0.5	S1	5	9186.54	75.61
0.5–1.0	S2	4	1856.53	15.28
1.0–1.5	S3	3	634.47	5.22
1.5–2.0	N1	2	336.14	2.77
> 2.0	N2	1	135.98	1.12

who own the land and affect it directly such as land owners and policy makers. Land characteristics by itself can influence the land cover change (e.g., geological state).

Suitable site selection process considers three parameters such as location, physiographic feature, and planning aspects (Soni et al. 2013). Locational analysis encompasses any spatial analysis of the area like proximity to the different services. Physiographic feature describes features and attributes of the land surface. For instance, soil type, hydrology, vegetation, and topography are main parameters in the suitable site selection process. Planning aspect is another important parameter for suitability analysis (e.g., land use, population density, administration, etc.).

Urban green spaces as important part of urban ecosystems play a significant role in environmental, economic, and social aspects in urban areas (Mensah 2014). Furthermore, green spaces sequester CO_2 and produce O_2; diminish air pollution and noise; control microclimates; decrease the heat; maintain diversity; have recreational and social values; and produce a vitamin “G” for health, well-being, and social protection (Uy and Nobukazu 2008). Applying the ecological element threshold technique will serve to quantify how much green area is needed to maintain an ecological stability in urban areas (Uy and Nobukazu 2008). In general, there are many factors that affect LULC like land owner’s activities, external driving forces, land characteristics, and government policy.

Methods and materials

To better understand how to develop urban green space in GIS-based multi-criteria analysis, a mixed approach was employed (Creswell 2014). As presented in Table 1, various spatial and non-spatial datasets were obtained from different sources and analyzed and interpreted in qualitative and quantitative research methods using Arc GIS 10.3 and ERDAS Imagine 2013 softwares for analysis and mapping purposes. The existing situation of land use was analyzed and

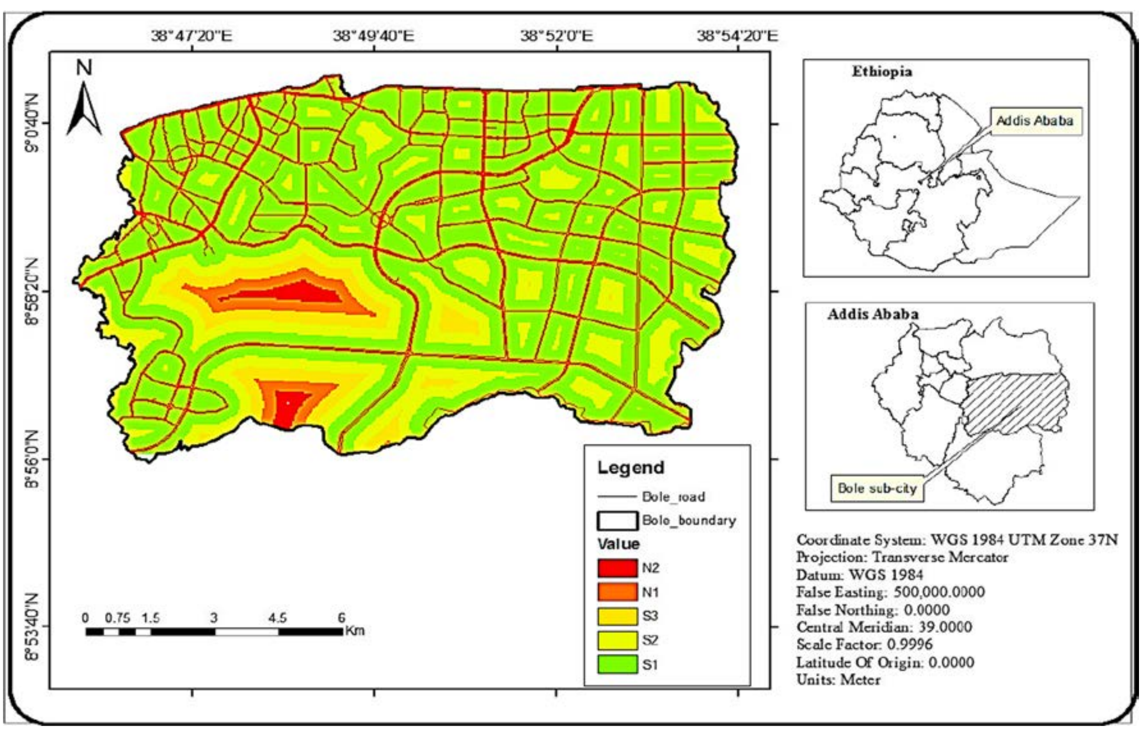

Fig. 3 Reclassified distance from road map

Table 6 Reclassified distance from stream and area coverage of suitability levels

Distance from stream (km)	Level of suitability	Value	Area (ha)	Percent of total area
< 0.5	S1	5	5231.63	42.39
0.5–1.0	S2	4	3500.28	28.36
1.0–1.5	S3	3	2369.57	19.20
1.5–2.0	N1	2	1139.38	9.23
> 2.0	N2	1	99.93	0.81

interpreted from satellite imageries and field observation in qualitative and quantitative methods. Input datasets included Advanced Space Born Thermal Emission and Reflection Radiometer (ASTER) global DEM and Landsat TM (2015).

There are ten sub-cities in Addis Ababa. The study employed purposive sampling technique to select *Bole* sub-city because this sub-city is one of the largest sub-cities in terms of area, and there are many business centers, organizations, recreational sites, and airport; however, urban forest area coverage is relatively smaller than other sub-cities (*Yeka*, *Gullele*, *Kolfe Keranyo*, *Nifas Silk-Lafto*, and *Akaki Kality*) (Mekonnen 2012).

In order to select the best sites for urban green space in *Bole* sub-city, six GIS-based MCA steps were followed (Fig. 1).

The first step was to set the goal or define the problem. In this study, the aim of GIS-based MCA is to produce a map showing suitable sites for green space in the *Bole* sub-city. The second step was determining factors/criteria that are important for green space development. The factors used for site selection process for a green space were selected based on different literatures and prior knowledge of that particular area. Based on the literature and previous related studies conducted by different researchers (e.g., Heshmat et al. 2013; Manlun 2003; Kuldeep 2013; Pantalone 2010; Yousef and Mohammad 2014; Ahmed et al. 2011; Elahe et al. 2014), LULC, population density, soil type, slope, proximity to existing road, distance to existing park, distance to noisy influence, distance to historical place, and distance to stream were selected as factors that are important for the green space development in *Bole* sub-city. These datasets were collected from various sources and processed using ArcGIS software for multi-criteria analysis.

