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RESEARCH

Geospatial assessment of urban green space using multi-criteria decision analysis in Debre Markos City, Ethiopia

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Abstract

Urban green space (UGS) serves as a lung for city dwellers to breathe and is critical for fostering the sustainable growth of urban ecology and improving residents' quality of life. Debre Markos City (DMC) lacks natural recreational areas such as lakes and artificial green spaces. A notable UGS study utilizing multiple contributing factors integrated with remote sensing and GIS has a significant advantage in making residents more comfortable. This study, therefore, aimed to assess the conventional methods (existing and proposed UGS) against remote sensing and GIS-based, and to identify, quantify and allocate the proper suitable site for UGS development.. Hence, ten UGS influencing factors were selected. Each criterion was analyzed with the use of its proper algorithm. Multicriteria decision-making (MCDM) analysis integrated with Analytical Hierarchy Process (AHP) method and Remote Sensing and GIS were applied. The weighted sum overlay analysis method of spatial analysis was implemented based on the criteria weight of each factor. A 90.6% and 0.8855 accuracy assessment and kappa coefficient were recorded for land use/land cover classification, respectively. The value of the consistency ratio was 0.043, which is < 1 and acceptable. Results revealed that 13.12% (2201 ha), 25.47% (4271.7 ha), 30.89% (5180.8 ha), 22.49% (3772.7 ha), and 8.2% (1345.8 ha) of the total area coverage had *very high*, *highly*, *moderately*, *poorly* and *unsuitable* for UGS development activity at DMC, respectively. In this study, a resident can access UGS with less than 1 km radius distance, closer to the national standard of Ethiopia (i.e. 500 m). However, in the existing UGS, a person is forced to walk or travel more than 8.4 km to get the service. In conclusion, remote sensing and GIS can make life easy to access UGS in the study area with minimum distance, cost, and a short period. It is recommended that policymakers, planners, and executive bodies in Ethiopia consider the future urban demand of dwellers with proper studies earlier to establish other urban infrastructures.

Keywords AHP, GIS, MCDM, Remote Sensing, Urban green space

Introduction

Urban green space (UGS) refers to vegetation found in urban environments such as parks, squares, open spaces, residential gardens, or street trees (Kabisch and Haase 2013). As a highly demanded public resource, UGS plays an important role in improving citizens' quality of life (Shekhar and Aryal 2019; Ahn et al. 2020). Hence, UGS helps to protect urban ecology (Ziter et al. 2019) such as reducing the impact of the urban heat island (Ke et al. 2021; Dong et al. 2022), air purification in urban (Teixeira et al. 2021), lowering surface runoff (Mugiraneza et al. 2022), enhancing biodiversity

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(La Sorte et al. 2020), enhancing carbon storage (Barber et al. 2021; Zhang et al. 2022) as well as maintaining ecological balance (Pecina et al. 2021; Teixeira et al. 2021). As for the inhabitants, UGS serves as an urban metabolism center and a lung for city and town dwellers because it provides a core service to improve urban quality of life, and recreational places, which is a necessary component for urban planning and development and carbon sequestration (Assaye et al. 2017; Amorim et al. 2021; Gelan 2021).

The 2030 Agenda for Sustainable Development Goal 11 aims to make cities and human settlements inclusive, safe, resilient, and sustainable (Emas 2015). Policymakers around the world are addressing urbanization and unplanned urban growth (Vargas-Hernández et al. 2017; Jarah et.al. 2019). It has been discovered that urban planning fails in practice in some developing countries because planning is frequently overambitious, especially in light of the administrative system's ability to enforce their implementation (Akanbang et al. 2018; Jarah et.al. 2019). Urban greenspaces in Africa are still hardly recognized in policymaking (Roberts et al. 2012). There is a scarcity of green infrastructure approaches that integrate well into city planning and governance systems (Turok 2014; Herslund et al. 2018). The basic principles of connectivity, multi-functionality, and social inclusiveness must be considered during planning to achieve the development of green spaces that provide environmental, economic, and social benefits (Girma et al. 2019). Green spaces should be prioritized on the development agendas of urban planning authorities and the allied institutions that manage greenspaces (Adjei Mensah 2015). Therefore, UGS planning, development, and management are key issues for accelerating urbanization. These spaces offer significant benefits to urban dwellers (James et al. 2009; Anguluri and Narayanan 2017) and also provide important habitats for wildlife (Goddard et al. 2017). Well-planned, managed, and funded cities are strongly committed to creating economic, social, environmental, and other non-quantifiable values that can significantly improve the quality of life for all (Habitat 2020).

In the 1960s and 2014, the world's urban population was 34% and 54% of the whole population, respectively. However, by 2050, the proportion of people living in urban areas is expected to reach 66% (UNDESA 2014). Similarly, the fastest global urban population is expected to grow by 2.5 billion city dwellers between 2018 and 2050, with nearly 2.25 billion (90%) of this increase concentrated particularly in low- and middle-income nations of Asia and Africa (Cilluffo and Ruiz 2019). In contrast, urban spatial planning and effective land-use management and development practices in sub-Saharan Africa continue to receive little attention, as in Ethiopia,

especially in regional towns such as Debre Markos (Habitat 2016).

Ethiopia, a low-income country that has experienced rapid urbanization, emerged to create great challenges for planning and development decisions of UGS in cities. As a result, UGS planning and development without a detailed analysis of considering multiple factors made mistakes and could not fulfill citizens' right to access UGS. Thus, this fast urbanization has postured more noteworthy weight on characteristic assets and the environment (Ramachandra and Kumar 2009) and the extent of land used for infrastructure and building development has enlarged at the expenditure of UGS (Sandström 2002). In Ethiopia, UGS is not well planned, allocated, and managed yet in most urban cities such as DMC.

Rapid urbanization and anticipated human advancement will soon necessitate the need for very attractive and sizable UGS sites. Except for the Yeraba natural forest, which is found in the city's southeast, DMC lacked natural attractions like lakes, river beaches, caves, and other green spaces. Moreover, due to the city's oldness, most roads are very narrow and are not designed for a modern way of life. In addition, UGS was mostly planned by only considering its location for its proximity to urban residents.

DMC recently expanded dramatically by incorporating free cultivated lands, grasslands, forest lands, and other open spaces land use types from surrounding rural districts for urban development. This opportunity will provide many benefits for UGS development in terms of better structural planning and opportunities to review past problems. Hence, unplanned (poorly managed) urban expansion can jeopardize sustainability through urban sprawl, pollution, and environmental degradation. As a result, determining and assessing appropriate spatial analysis for UGS is the primary responsibility of improving the urban ecological environment while taking into account several factors, such as physical and mental health (Braubach et al. 2017; Marques da Costa and Kállay 2020). However, according to DMC (2021), structural plan, residents enforced to travel more than 8.4 km (16.8times) and 5.4 km (10.8times) farther than the standard set of the country in the existing UGS and the recently proposed UGS designed by the city, respectively to get the service. Moreover, UGS infrastructure standard of Ethiopia proposes a 500 m radius of public green open spaces within city boundaries (Eshetu et al. 2021).

Globally, many researchers used remote sensing-based UGS site suitability analysis integrated with the AHP method in different cities (Piran et al. 2013; Rasli et al. 2016; Saeedavi et al. 2017; Li 2018a). However, in Ethiopia, even though, MCDM with AHP analysis is applied for many suitability analyses such as cropland suitability

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(Kahsay et al. 2018; Debesa et al. 2020), environmental pollution (Worqlul et al. 2017; Dawit et al. 2020) and irrigation potential (Mussa and Suryabhagavan 2021; Balew et al. 2022) and groundwater potential assessment (Kassahun and Mohamed 2018; Markos et al. 2021; Abate et al. 2022; Guduru and Jilo 2022; Kabeto et al. 2022). Land suitability mapping methods and GIS have been used to assist urban green space planners in developed countries in recent decades; however, their application and practices for UGS assessment are limited in developing countries such as Ethiopia. Only a few recent researches have been conducted in this area, such as suitable site selection for UGS development using GIS and RS based on multi-criterion analysis (Hailemariam 2021), urban green space development using GIS-based multi-criteria analysis in Addis Ababa metropolis (Abebe and Megento 2017)and urban green spaces planning in Sululta town, Ethiopia (Gelan 2021). So, previous studies only showed selecting potential sites for green spaces However, in this study therefore aimed to fill the existing research gap by investigating the importance of locating, planning, and developing UGS sites with reasonable scientific justifications before their establishment. And the study is exceptional with its descriptive statistical comparison by distance (proximity) method of three scenarios (existing, proposed, and remote sensing and GIS-based scientific studies) distance to travel to get UGS services for residents who contribute to the effective planning of green spaces in a sustainable manner. In addition, no scientific study has previously been conducted in the study area using the joined frame of Remote Sensing and GIS methods. Because it uses remotely sensed geographical data, it saves time, effort, and money. Remote sensing, with its benefits of data availability such as spatial data, spectral data, and temporal data coverage of enormous unreachable areas in a short time, has become a practical tool in the assessment, monitoring, and conservation of UGS (Cetin 2015). Therefore, this study aimed to assess the conventional methods of existing and proposed UGS versus remote sensing and GIS-based, and to identify, quantify and allocate the proper suitable site for UGS development in Debre Markos City.