The third step was standardizing each factor/criterion scores. It is important to set the suitability values of the factors

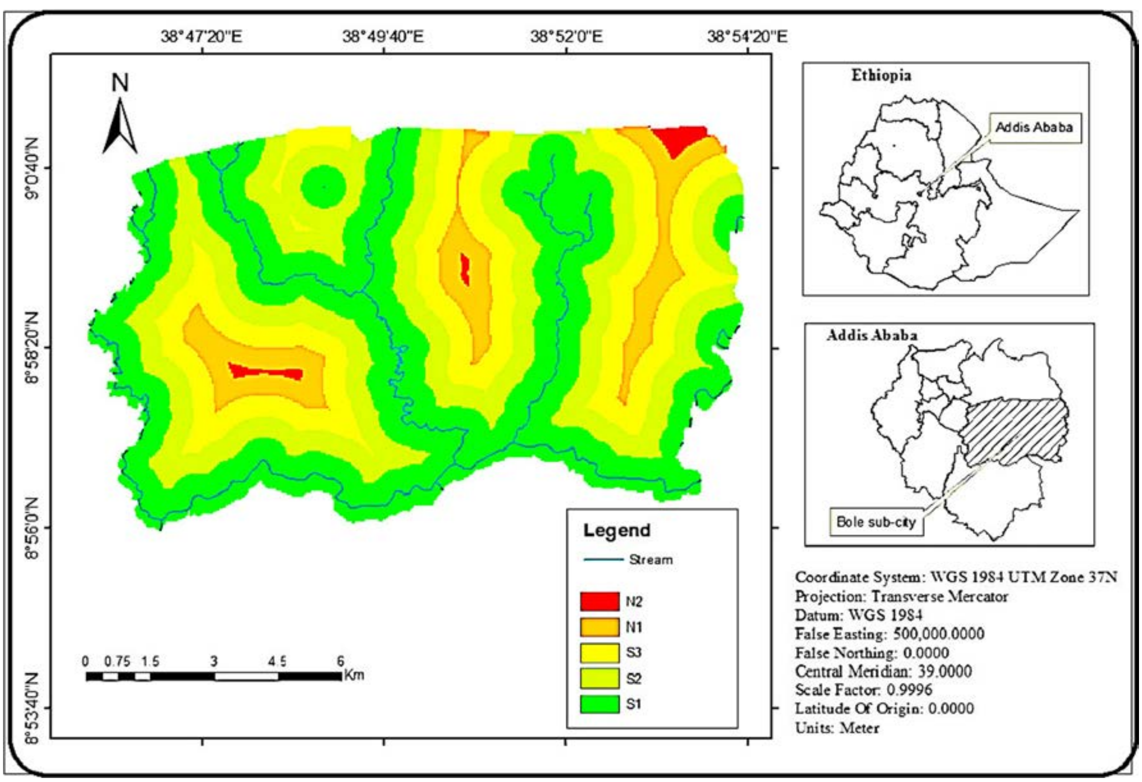

Fig. 4 Reclassified distance from stream map

Table 7 Reclassified distance from historical place and area coverage of suitability levels

Distance from historical place (km)	Level of suitability	Value	Area (ha)	Percent of total area
< 1.5	S1	5	2281.048	18.87
1.5–3.0	S2	4	3631.902	30.04
3.0–4.5	S3	3	3858.738	31.92
4.5–6.0	N1	2	1948.413	16.12
> 6.0	N2	1	368.184	3.05

to a common scale to make comparisons possible. Therefore, all input datasets were changed into a raster at 30 m resolution and to a common measurement scale using conversion. Based on FAO land suitability classification, the datasets were reclassified from highly suitable (S1) to permanently unsuitable (N2); where S1 represents the highly suitable, S2 moderate, S3 less suitable, N1 not suitable, and N2 represents permanently unsuitable conditions for green space.

The fourth step was defining weights for each criterion based on its importance for the green space development. Several methods are available to determine the weight-like analytical hierarchy process (AHP), ranking, and rating.

In this study, the AHP method was adopted to assign weight for each factor because AHP uses a hierarchical structure; it enables decision-makers to define high-level strategic objectives and specific metrics for a better assessment of strategic alignment, and it can be applied in any organization with any level of maturity because the inputs are normalized using either numerical data or subjective judgments when metrics are not available and the process gives itself to sensitivity analysis (Saaty 1980).

AHP and the GIS are integrated techniques used to assess suitable land use for UGS (urban green space) in *Bole* sub-city. A pairwise comparison matrix was constructed, where each criterion was compared with the other criteria, relative to its importance, on a scale from 1 to 9.

Priority vector is also called normalized principal eigenvector. To normalize the values, it divided the cell value by its column total and calculated the priority vector or weight to determine the mean value of the rows (Saaty 1980). Accordingly, 0.31, 0.20, 0.11, 0.04, 0.03,0.09, 0.04, 0.07, and 0.11 was obtained as a weight value for the LULC, population density, distance from the road, distance from the stream, distance from the historical place, noise influence,

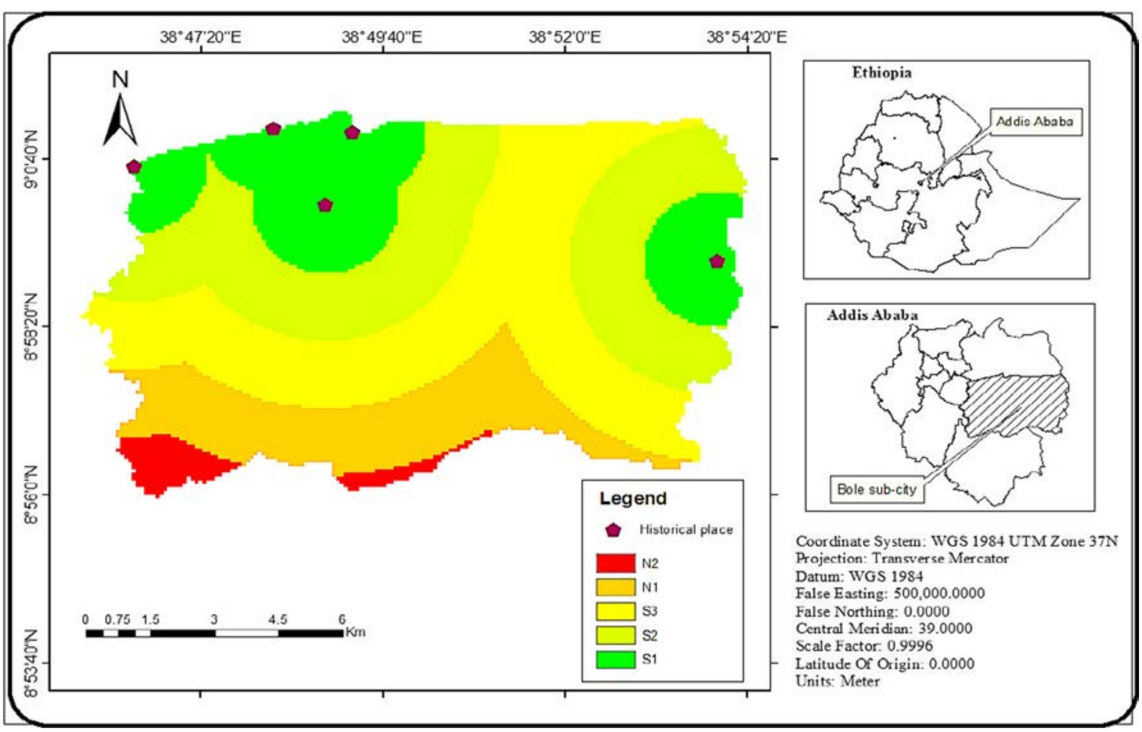

Fig. 5 Reclassified distance from historical place map

Table 8 Reclassified distance from factory and area coverage of suitability levels

Distance from factory (m)	Level of suitability	Value	Area (ha)	Percent of total area
> 4	S1	5	3550	29.36
3–4	S2	4	2052	16.97
2–3	S3	3	1966	16.26
1–2	N1	2	2141	17.71
< 1	N2	1	2381	19.69

distance from the existing park, and, slope, and soil type, respectively, with 0.01 of consistency ratio (Table 2).

A consistency ratio of less than 0.1 shows a consistent comparison between the criteria, and it was considered as acceptable (Table 3) (Saaty 1980).

$$CR = \textit{consistency index}\ (CI)/\textit{random consistency index}\ (RI) \quad (1)$$

$$CI = (\lambda_{max} – n)/n – 1 \quad (2)$$

Where λ max is the principal eigenvalue; n is the number of factors.

λ_{max} = Σ of the products between each element of the priority vector and column totals.

Step five was to aggregate the criteria using weighted linear combination and apply it in the ArcGIS raster calculator. Validating or verifying the result was the final step. It helps to assess the reliability of the output and usually assessed by ground truth verification and sensitivity analysis. Sensitivity analysis was performed by changing the weight of criteria and field survey was conducted for ground truth verification.

In weighted linear combination (WLC) procedure, factors or parameters (Vi) multiplied by the weight of the suitability parameters (Wi) to get composite weights and then summed. WLC is a straightforward linear method for calculating composite weights. This function multiplies and sums up the layers to produce suitability maps for green space. Therefore, the weighted linear technique (Mendoza 1997) was applied to generate a suitable site map for green space.

$$E = \sum_{i=1}^{n} (wi^{*}vi) \quad (3)$$

Where, Wi = relative importance or weight of factors/ parameters I; Vi = relative weight of parameters I; and n = total number of parameters related to the study.

In this paper, AHP method, sensitivity analysis, and field observation were employed for the purpose of quantification and validation of data. Sensitivity analysis and field

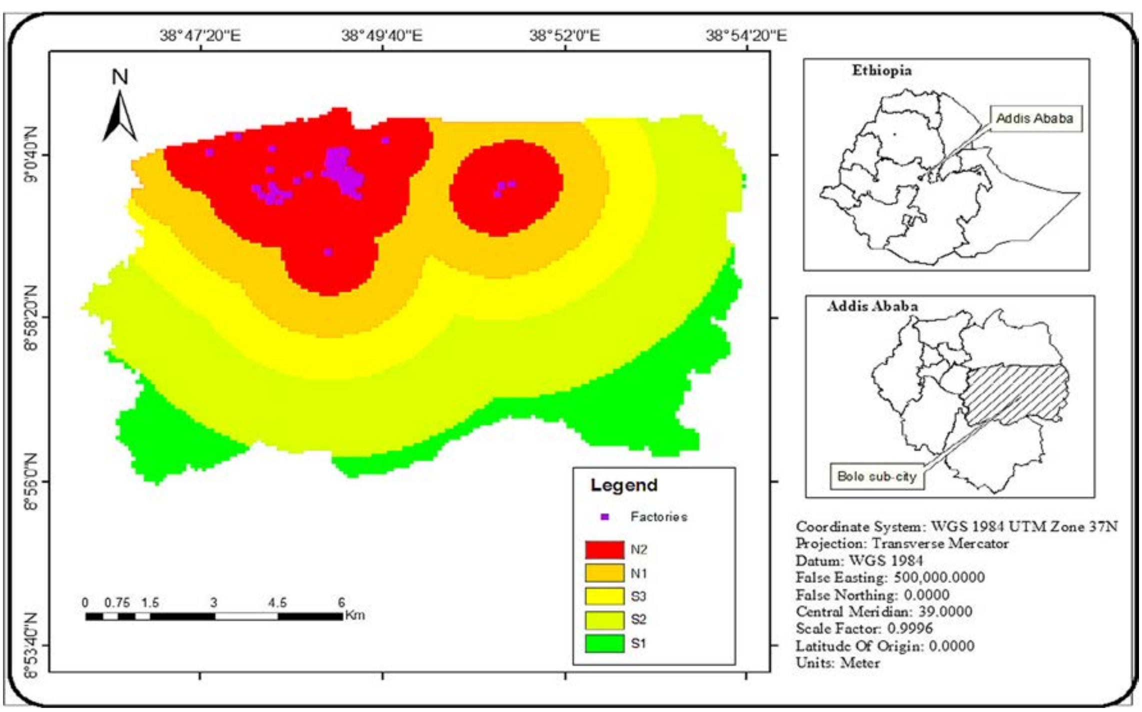

Fig. 6 Reclassified distance from factory map

Table 9 Reclassified distance from park and area coverage of suitability levels

Distance from park (km)	Level of suitability	Value	Area (ha)	Percent of total area
> 6	S1	5	2066.91	17.11
4.5–6	S2	4	1964.50	16.26
3.0–4.5	S3	3	2917.54	24.15
1.5–3.0	N1	2	2791.43	23.11
< 1.5	N2	1	2338.60	19.36

observation were used as a tool to check the final result through assessing the ground truth and validation and calibration of numerical models. Hence, quantification and validation of data determine the reliability of the results in GIS-based multi-criteria analysis.