Research methods

Description of the study area

DMC, earlier named Menkorer, is the prior capital of Gojjam Province and is a regiopolitan city in northwestern Ethiopia (Fig. 1). The city was named Debre Markos after its main church, which was founded in 1869 and dedicated to St. Marco. It is located in the East Gojjam administrative area of the Amhara National Regional State. It has Latitude 10° 19′ 60″ North, Longitude 37° 43′ 0″ East. DMC has located 300 km to the North Western part of Addis Ababa City, the capital city of Ethiopia and 265 km Southeast of Bahir Dar, the capital of the Amhara National Regional State. The study area has relatively sloppy topography. The city has an elevation of 2,446 m.a.s.l from the average MSL. It is also located at the foothill of Choke Mountain, which is also known as the water tower of the Upper Blue Nile River, in the East Gojjam Administrative Zone. The most common land cover types in the study area include settlement/residence, agricultural land, grassland, forestland, urban open space, and a very small amount of water bodies. Basalt, Sandstone and Chert are the dominant lithogical units in the study area.

According to the National Meteorological Agency (NMA), DMC has a temperate and warm climate typical of the elevated portions of Ethiopia. The climate is classified subtropical highland (koppen: cwb), despite the proximity to the Equator. The minimum and maximum temperatures average between 14 and 20 °C. The mean annual air temperature is 17.3 °C. March and April are the warmest months with average temperature of 19.8.1 °C. July and August are the coldest months with average temperatures of 15.7 °C. The average annual temperature is 17.5 °C. The average rain fall is considerably irregular going from 15 mm in January to 433 mm in July, being therefore still the main differentiator of the seasons of the year (NMA 2022).According to 1994, national census report DMC has a total population of 49,297 with 9,617 homes, of whom 22,745 were male and 26,552 were female. Based on the 2007 national census result directed by the Central Statistical Agency of Ethiopia, DMC's population was 62469, with 29,901 male and 32,568 female, while, in 2012 the total estimated population of Debre Markos city projected in 2008 by CSA was 262,497, of whom 129,921 were male and 132,576 female (Central Statistical Agency 2007).

Data source

The primary data of the study, like Ground control points (GCP), were collected with the help of GPS. While secondary data were collected from websites, mapping agencies, rainfall stations and DMC data source archives such as DMC plan institutions (see Table 1).

Methods

Multicriteria decision analysis (MCDA) integrated with Analytical Hierarchy Process (AHP) was applied to determine an ideal place for UGS. There was no universally agreed factor for urban green space organization (Jabir and DasS 2014). As a result, by analyzing a review of the literature, expert opinions, personal experiences, and previous research on this topic done by different researchers (Manlun 2003; Uy and Nakagoshi
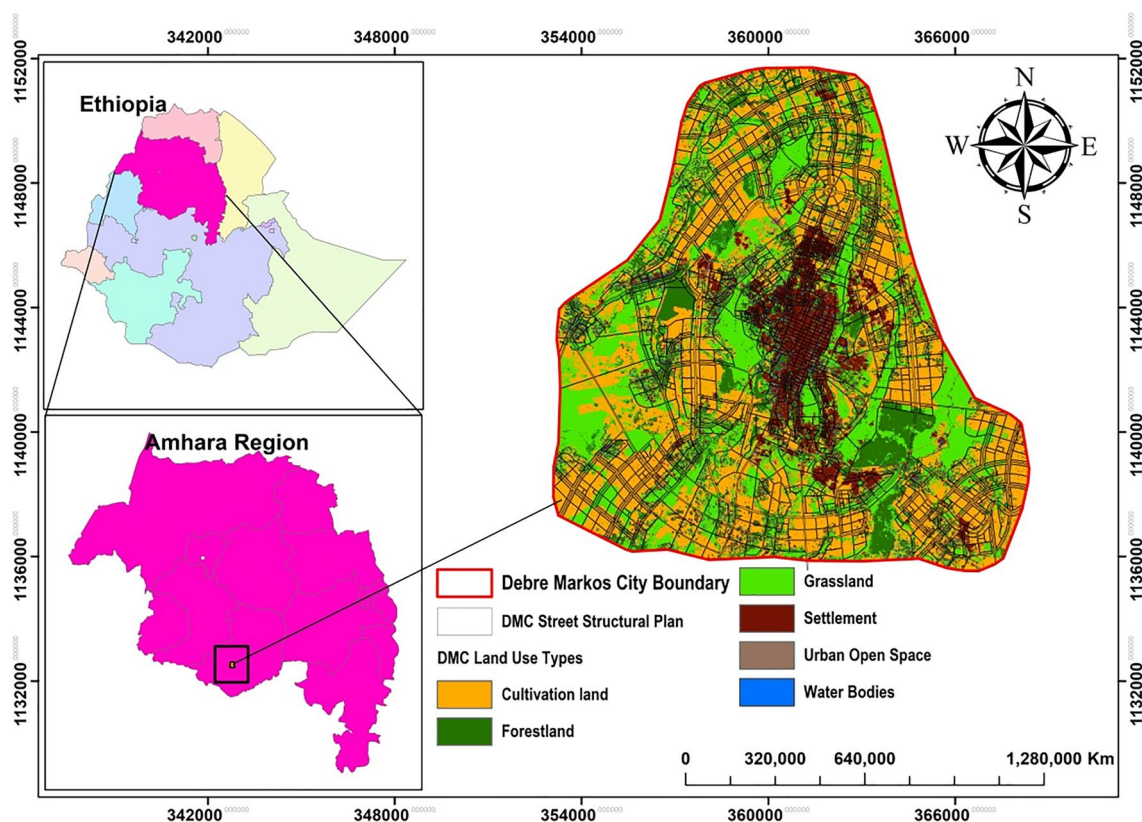
Fig. 1 Location map of DMC

Table 1 Sources of data and data type descriptions

No	Type of data	Year	Source of data	Data Explanation	Usage
1	Digital elevation model (DEM)	2021	USGS earth explorer (shuttle radar topographic mission, SRTM)	DEM with 30*30 m spatial resolution	Slope & elevation
2	Sentinel 2A	2022	https://scihub.copernicus.eu/	A geographical feature (that has 10 m spatial resolution) can be used in diverse land features The spatial location of settlements plan and supervised classification	Preparing NDVI and land use and land cover map proximity to settlement
3	Water source data	2021	Stream density and rivers data	Rivers, wetlands, reservoirs	Proximity to a water source
4	Road data	2022	DMC Administration Plan Institution	Road map data of DMC	Proximity to roads
5	Religious institutions	2022	DMC Administration Plan Institution	How far are religious institutions from urban green space	Proximity to religious institutions
6	Flood susceptibility data		Derived from slope, rainfall, land use and land cover, and river distance	Derivation of slope, rainfall (30 years to 2021), land use and land cover (sentinel 2A), and river distance	Flood susceptibility map

2008; Chandio et al. 2011; Pareta 2013; Tahmasebi et al. 2014; Abebe and Megento 2017; Dağıstanlı et al. 2018; Li 2018b; Ustaoglu and Aydınoglu 2020; Gelan 2021) Ten UGS determinant factors namely slope, elevation, proximity to the resident (settlement), existing land use, proximity to water sources, proximity to the marketplace, proximity to the road, proximity to the religious institution, flood-prone vulnerability and vegetation coverage (Normalized Difference Vegetation Index) were identified. Finally, all these factors were analyzed with the

ArcGIS environment with the application of the weighted sum overlay analysis method.

Normalized Difference Vegetation Index (NDVI) in sentinel 2A data can be defined as the proportion of the alteration between band 8 (near infrared, NIR) and band 4 (red, R), to the sum of band 8 (near infrared, NIR) and band 4 (red, R). It is calculated as follows in Eq. 1 below:

$$NDVI = \frac{Band\ 8\ (NIR) - Band\ 4\ (R)}{Band\ 8\ (NIR) + Band\ 4\ (R)} \tag{1}$$

DEM data was the decisive source of elevation and slope thematic maps of the study area, obtained from USGS/Copernicus Sentinel 2A. Proximity to settlement, proximity to the road, proximity to water sources, proximity to the marketplace, and proximity to religious institutions were computed using the Euclidian distance spatial analysis tool. The flood susceptibility map was developed from the sum of four main factors: slope, rainfall, distance to rivers, and land use/land cover data. These data were computed and overlaid with the different weighted values (Table 2).

Analysis of land use/land cover

Land use/ land cover classification analysis of the study was conducted using a supervised classification algorithm by ERDAS Imagine software. Accuracy assessment evaluation was analyzed with Ground Control Points (GCP) gathered from both Google Earth Pro and Global Positioning System (GPS). A total of one hundred twenty-eight GCPs were collected (forty-six from GPS data collection and eighty-two from Google Earth pro). The study's land use/ land cover map was analyzed with satellite image classification and its validation was done with GCPs. A land use/land cover map was established and checked with an overall accuracy equation and the kappa coefficient of image classification algorithm, as presented below. According to (Congalton 2001), the overall accuracy of UGS (O_aUGS) and kappa coefficient (K) is computed as follows in Eq. 2 and Eq. 3, respectively;

$$OaUGS = \frac{\Sigma Xc}{GCP} * 100 \tag{2}$$

where; O_aUGS, Overall Accuracy of UGS, ΣX_c, the summation of an accurately classified diagonal matrix, and GCP, the total number of GCP collected.

$$K = \frac{TN \sum_{j=1}^{f} Pjj - \sum_{j=1}^{f}(Pj + *P + j)}{(TN)^2 - \sum_{j=1}^{f}(Pj + *P + j)} \tag{3}$$

where; **TN**—total number of observations, *f*- number of rows in the matrix, P_{jj} is the number of observations in the row *j*, and the column *j*, P_{j+} is the marginal totals of the row *j* and P_{+j} the marginal totals of the column *j*.

Multicriteria decision analysis

The weights of all numerous UGS contribution items detected in the thematic map layers would have a different value. Accordingly, a method of MCDA designed by (Malczewski 1999) in combination with an analytical hierarchy process (AHP) of Saaty was applied (Saaty 1980). Biases in the decision-making process can be reduced by using AHP which helps to capture objective assessment measures and offers an appreciated method for confirming consistency (Ishizaka and Lusti 2003). To determine the relative importance or weight of each decision criteria of factor, AHP used a pairwise comparison matrix involved in three steps, namely; (1) design a comparison matrix at each level of the hierarchy, commencing at the top (2) compute the comparative importance or weight of each factor and (3) valuation of consistency ratio (C.R). To end with, weighted sum overlay analysis was functional to find the appropriate site rating of UGS.

The inconsistency assessment of criteria weighting can be assured through the computation of pairwise comparison matrix value of consistency ratio (C.R). Therefore, C.R is the measure of how much a matrix diverges from its consistency, and C.R. value should be less than 0.1 (10%) to be reflected as acceptable (Saaty 1980).

Table 2 Important scale of relative importance of numbers in AHP (Saaty 2008)

Power of importance	Description
1	Equally important
3	Moderately important
5	Strongly important
7	Very strongly important
9	Extremely important
Reciprocals importance values of the above numbers	If criteria *i* has one of the above non-zero numbers assigned to it as compared with activity *j*, then *j* has the reciprocal importance value as compared with *i*
1.1–1.9	If the criteria's have very closely important to each other

Given a positive reciprocal comparison matrix UGS $(n \times n) = (a_{ij})$, the Eigenvector (EV) method obtains the priority vector by

$$UGS_w = \lambda_{max}(UGS)\ W, \text{with } W_j \geq 0, j = 1,...,n \text{ and } \sum_{j=1}^{n} Wj = 1 \tag{4}$$

where, λ_{max} (UGS)—maximum eigenvalue of the pairwise comparison matrix of UGS.

Consistency Index (C.I.) is computed the ratio of the difference between λ_{max} and the number of criteria/factors (C) as in Eq. 5 below:

$$C.I = \frac{\lambda max - C}{C - 1} \tag{5}$$

The C.R. value is calculated by the ratio of CI of the pairwise comparison matrix divided by RI in the hierarchy as follows in Eq. 6:

$$C.R = \frac{CI}{RI} * 100 \tag{6}$$

C is the number of factors /criteria used, λ_{max} is the maximum eigenvalue, R.I is the Random Index, and C.R is the consistency ratio. However, the RI is the mean consistency index of a randomly produced comparison matrix. As shown in Table 3 below, Saaty's ratio index is not practical for *C* less than two factors /criteria. For instance, take 1.49 RI value when the numbers of criteria/factors are ten under Saaty's RI generation.

Lastly, each criterion's thematic map layers were examined using weighted sum overlay analysis toolbox in the ArcGIS 10.8.2 software according to their computed weight.

$$UGSi = \sum_{C=1}^{10} fwi * Api \tag{7}$$

where, **UGS*i*,** Urban Green Space identification, **fw*i*,** factor weight/Weight of criteria in the matrix, **Ap*i*,** assigned normalization score of pixel value *C*, number of input factors/criteria that contribute for UGS$_i$.

Conceptual design

The overall conceptual design for the proposed UGS environmental assessment would be designed as follows below in Fig. 2.

Result and discussion

Slope of the land

The slope of DMC was derived from DEM data obtained from USGS/SRTM. As the slope is very steep, greening the land is difficult because it needs some landscape modifications such as reshaping, and vice versa (Lo and Jim 2010). On the other hand, several studies have demonstrated that low-slope areas are highly suitable for developing urban green areas (Piran et al. 2013; Mahdavi and Niknejad 2014; Pramanik 2016; Abebe and Megento 2017; Dağıstanlı et al. 2018). The slope of DMC ranges from 0 degrees (flat/gentle slope) to 70 degrees (steep slope). As a result, this study deemed lower slope land to be more suitable than higher slope land, and areas with slopes of 0–4 degrees, 4–8 degrees, 8–12 degrees, 12–22 degrees, and 22–70 degrees were deemed very highly suitable, highly suitable, moderately suitable, poorly suitable, and unsuitable, respectively, for identifying suitable sites for urban green space development (Table 4). However, land slopes approaching to seventy degrees indicate that the study area consists of steep slopes, making urban greening difficult to establish and requiring huge investment costs (Newburn et al. 2006). According to (Pokhrel 2019), earlier studies on UGS geospatial analysis show that areas with flat to gentle slopes are very highly suitable for developing urban green space, particularly green parks. Moreover, the landscapes of the area determine the cost and design of the construction of UGS (Zhu 2018).

Proximity to the road

One of the fundamental elements that makes UGS more convenient for users is the availability of road infrastructure, such as road proximity and road width, which is important in supplying feasible routes to the local population to access urban green areas in their surroundings (Bunruamkaew and Murayama 2011; Kienast et al. 2012; Morckel 2017). The green space site is also preferred if it is located reasonably far from roads so that access to transportation is possible (Chandio et al. 2011; Tahmasebi et al. 2014). By calculating Euclidian distances, the primary road (60 m,40 m) radius of the road network has been considered as very highly suitable, the secondary road (30 m, 25 m) radius was found to be highly suitable, and the tertiary road (20 m,16 m) radius was considered as moderately suitable. Furthermore, the Quaternary road (12 m,10 m) has been deemed unsuitable, and the Quinary road (8 m) from the road network has considered as unsuitable (Table 4). Main

Table 3 RI value of consistency index for various number of input criteria(*C*) used developed by (Saaty 2008)

C	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49
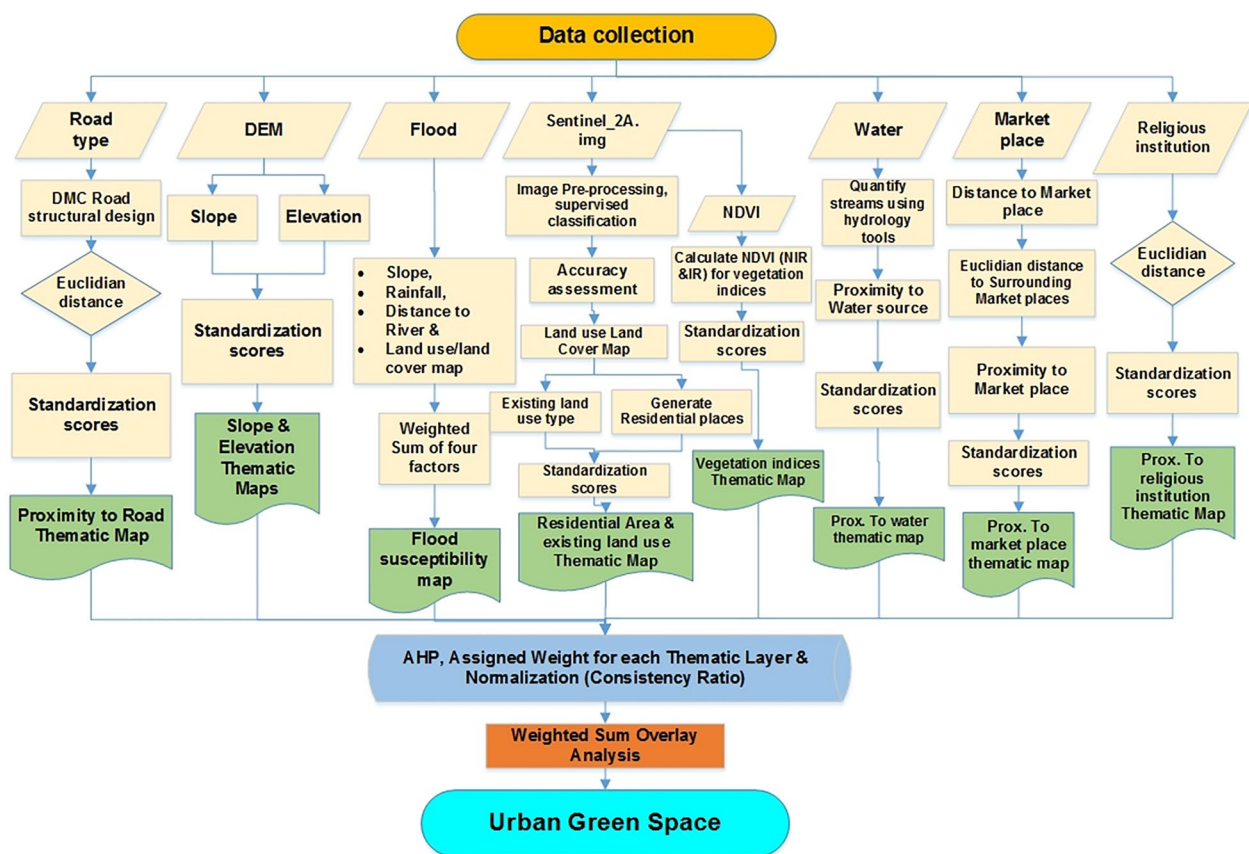
Fig. 2 Conceptual design of UGS in DMC

roads contribute a lot for this purpose because they reduce traffic flow and serve as parking at the edge. Findings have also revealed that the choice of appropriate urban green spaces is influenced by the types of roads (Gül et al. 2006). Previous studies have also shown that greater consideration should be given to developing urban green spaces in areas with access to major roads than in areas with only local roads (Gül et al. 2006; Chandio et al. 2011). As shown in Figs. 3, 4, 5 (i) below, DMC has proposed as well as existing roads that range from very wide to narrow road widths, including 60 m, 40 m, 30 m, 25 m, 20 m, 16 m, 12 m, 10 m, and 8 m width. All values on the maps indicated how far a given area from the roads is. For example, in Fig. 3(a) the value of 5025.58 m showed that the area is very far from the 60 m width main road.