Results and discussions

Suitability analysis for urban green space development

Suitability of land use/land cover

The LULC of the study area was analyzed using 15 m resolution of Landsat image, land use plan of the city, and ground truth verification. By reviewing different literature (e.g., Heshmat et al. 2013; Ahmed et al. 2011; Manlun 2003), it was advisable to select land, which was occupied by bare and grasslands for green space development. In the study area, major LULC classes were built-up (60.2%), cultivated land (14.4%), plantation (1.1%), forestland (3.4%), grassland (3.4%), transport area (16.4%), and bareland (1.0%) (Table 4 and Fig. 2).

Suitability distance from roads

Elahe et al. (2014) and Ahmed et al. (2011) suggested that the green space site is preferable when it is located at a suitable distance from roads in order to access transportation. It was reclassified as unsuitable road greater than 2 km relatively compared to the other. The distance starting from 0.5 up to

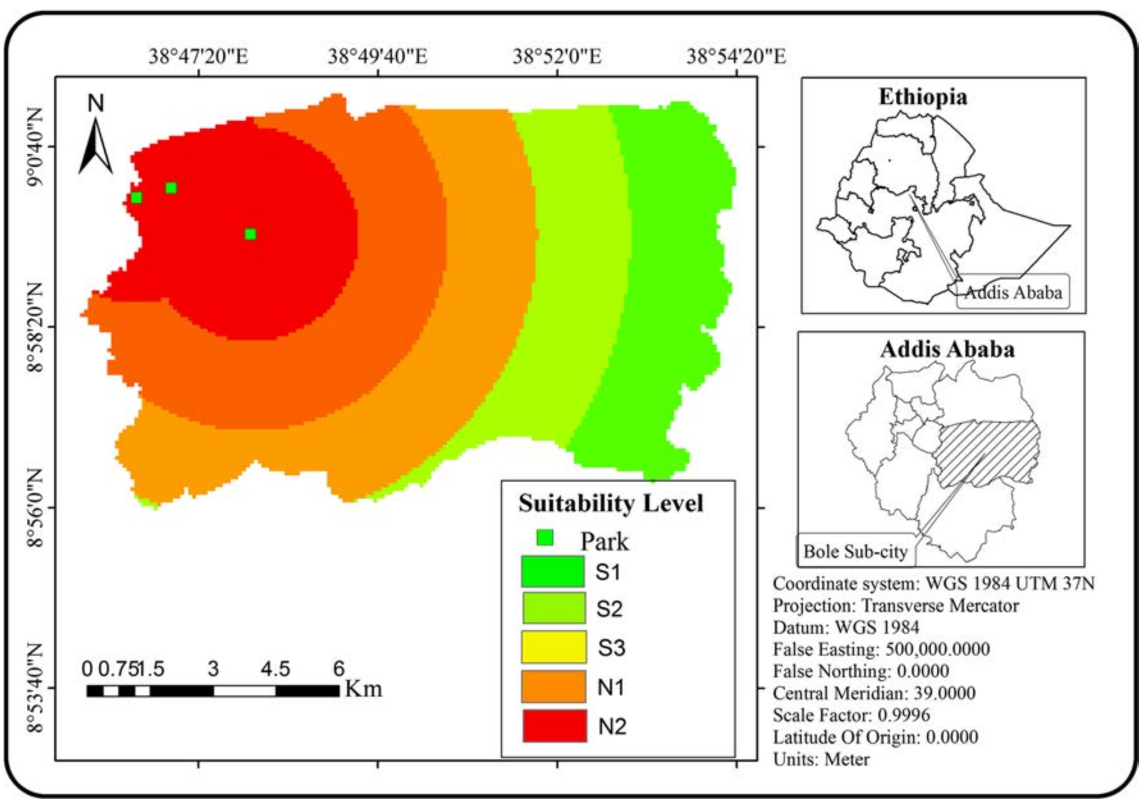

Fig. 7 Reclassified distance from park map

Table 10 Reclassified slope and area coverage of suitability levels

Slope (%)	Level of suitability	Value	Area (ha)	Percent of total area (%)
< 5	S1	5	8567.26	71.18
5–10	S2	4	2849.83	23.68
10–15	S3	3	535.77	4.45
15–30	N1	2	77.87	0.65
> 30	N2	1	5.92	0.05

1 km was considered as moderately suitable and highly suitable is distance less than 0.5 km. The result indicated that 75.61% of the total area is highly suitable with the class value of 5 and 15.28% is moderately suitable for green space development. The land that is unsuitable for green space constitutes 1.12% (Table 5 and Fig. 3).

Suitability distance from the stream

The closer lands to the stream banks get more preferences and it is to maintain the environmental health of the area (Kuldeep 2013). Manlun (2003) and Heshmat et al. (2013) also noted that lands closest to water resources like rivers, lakes, and reservoirs are highly suitable for green space development. Therefore, based on this argument, distance from the stream less than 0.5 km (42.39% of the area) is highly suitable relative to the other and in between 0.5 and 1 km is moderately suitable (28.36% of the area). Whereas 0.81% of the area is relatively considered as totally unsuitable, i.e., greater than 2 km from the stream (Table 6 and Fig. 4).

Distance from historical place

Developing of green space closer to historical place can maintain and preserve the historical place in the case of maintaining ecological balance (Manlun 2003). Therefore, the land which is closer to historical place is more suitable than the farther land. Distances from the historical place less than 1.5 km and in between 1.5 and 3 km are highly suitable and moderately suitable, respectively, and greater than 6 km is relatively considered as totally unsuitable. Of the total area, 18.87% is highly suitable whereas 3.05% is totally unsuitable (Table 7 and Fig. 5).