The most widely available road type in DMC is the 16 m width with a maximum distance 1130 m in all direction shown in Fig. 4 (f). The second mostly accessible road type was the 20 m width road with a maximum distance of 1605 m far from a given direction also shown in Fig. 4 (e) below. However, a 25 m width road was not accessible for all areas with having 8982 m far for the northern part of the city dwellers (Fig. 3d) above.

Normalized difference vegetation index

The most important factor for UGS is the Normalized Difference Vegetation Index (NDVI), which shows the overall coverage of vegetation (Gül et al. 2006; Mahmoud and El-Sayed 2011; Dağıstanlı et al. 2018; Li 2018a). Results revealed that the NDVI value of sentinel 2A data ranges from -1 to $+1$ in the study area. The negative sign indicates less / no vegetation, while the positive sign shows dense vegetation found in an area. However, its result was within the range of -0.999173 to $+0.999728$ (Fig. 5 and Table 4). Therefore, a magnificent amount of dense forest vegetation was recorded at DMC. Previous research has also found that as the NDVI vegetation prominence of a given environment increases or becomes greater, so does the adaptability of urban green space, with the NDVI value approaching $+1$. (Wu et al. 2021). Moreover, as (Li et al. 2018a, b), for UGS development, the calculated NDVI value should be greater than 0.1, representing grasslands and shrubs.

As indicated in Fig. 5(k, l) above, the elevation of the study area ranges from 2206 to 2548 m, and its religious distance from 0 to 3753 m, respectively. The

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Table 4 Input factor and sub-factor with their respective normalization scores and factor degree of suitability ranking

Input factor	Unit of measurement	Sub-factor	Normalization scores	Degree of suitability ranking
Slope	Degree	0–4	1	Very highly suitable
		4–8	2	Highly
		8–12	3	Moderately
		12–22	4	Poorly
		22–70	5	Unsuitable
Elevation	Meters	2204–2284	1	Very highly suitable
		2284–2354	2	Highly
		2354–2409	3	Moderately
		2409–2451	4	Poorly
		245–2548	5	Unsuitable
Proximity to road/ road type	Meters	Primary road (60 m,40 m)	1	Very highly suitable
		Secondary road (30 m, 25 m)	2	Highly
		Tertiary road (20 m,16 m)	3	Moderately
		Quaternary (12 m,10 m)	4	Poorly
		Quinary (8 m)	5	Unsuitable
Proximity to religious institutions	Meters	< 500	1	Very highly suitable
		500–1000	2	Highly
		1000–1700	3	Moderately
		1700–2500	4	Poorly
		2500–3753	5	Unsuitable
Existing land use	Land use type	Cultivation land	2	Highly
		Grassland	1	Very highly
		Forestland	1	Very highly
		Water bodies	3	Moderately
		Settlement	4	Poorly
		Urban open space/bare land	1	Very highly
Proximity to Market place	Meters	0–220	5	Unsuitable
		220–580	4	Poorly
		580–1055	3	Moderately
		1055–1705	2	Highly
		1705–2854	1	Very highly
NDVI	Value (− 1 to + 1)	− 0.9992–0.0862	5	Unsuitable
		0.0862–0.2111	4	Poorly
		0.2111–0.336	3	Moderately
		0.336–0.4844	2	Highly
		0.4844–0.9997	1	Very highly
Proximity to settlement	Meters	0–200	1	Very highly
		200–500	2	Highly
		500–1000	3	Moderately
		1000–1600	4	Poorly
		1600–2750	5	Unsuitable
Proximity to water/streams	Meters	871–1089.15	5	Unsuitable
		653.5–871	4	Poorly
		435.7–653.5	3	Moderately
		217.8–435.7	2	Highly
		0–217.8	1	Very highly
Flood susceptibility	Weighted sum value of 4 contributing factors	100–185	5	Unsuitable
		185–260	4	Poorly

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Table 4 (continued)

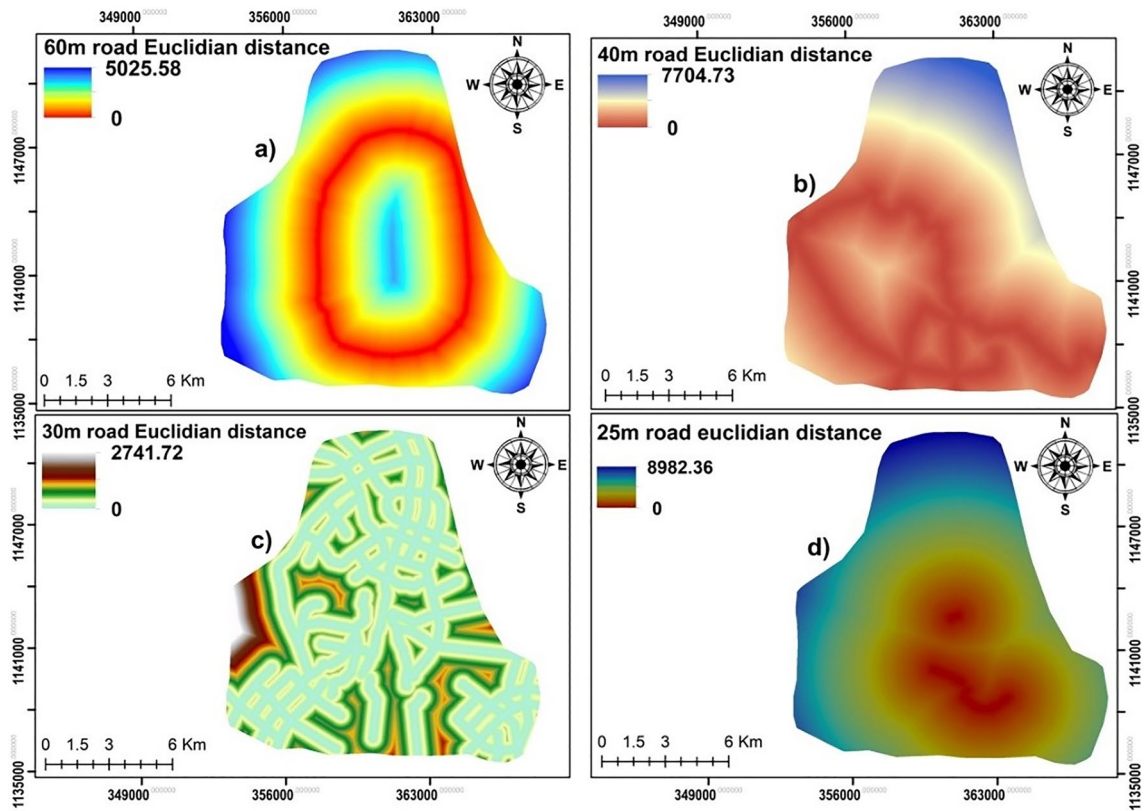| Input factor	Unit of measurement	Sub-factor	Normalization scores	Degree of suitability ranking
		260–310	3	Moderately
		310–360	2	Highly
		360–485	1	Very highly

Fig. 3 Proximity to road maps **a** 60 m **b** 40 m **c** 30 m **d** 25 m

slope ranges from 0 to 70 degrees. It shows that the study area (DMC) also had a very steep slope aligned in the southern and northwestern regions of the city (Fig. 6q). However, the maximum distance of its market proximity in any direction is 2853 m. The farthest location was obtained to the southern direction of the city as shown in Fig. 6(r) below (Fig. 7).

Proximity to market place

Marketplaces are mostly the source of environmental pollution for UGS in developing countries such as Ethiopia. Therefore, UGS suitability assessment and development should be far from such areas to protect them from pollution and make them very clean, attractive, and visitable by the residents. Therefore, in this study, the distance from the marketplace is between 1705 and 2854 m considered to be highly suitable, and between 1055 and 1705 m is considered highly suitable in this study. Moreover, distances between 580 and 1055 m and 220 m to 580 m are moderately suitable and poorly suitable for urban green spaces, respectively. Whereas distances less than 220 m are considered unsuitable (Table 4). Also, as shown in Fig. 8(n), proximity to marketplaces ranges from 0 to 2853.56 m distance, the nearest area is affected by pollution from marketing and is not suitable for GS.
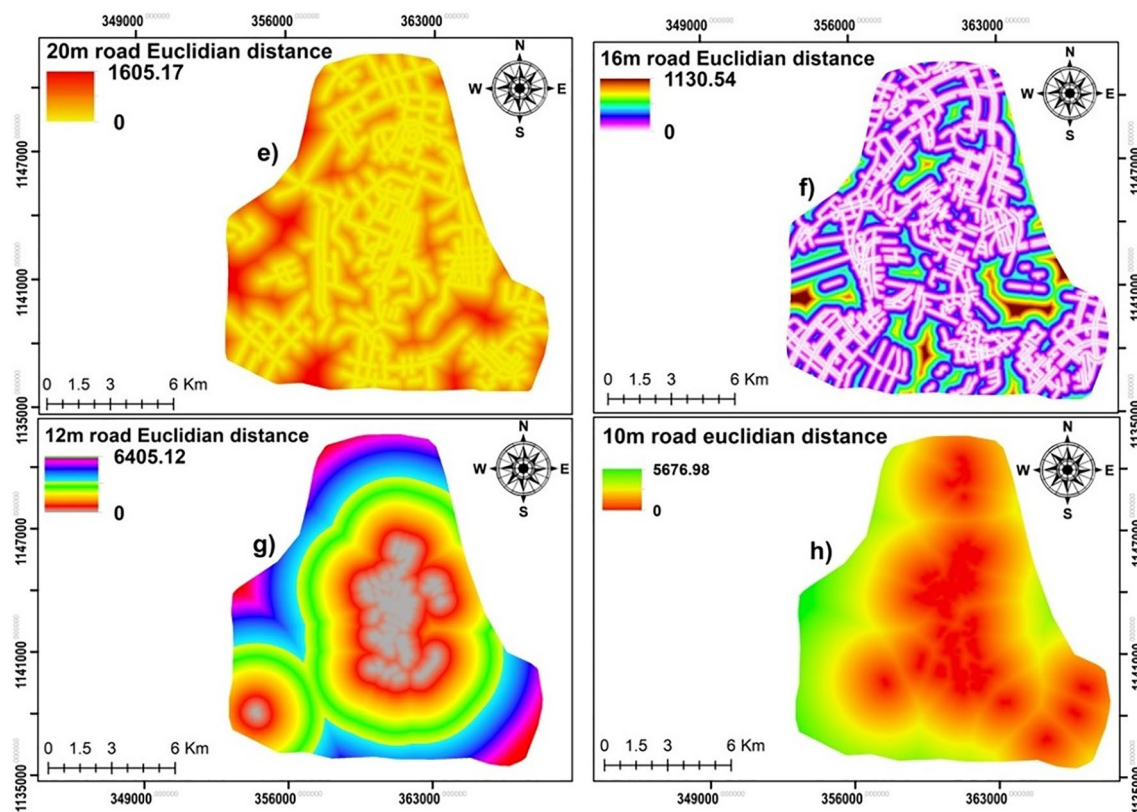
Fig. 4 Proximity to road maps **e** 20 m **f** 16 m g 12 m h 10 m

Proximity to the water source

Water source is one of the key factors that regulate and make UGS development works easily because it is the heart of the growth and development of green plants. Owing to, the above fact any UGS should be sited near water source areas. Studies highlight that lands near rivers, lakes, and reservoirs are highly suitable for developing green space (Manlun 2003; Pareta 2013; Piran et al. 2013; Abebe and Megento 2017). Therefore, in this study, a distance less than 217.8 m from the river is considered highly suitable, and between 217.8 m and 435.7 m is considered highly suitable. Moreover, distances between 435.7 m and 653.5 m and 653.5 m to 871 m are considered moderately suitable and poorly suitable for urban green spaces, respectively. Whereas distances between 871 m and 1089.15 m are relatively considered unsuitable (Table 4). However, the land should be out of flood risk since streams are usually obtained at the lower relative elevation point in a given location. The source of water determines urban green space water consumption, such as from blue water resources (that is groundwater or surface water) to irrigate those (Nouri et al. 2019; Guo et al. 2021). In this study, therefore, seasonal and permanent streams

are used as an alternative/supporting mechanism to replace or support groundwater sources of the city to irrigate UGS.

Proximity to religious institutions

Places closer to religious sites, and cultural and historical spaces are highly suitable for the good physical shape and spiritual lifestyles as related to places far away from these spaces (Pokhrel 2019). As a result, in this study, distances less than 500 m from religious institutions are classified as very highly suitable, and distances between 500 and 1000 m are classified as highly suitable. Furthermore, distances 1000 m to 1700 m and 1700 m to 2500 m are considered moderately and poorly suitable for urban green spaces, respectively. Distances between 2500 and 3753 m are regarded as unsuitable for the development of UGS. (Table 4).

Proximity to residential/settlement areas

Given their numerous ecological, social, and economic advantages, green spaces must be accessible to settlement areas in urban areas (Zhang et al. 2013; Malmir et al.
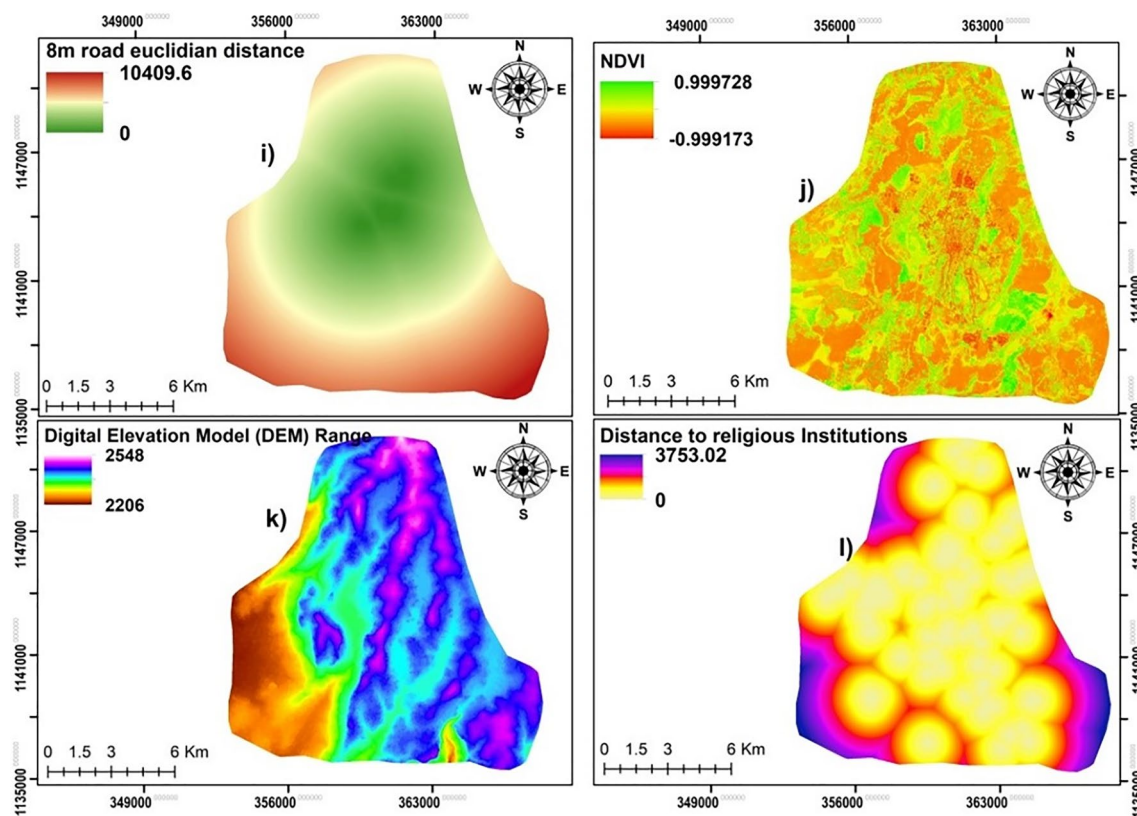
Fig. 5 Proximity to road distance **i** 8 m **j** NDVI **k** the minimum and maximum value of digital elevation model (DEM) **l** distance to the religious institution

2016; Ustaoglu and Aydınoglu 2020). Scholars contended that a significant distance between settlement areas and green spaces harmed users and that green spaces such as playgrounds, parks, and sports fields closest to settlement areas were the most popular (Hörnsten and Fredman 2000). Globally, different countries have set their own UGS accessibility legal frameworks for the citizens based on their context of development and environmental policy. In Europe, for instance, the European Environment Agency (EEA), in outlining the urban green space provision goal, maintains that every person should have the right to use a green space within 15 min (t) of their dwelling and a maximum walking distance of approximately 900–1000 m (Stanners and Bourdeau 1995). In Ethiopia, however, according to the National Urban Green Infrastructure standard offers 15 m^2 per capita public urban green open spaces within the frontiers of the city, and every dweller living in the interior of 500 m distance from public urban open green spaces (should have at least 3000m^2 area in size) (Eshetu et al. 2021). As a result, the distance between green spaces and the settlement area is critical to consider. The proximity of the settlement area was used as a criterion in this study.

Based on this, areas identified within 200 m of the settlement area were deemed highly suitable by using Euclidian distances, and areas ranging from 200 to 500 m were deemed highly suitable. Furthermore, the areas 500 m to 1000 m, 1000 m to 1600 m, and 1600 m to 2750 m from the settlement area were deemed moderately appropriate, poorly suited, and unsuitable for developing urban green spaces, respectively (Table 4).