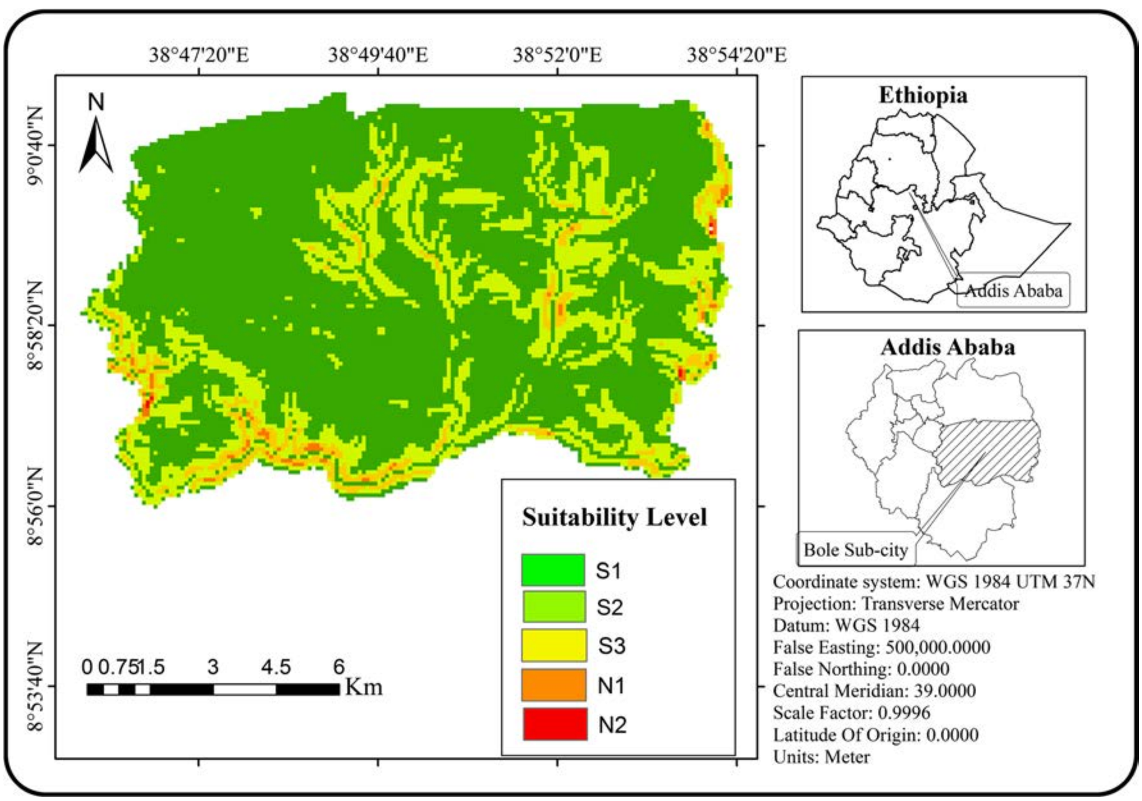

Fig. 8 Reclassified slope

Table 11 Reclassified soil and area coverage of suitability levels

Soil type	Level of suitability	Value	Area (ha)	Percent of total area
Chromic vertisols	S1	4	1566.69	12.97
Pellic vertisols	S2	3	8353.12	69.15
Etruic nitosols	S3	2	1830.76	15.16
Orthic solonchaks	N1	1	328.40	2.72

Source: Ministry of Agriculture 2013

Distance from noise influence

Noisy areas are not suitable for green space like the factory area because of high sound pollution and smokes (Manlun 2003). Therefore, the farther lands from the factory get more preferences for developing green space. The study considered the reclassified distances as totally unsuitable if less than 1 km, not suitable between 1 and 2 km, less suitable from 2 to 3 km, moderately suitable from 3 to 4 km, and highly suitable greater than 4 km for developing green space. In the study area, highly suitable area covers the highest share (29.36% of the total area) as compared to other level of suitability (moderately suitable, 16.97%, and totally not suitable, 19.69%) for developing green space (Table 8 and Fig. 6).

Distance from the park

In the study area, there are three main parks such as *Shalla*, *Peacok*, and *Adowa* Parks. The area which is the farthest from the existing park highly requires the green space because that area lacks green space or vegetation (Pantalone 2010). Therefore, if distance from the park is greater than 6 km, it will be considered as highly suitable; 1.5–6 km, moderately suitable; and less than 1.5 km, permanently not suitable for developing parks (Table 9 and Fig. 7).

Suitability of slope

Different researchers show that areas with low slopes are highly suitable for developing park (e.g., Heshmat et al. 2013 and Yousef and Mohammad 2014). Based on FAO (2006), the slope value 0 to 0.2% is considered as flat and up to 5 gently slope. Five to 10% and 10 to 15% is called sloping and strongly sloping, respectively. Whereas 15 to 30% and above 30% is moderately steep and steep, respectively. Therefore, this study considered the gently slope as more highly suitable than the land with steep slope. The majority of the study area falls under the slope class of less than 5%, which covers 71.18% of the total study area. The slope value greater than 30%, which has the least coverage about 0.05% is steep slope totally unsuitable compared to the other (Table 10 and Fig. 8).