Elevation of land surface
Elevation data was also obtained from DEM data. Elevation plays an important role in selecting suitable sites for urban green spaces and should be considered as a major factor (Gül et al. 2006; Mahmoud and El-Sayed 2011; Dağıstanlı et al. 2018; Li 2018b). In this study, the elevations between 2204 and 2284 m, 2284 m − 2354 m, 2354 m − 2409 m, and 2409 m − 2451 m were considered very highly suitable, highly suitable, moderately suitable, and poorly suitable, respectively. Areas with elevations between 2451 and 2548 m were considered unsuitable for developing urban green spaces (Table 4). Previous research has shown that as the elevation of the land increases, so does its suitability for UGS development.
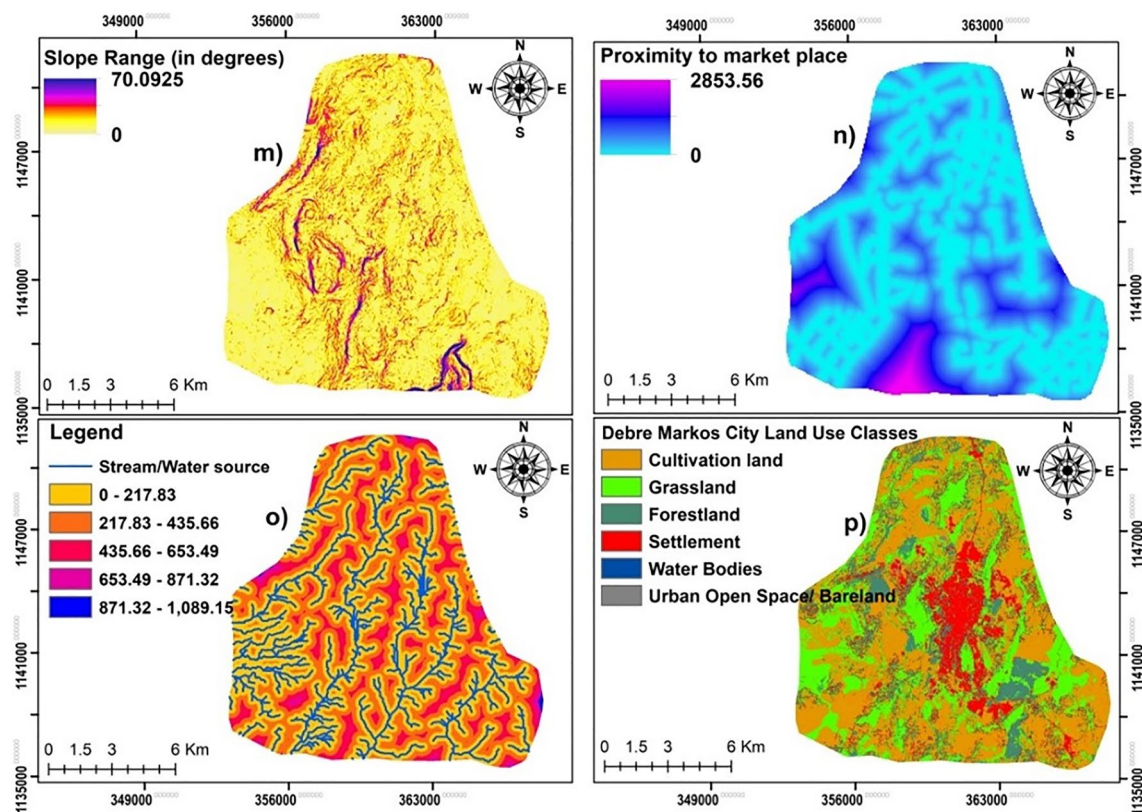
Fig. 6 Thematic maps of DMC **m** slope in degrees **n** proximity to marketplace **o** streams **p** land use /land cover map

The lower the elevation associated with flat slope land areas, the less human intervention is required for design and construction, the better the place for biological habitats to live, and the more advanced the suitability of UGS (Wu et al. 2021).

Land use/land cover type

DMC's land use/land cover data were categorized into six main classes: cultivation land, grassland, forestland, settlement/ resident, water bodies, and urban open space/ bare land (Fig. 9). In this study, grassland, forestland, and urban open space/bare land were considered very highly suitable, cultivation land was considered highly suitable, water bodies were moderately suitable, and settlement areas were poorly suitable for urban green space development (Table 4). Research conducted by (Li et al. 2018a, b) confirmed that based on their suitability rating, a forest plantation, grassland, and open space are categorized under the very high suitability class; while cultivation/urban agriculture, water bodies, and settlement/ construction area are categorized under high, moderate, and poor suitability classes for UGS site selection, respectively.

Accuracy assessment is the precision and error matrix measurement applied for land use /land cover supervised classification analysis. Therefore, an overall accuracy assessment and kappa coefficient of urban green space assessment recorded for land use /land cover analysis were 90.6% and 0.8855, respectively as shown in Table 5 below.

Flood susceptibility

Flood susceptibility mapping development includes a slope, rainfall, distance to the river, and an area's land use /land cover conditions. Flood-susceptibility mapping has also been used as a parameter for UGS suitability study in DMC. According to research studies, places with lower flood susceptibility are more suitable for UGSs assessment than places with higher flood susceptibility, and urban green spaces should be as far away from flood susceptibility areas as possible (Piran et al. 2013; Peng et al. 2016; Foto-vatikhah et al. 2018; Zhao et al. 2019). In this study, high flood-risk areas were unsuitable for developing urban green spaces, whereas low and medium
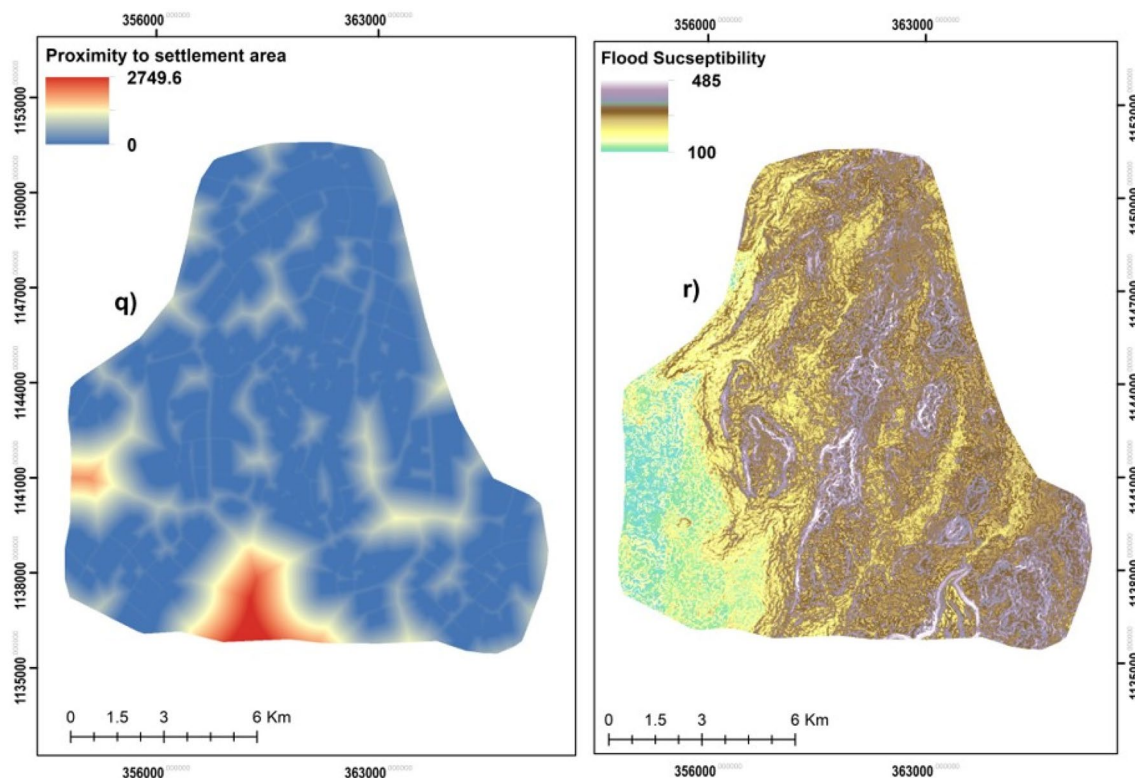
Fig. 7 **q** proximity to settlement **r** flood susceptibility map

flood-risk areas were deemed very highly and highly suitable (Table 4).

Criteria and sub-criteria for suitability analysis

All the selected causative input factors/criteria of the UGS assessment pairwise comparison matrix have been indicated in Table 6 below. As specified in the column of the weight of criteria (CW) value in Table 6 demonstrated that proximity to the settlement, proximity to the road, the slope of the landscape, existing land use land cover condition, and vegetation cover of DMC ranks from one to fifth, respectively. On the other hand, the remaining elevation, proximity to the water source, proximity to the religious area, flood susceptibility, and proximity to the marketplace ranks from sixth to tenth, respectively.

The computed criteria weight (CW) of all factors of UGS is indicated in Table 6. Accordingly, the calculated $\lambda_{max,}$ (biggest eigenvalue) and the Consistency Index (CI) value were 10.577 and 0.064, respectively. Since the input contributing factor (C) for the suitability of UGS is ten its Random Index (RI) is 1.49. Therefore, a calculated Consistency Ratio (CR) value of 0.043 was obtained, which is less than 0.1, and deemed acceptable.

UGS spatial analysis

The most central part of DMC has very high and highly suitable UGS due to its proximity to the settlement, proximity to main roads, nature of the gentle slope, less susceptibility to flooding, and other factors set in the pairwise comparison matrix, criteria weight (Table 6). However, in contrast, the most periphery of the city is poorly suitable and unsuitable for urban green spacing because of flood susceptibility, very far places for roads, less proximity to water access, bare to less vegetation coverage, and far from residents for recreation purposes, very steep slope, and other related factors. The other main constraints of poorly suitable and unsuitable sites for UGS development, these areas are recently included under the city sprawl (expansion) program. Therefore, they have very little access to many economic, social, and infrastructural activities, and most lands are used for crop cultivation and have less productivity.

One can find very beautiful and attractive urban green spaces around the small streams of the Wuseta and Wutren rivers margins as indicated in the final UGS map Fig. 10 above. Most areas in the city had a maximum of 1.1 km distance from seasonal and permanent flow streams. Within the center of the city too, there are areas
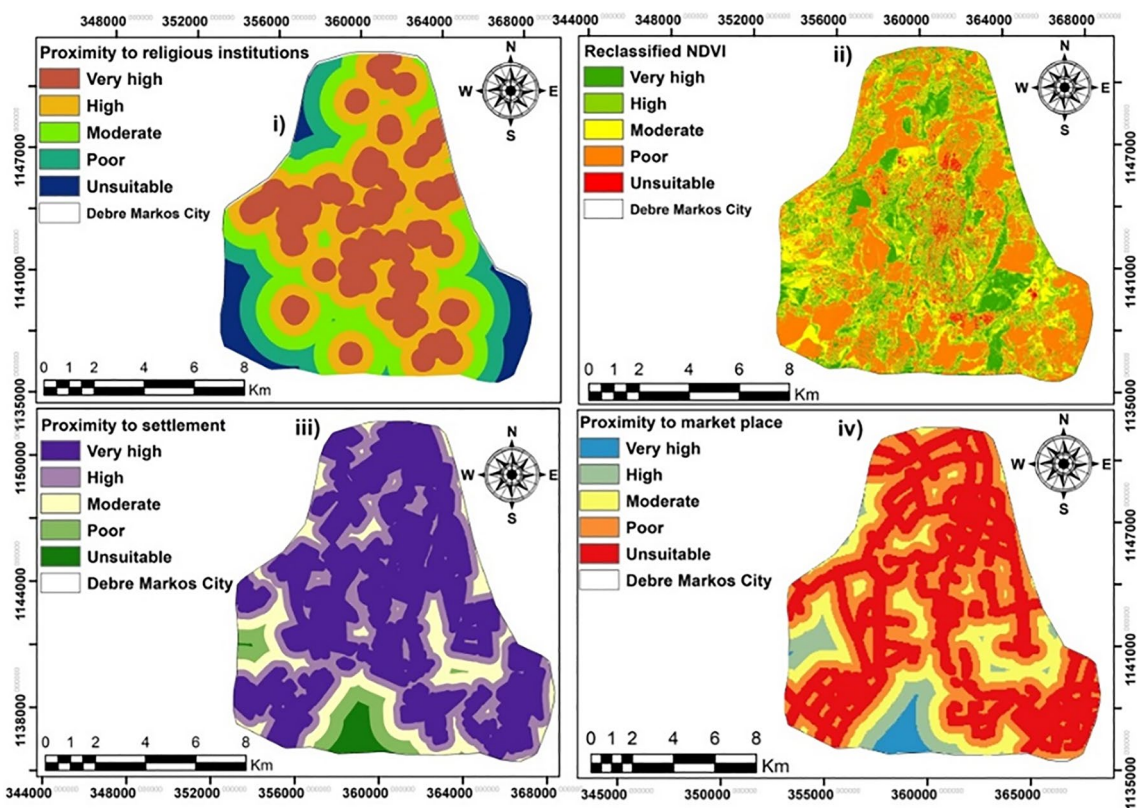
Fig. 8 reclassified maps of **i** proximity to the religious institution **ii** NDVI **iii** proximity to settlement **iv** Proximity to marketplace

suitable for UGS development activity as shown in Fig. 11 above.

As the statistical data obtained shown in Table 7 below, approximately one-third of the area coverage of DMC has moderately suitable land for the development of urban greening with a low cost of investment. Moreover, 70 percent of the total land has been within the range of very high suitable to moderate suitability. Therefore, DMC can be changed to favorable greening sites if good emphasis, attention, and proper planning structure are given or designed for UGS development and implementation. Furthermore, most very high and highly suitable urban green spaces are found within a fair distance from the downtown /center of DMC (Fig. 11). Thus, the residents/ dwellers of the city can address these areas with minimum cost, less exertion, and a short time for entertainment.

Based on area coverage, very high suitable, high suitable, moderately suitable, poor suitable, and unsuitable ratings account for about 13.12%, 25.47%, 30.89%, 22.49%, and 8% of the total DMC area coverage, respectively as shown in Table 7 above. More than 92% of DMC ranged from very high to poorly suitable for UGS development activity. However, the residual 8% of the

landscape needs a very high investment to make it suitable for urban greening due to slope steepness, the very far site from a resident, inaccessible to the road, the inadequacy of a water source, and other associated factors.

Existing and proposed UGS of DMC
The existing UGS of the city is very limited in scope and space. For example, the iconic UGS of the city is obtained at the Square of Negus Tekele Haimanot, where most people can address it from different directions. Other green spaces do not have vast space (accounts for only 28.5 hectares of the total land) and less attraction for entertainment. According to the DMC data, stadiums (asphalt cover and grass cover lands), open spaces, and grass and forest plantation sites on various squares reserve most of the existing recreational sites (also considered UGS) of the DMC. However, the newly proposed UGS designed by DMC has 424.36 hectares of land, which accounts for 2.5 percent of the total area coverage, and can be achieved by the city's past (2012) projected population.

Though the newly proposed UGS design has many advantages as compared to that of the existing UGS, the newly proposed (designed) UGS has also some
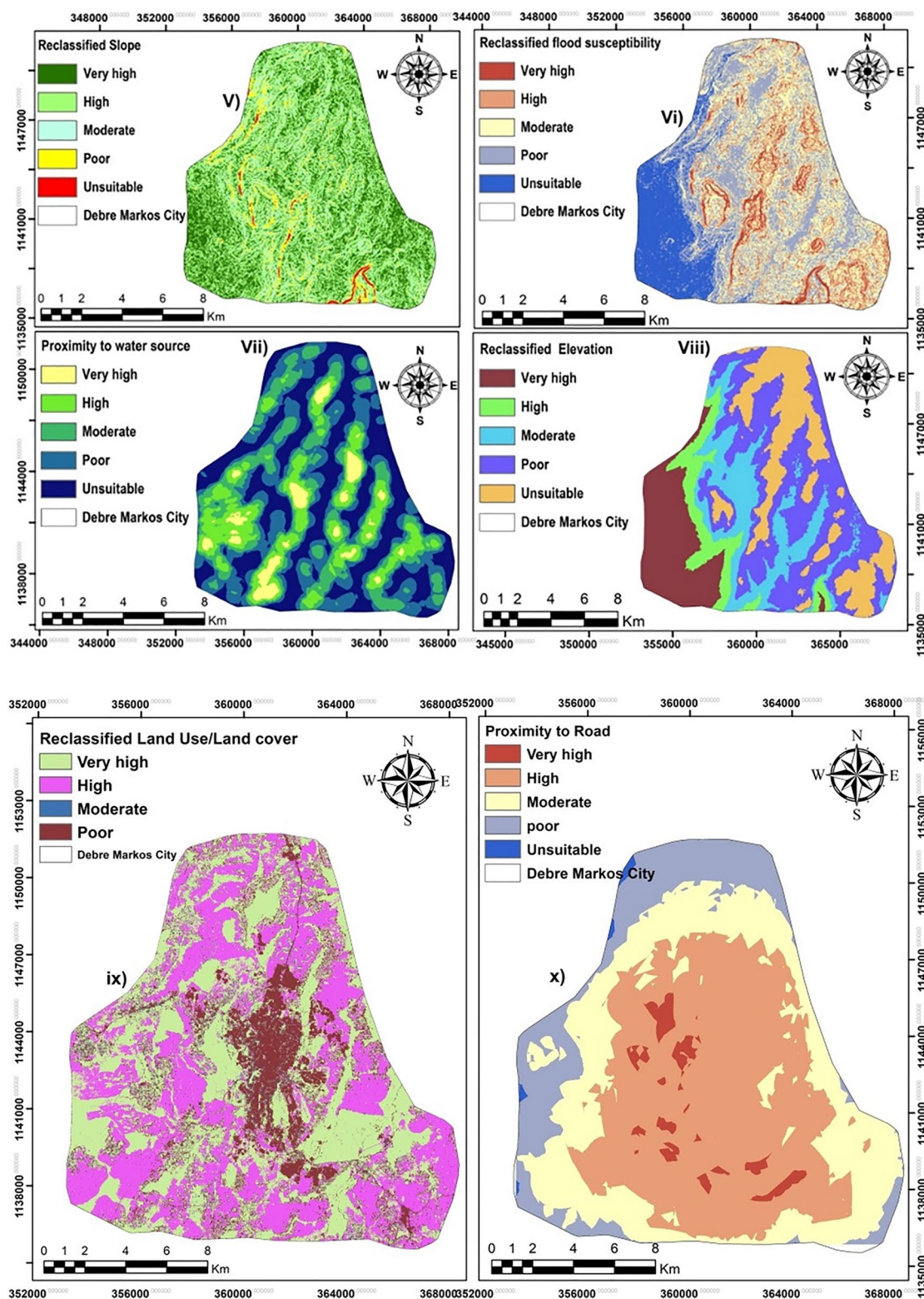
Fig. 9 Reclassified maps of **v** slope, **vi** flood susceptibility, **vii** proximity to the water source and **viii** elevation **ix** land use land cover map x proximity to the road

Table 5 Accuracy assessment report of UGS assessment of DMC

CN	Cult	GL	FL	Stl	Wa	UOS	GTP	Users' accuracy
Cult	25					2	27	92.59
GL		22	3				25	88
FL		1	24				25	96
Stl	1			23	2		26	88.46
Wa				1	9		10	90
UOS	2					13	15	86.67
Totals	28	23	27	24	11	15	128	
Producers' accuracy	89.29	95.65	89	95.83	81.82	86.67		

Cult cultivation land, *GL* grassland, *Stl* settlement area, *FL* forest land, *Wa* water bodies, *UOS* Urban open space, *GCP* ground control point, *CN* class name