Suitability of soil type

Soil of Addis Ababa is classified into seven categories, namely chromic vertisols, pellic vertisols, etruic nitosols, orthic

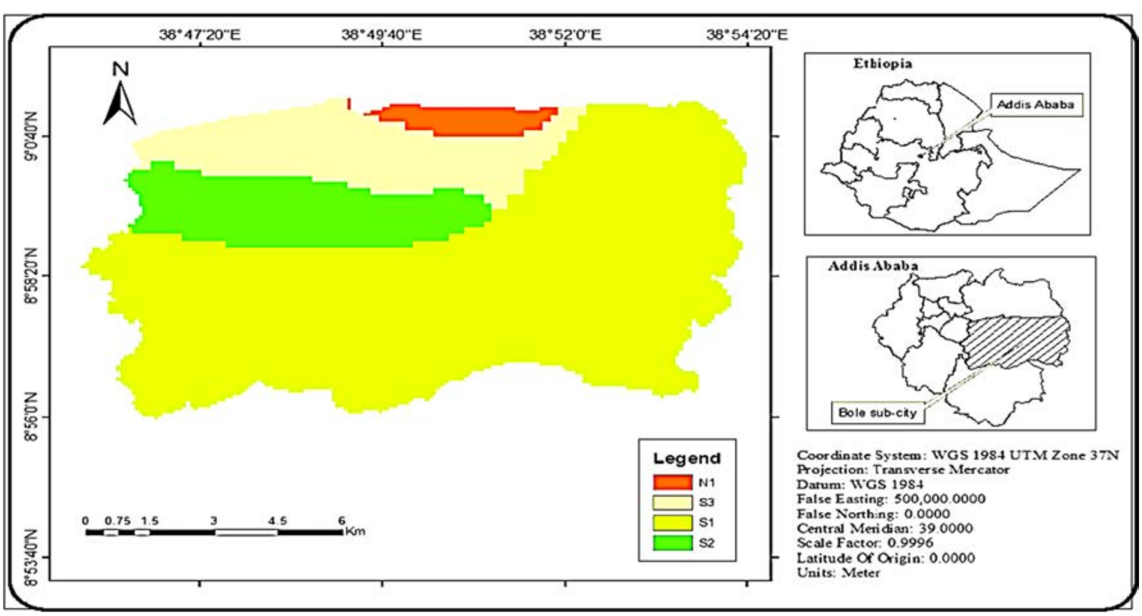

Fig. 9 Reclassified soil map

Table 12 Reclassified population density and area coverage of suitability levels

Population density (pop/ha)	Level of suitability	Value	Area (ha)	Percent of total area (%)
> 80	S1	5	1135.52	9.41
50–80	S2	4	1942.08	16.10
20–50	S3	3	1129.76	9.37
5–20	N1	2	3050.88	25.29
< 5	N2	1	4804.32	39.83

Source: Central Statistical Authority of Ethiopia (2007)

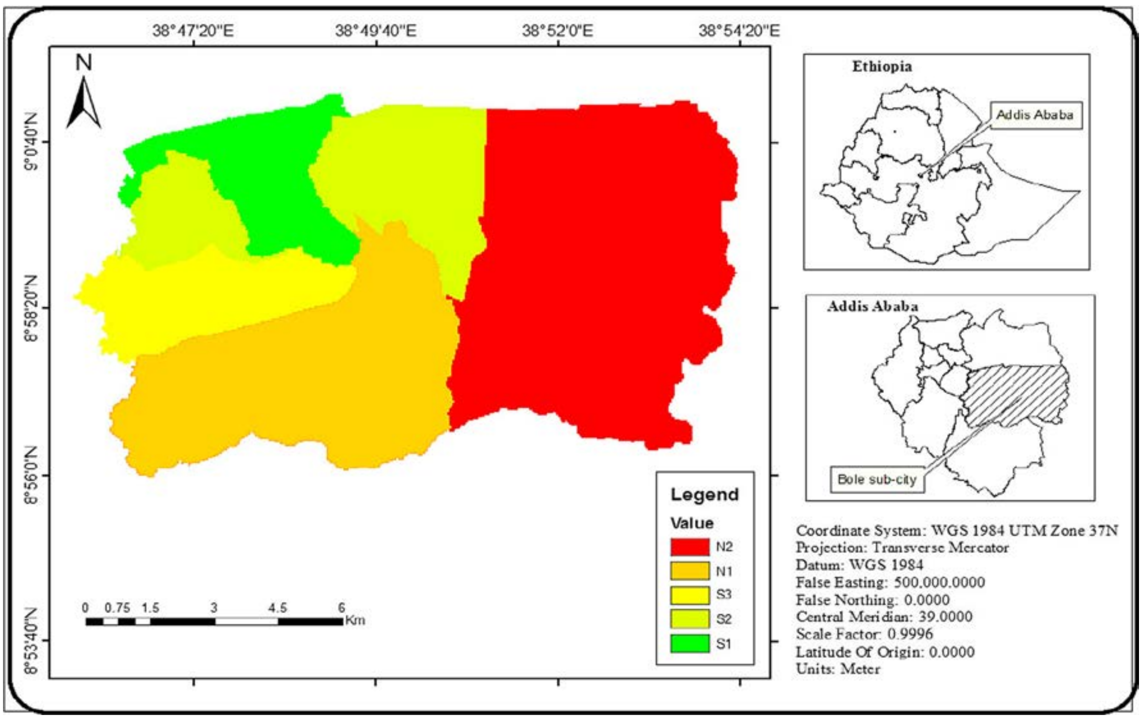

Fig. 10 Reclassified population map

Table 13 Suitability level per criterion for park site selection

Criteria	Measurement unit	Suitability level					Weight (%)
		5 S1	4 S2	3 S3	2 N1	1 N2	
LULC	Class	BL & GL	Pl	FL	CL	BA& TA	31
Pop. den.	Pop/ha	> 80	50–80	20–50	5–20	< 5	20
Distance to road	km	< 0.5	0.5–1.0	1.0–1.5	1.5–2.0	> 2.0	11
Distance to stream	km	< 0.5	0.5–1.0	1.0–1.5	1.5–2.0	> 2.0	4
Distance to HP	km	< 1.5	1.5–3.0	3.0–4.5	4.5–6.0	> 6.0	3
Distance to factory	km	> 4	3–4	2–3	1–2	< 1	9
Distance to park	km	> 6.0	4.5–6.0	3.0–4.5	1.5–3.0	< 1.5	4
Slope	%	< 5	5–1	10–15	15–30	> 30	7
Soil type	Class	Chromic vertisols	Pellic vertisols	Etruic nitosols	Orthic solonchaks		11

BL bareland, *GL* grassland, *Pl* plantation, *FL* forestland, *BA* built-up area, *HP* historical place, *Pop. den.* population density, *TA* transport area

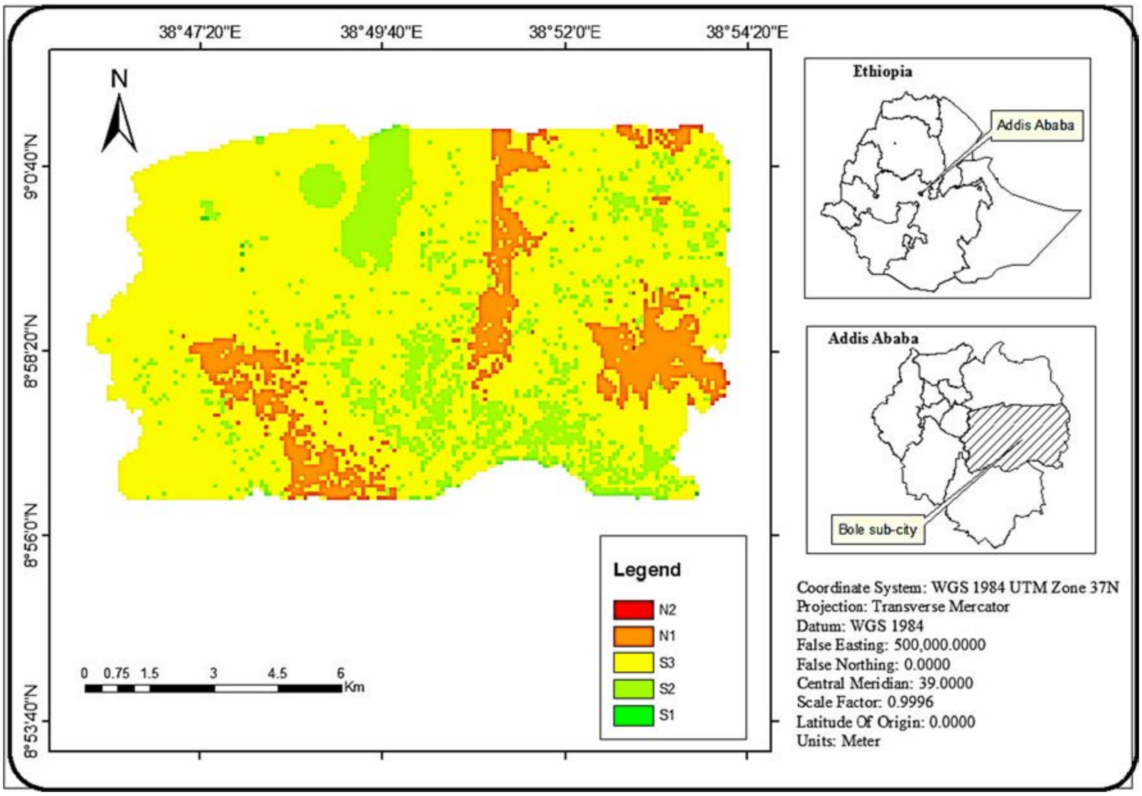

Fig. 11 Final suitability map

solonchaks, calcic xerosols, chromic luvisols, and leptosols (MoA 2007). Specifically, in the study area, only four soil types are available. Based on the UNEP (2005) soil suitability standards, vertisols are considered as suitable soil because of 30% or more clay which is a high natural fertility and covers large area (82.12%). Based on color, chroma and pellic verisols are a great group; chroma vertisols have high amount of clay relative to pellic vertisols (Kamara and Haque 1988). Etruic nitosols are relatively less suitable but fertile soils that cover 15.16% of the area. Orthic solonchaks soils have high content of salts and common in arid and semi-arid areas (FAO 2007). In this study, this soil is considered as unsuitable compared to other types and cover 2.72% of the area (Table 11 and Fig. 9).

Table 14 Suitability area and the percent of total area coverage

Level of suitability	Area (ha)	Percent of total area
S1	501	4.15
S2	2900	24.04
S3	6002	49.76
N1	2420	20.06
N2	240	1.99

Population density

Population density is one of the major criteria for suitable site selection of green space. Some researchers (e.g., Elahe et al. 2014; Heshmat et al. 2013; Pantalone 2010; Ahmed et al. 2011) recommend that areas closer to residential areas are highly suitable for developing green space. The northwest

Table 15 Weight value (%) for each input criterion in five scenarios

Criteria	Scenario (%)				
	A	B	C	D	E
LULC	31	40	25	35	29
Population density	20	21	24	23	19
Distance to road	11	14	20	10	16
Distance to stream	4	8	3	5	3
Distance to historical place	3	2	6	10	4
Distance to factory	9	6	2	7	8
Distance to park	4	2	9	3	5
Slope	7	2	7	4	8
Soil type	11	5	4	3	8
Consistency ratio	1	4	3	5	2
Total suitable area (%)	28	12	30	13	27

and northern part of the study area is highly populated and suitable for developing green space. The eastern part is sparsely populated and hence unsuitable for green area. With respect to population density, highly suitable and moderately suitable areas cover 1135.52 and 1942.08 ha of the total area, respectively, (Table 12 and Fig. 10).

AHP pairwise comparison matrix was created and criteria weights were calculated for each factor by comparing factors on a scale from 1 to 9. The reclassified input datasets were assigned a weight value to express the importance of each criterion to the other criteria for suitable site selection for green space (Table 2). In order to select suitable sites for green space development all the reclassified input datasets were overlaid using the Weighted Overlay tool or a raster calculator in ArcGIS (Table 13 and Fig. 11).

According to GIS-based MCA, 501 and 2900 ha are highly suitable and moderately suitable for green space development. The large area is less suitable for green space development in the existing situation which covers 49.76% (6002 ha) of the area. The remaining 22.06 and 1.99% are unsuitable and permanently unsuitable for park development, respectively (Table 14). In the land use plan, the selected areas are mostly categorized under riverine, recreational, and open space.

In the revised structure plan, 15 to 20% was proposed for open spaces and environmental sensitive areas (parks, urban agriculture, recreation, mineral resources) (MUDC 2012). But, this is not enough for green spaces because the Ethiopian Planning Strategy and Urban Land Management Plan allocated 30% of the land for green areas, 30% for roads and infrastructure and shared public use, and 40% for building construction (MUDH 2015).

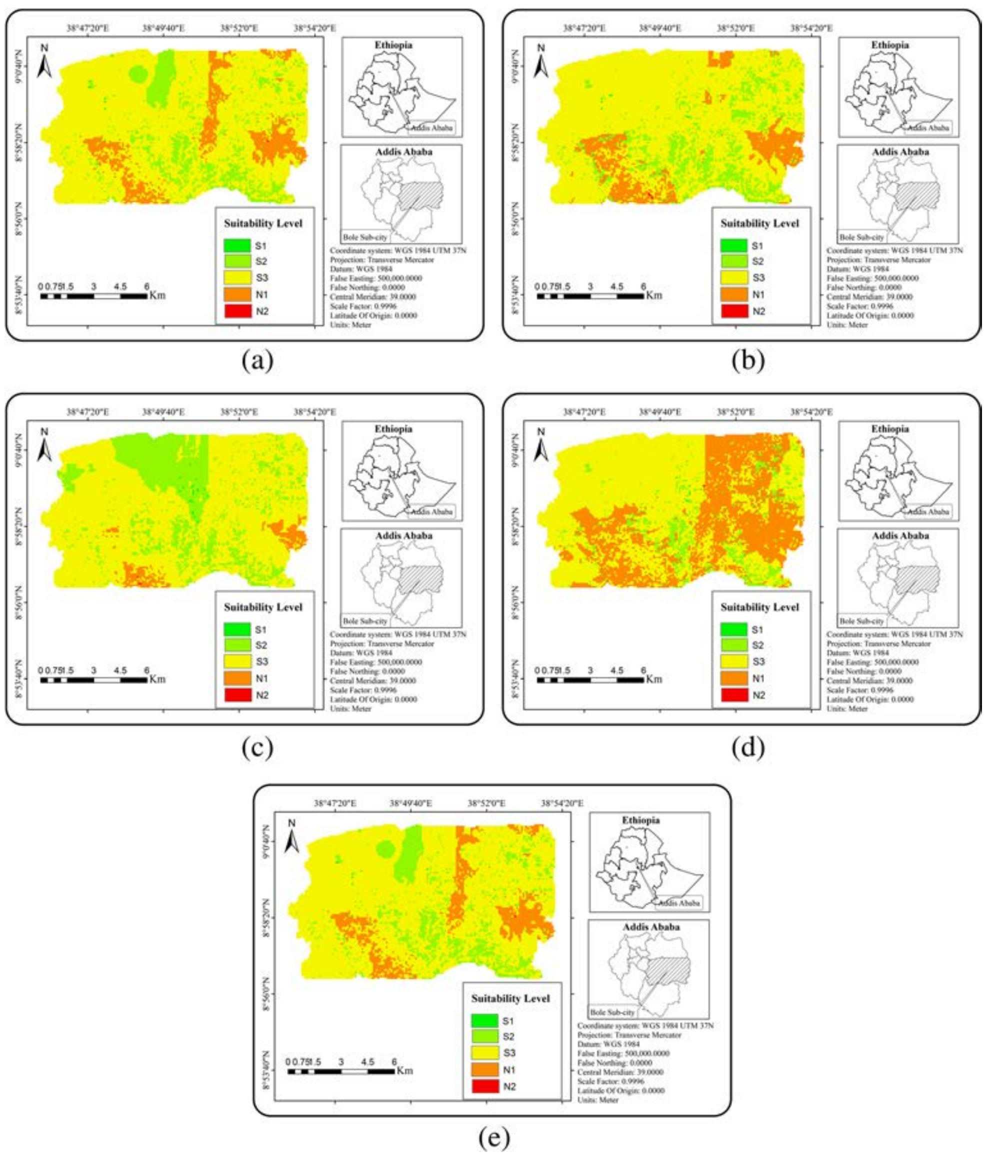

Fig. 12 Sensetivity analysis map of five scenarios

Fig. 13 Selected areas for green space

Sensitivity analysis

Sensitivity analysis determines the reliability of the model through assessment of uncertainties in the reproduction results (Chen et al. 2009). It is significant to the validation and standardization of statistical models. It can be used as a tool to check the final result against slight changes in the input data. Therefore, sensitivity analysis can benefit decrease uncertainty in how a MCDM method works and the constancy of its outputs by illustrating the effect of introducing small changes to specific input parameters on evaluation outcomes (Crosetto et al. 2000). In this study, sensitivity analysis was carried out by changing the weight values of each input criterion in five scenarios (Table 15 and Fig. 12). The weight value for each criterion was calculated using pairwise comparison matrix of AHP with a consistency ratio of less than 0.1.

In order to compare the effect of changes in weight value among five scenarios, scenario A was selected as base scenario which covers 28% of the total area. As the LULC (scenario B) increases, total suitable size diminishes from 28 to 12%. In scenario C, with an increase in population density and distance from the road, the total suitable area increased to 30% of the total area. In scenario D, the lowest weight value was assigned to the slope and soil type, then the total suitable area decreased to 13% of the total area. Whereas in scenario E, the weights are most likely similar to scenario A and total suitable area covers 27%.

Field verification

Field verification was made to assess ground truth of the suitable area using GIS-MCDS process with reference to the *Goro Selam sefer* area, one of the best suitable sites located in the northern part of the sub-city. The LULC of the selected area is mostly riverrine categorized under forestland, plantation, bareland, grassland, and some part cultivated land which is relatively suitable for green space development. With respect to distance to road, stream, historical place, noise influence, existing park, population, and slope, the selected area is identified as suitable site for green space development (Fig. 13).

Conclusions

The urban/built-up areas in Addis Ababa have expanded dramatically, while green areas declined. According to the new City Development Plan (2001–2010), the city has currently consumed more than 75% of its areas for development, leaving little space for green areas. This unprecedented growth is beyond the city's bearing capacity within its current socioeconomic, physical, and administrative situation. Added to these prime problems, the city is challenged by expanding squatter settlements, rising traffic congestion and more pollution, lack of green spaces, and inadequate water supply and sanitation.

From the analysis, we can see that the rapid urbanization in the city of Addis Ababa has given little room for green area development. Land suitability analysis is a critical element in determining areas suitable for some specific purposes such as green space development. However, proposing suitable sites for green space development using suitability analysis is a cumbersome job involving multi-criteria decision analysis steps.

The classification achieved in this study indicates that large area is less suitable for park development in the existing situation (49.76% of the area). As demonstrated in this study, remote sensing and GIS technologies can play a crucial role in urban research and help to get up-to-date information about the urban LULC dynamics with frequent coverage and low cost.

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