Table 6 Pairwise comparison matrix of UGS contributing factors/criteria

	S_l	Elv	P_{rx}.Reli	P_{rx}.R$_o$	E_{xt} LU	P_{rx}.M$_{kt}$	Veg	P_{rx}.Set	P_{rx}.Wr	F_{ld} Suc	WSv	CW	Rank
S_l	1.00	1.50	1.25	1.25	1.50	2.50	1.75	0.50	1.50	2.00	1.260	0.1192	3rd
Elv	0.67	1.00	1.50	0.40	0.80	1.50	1.50	0.40	0.80	1.50	0.842	0.0795	6th
P_{rx}.Reli	0.80	0.67	1.00	1.00	0.67	1.75	0.33	0.20	0.67	1.25	0.698	0.0662	8th
P_{rx}.R$_o$	0.80	2.50	1.00	1.00	0.67	1.25	3.00	0.50	2.50	3.00	1.369	0.1284	2nd
E_{xt} LU	0.67	1.25	1.50	1.50	1.00	2.00	1.25	0.33	1.25	0.80	1.001	0.0942	4th
P_{rx}.M$_{kt}$	0.40	0.67	0.57	0.80	0.50	1.00	0.67	0.20	0.80	0.80	0.554	0.0522	10th
Veg	0.57	0.67	3.00	0.33	0.80	1.50	1.00	0.50	1.00	3.00	0.977	0.0915	5th
P_{rx}.Set	2.00	2.50	5.00	2.00	3.00	5.00	2.00	1.00	3.00	5.00	2.503	0.2370	1st
P_{rx}.Wr	0.67	1.25	1.50	0.40	0.80	1.25	1.00	0.33	1.00	0.80	0.760	0.0724	7th
F_{ld} Suc	0.50	0.67	0.80	0.33	1.25	1.25	0.33	0.20	1.25	1.00	0.619	0.0595	9th

S_l slope, *Elv* elevation, *P_{rx}.Reli* proximity to a religious institution, *P_{rx}.R$_o$* proximity to the road, *E_{xt}LU* existing land use, *$Prx.M_k$* market, *Veg* vegetation, *P_{rx}Set* proximity to settlement, *P_{rx}Wr* proximity to water source/streams, *F_{ld}Suc* flood susceptibility, *WSv* weighted sum value, *CW* the weight of criteria

problems. These are (1) there is no scientific study conducted on UGS planning and development that was officially released on websites or international and national journals by DMC, (2) if the city planners per se conduct the study, the factors of suitability (except proximity to resident) for UGS consideration also unknown clearly, (3) often it only considered the location of urban residents or settlements, which will face problems during developmental implementation, (4) the slope classes that are not suitable for urban green spacing are also included as part of the proposed UGS, (5) it did not fulfill the National Urban Green Infrastructure standard offered by the country (Ethiopia) 15 m^2 per capita public urban green open spaces in the interior of city frontiers, with every dweller living within 500 m distance from public urban open green spaces (should have at least 3000m^2 area in size) (Eshetu et al. 2021). Based on the 2012 population prediction of Central Statistical Agency (2007), the population of DMC (262,497), the proposed UGS may fate the national standard of every citizen should get 15m^2 per capita. However, this number increased beyond this after ten consecutive year's population. In addition, a resident enforced to travel or walk more than 8.4 km in the existing UGS and more than 5.4 km in the proposed UGS to get the service as shown in Fig. 11 above. As shown in Table 8 below, on average, the dwellers should travel 4.213 km to get the existing UGS service for their entertainment within the city (Fig. 12).

In this geospatial analysis of the UGS study, the maximum distance to UGS in any direction to get a very high and highly suitable UGS was lowered to 1.3 km. Moreover, the maximum distance to reach moderately and poorly suitable UGS is 675 m only (Fig. 13 above and Table 8 below). The average distance to access UGS in this geospatial analysis study was 656 m and 337.5 m from very high to a highly suitable area and moderate to a poor suitable area, respectively (as shown in Table 8 below). Overall, wherever UGS development activity doing in any corner of the city, a resident can
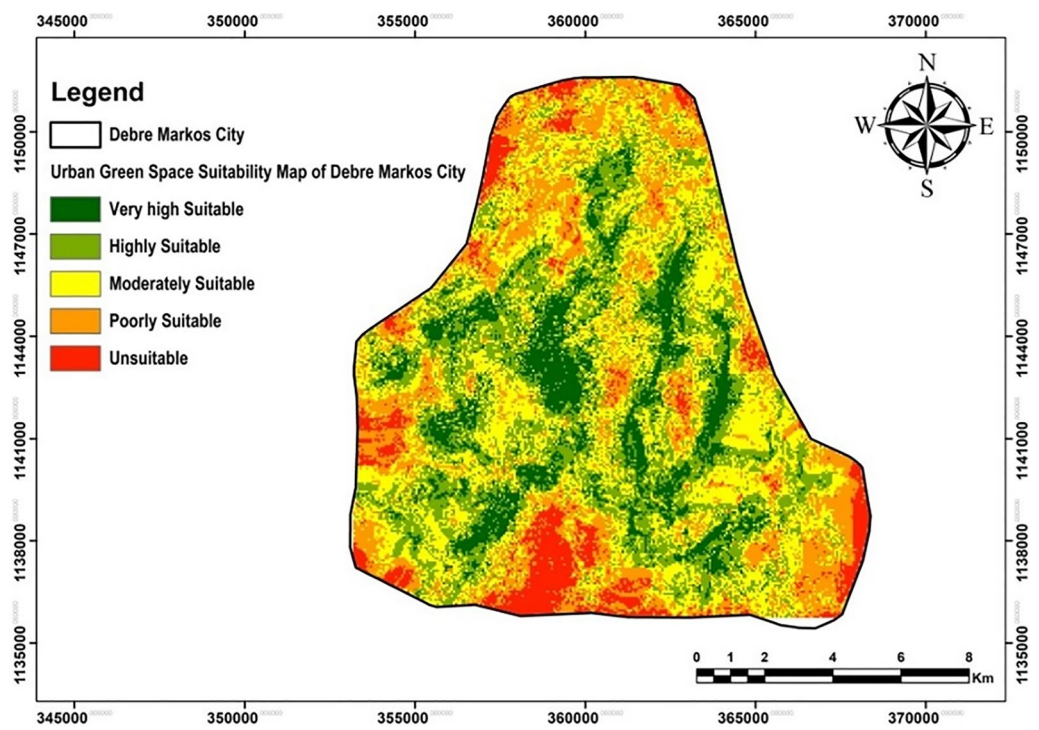
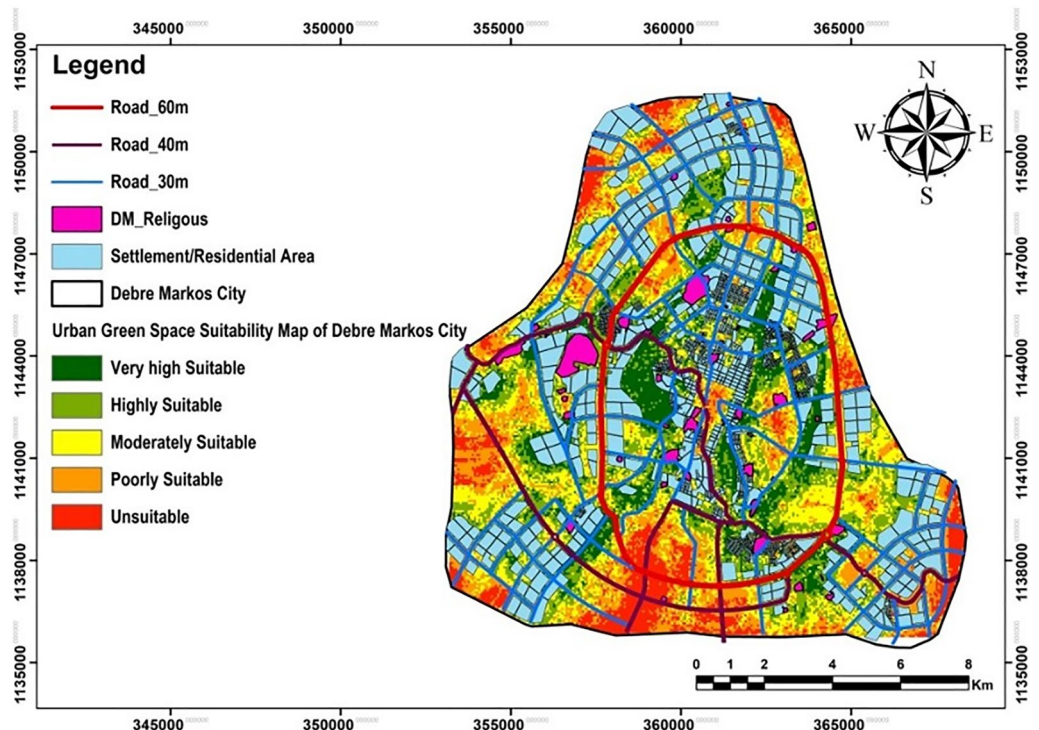**Fig. 10** UGS suitability map of DMC

Fig. 11 Final UGS suitability sites of DMC based on main roads, religious and settlement proximity

Table 7 Area coverage of UGS suitability map of DMC

S.No	Factor suitability rating	Standardization score	Area (Hectares)	Area coverage (%)
1	Very high suitable	1	2201.016	13.12
2	Highly suitable	2	4271.777	25.47
3	Moderately suitable	3	5180.769	30.89
4	Poorly suitable	4	3772.722	22.49
5	Unsuitable	5	1345.826	8.02
	Sum		16772.11	100%

Table 8 Distance to get UGS service of existing, proposed, and geospatial assessment studied UGS in DMC

No	UGS type	Distance to get UGS services in meters		
		Minimum	Mean	Maximum
1	Existing UGS	0	4213	8426
2	Proposed UGS (newly proposed by the city per se)	0	2710	5420
3	Geospatial assessment UGS (in this study)			
	3.1. distance to very high to high suitable UGS	0	656	1312
	3.2. distance to moderate to poor suitable UGS	0	337.5	675
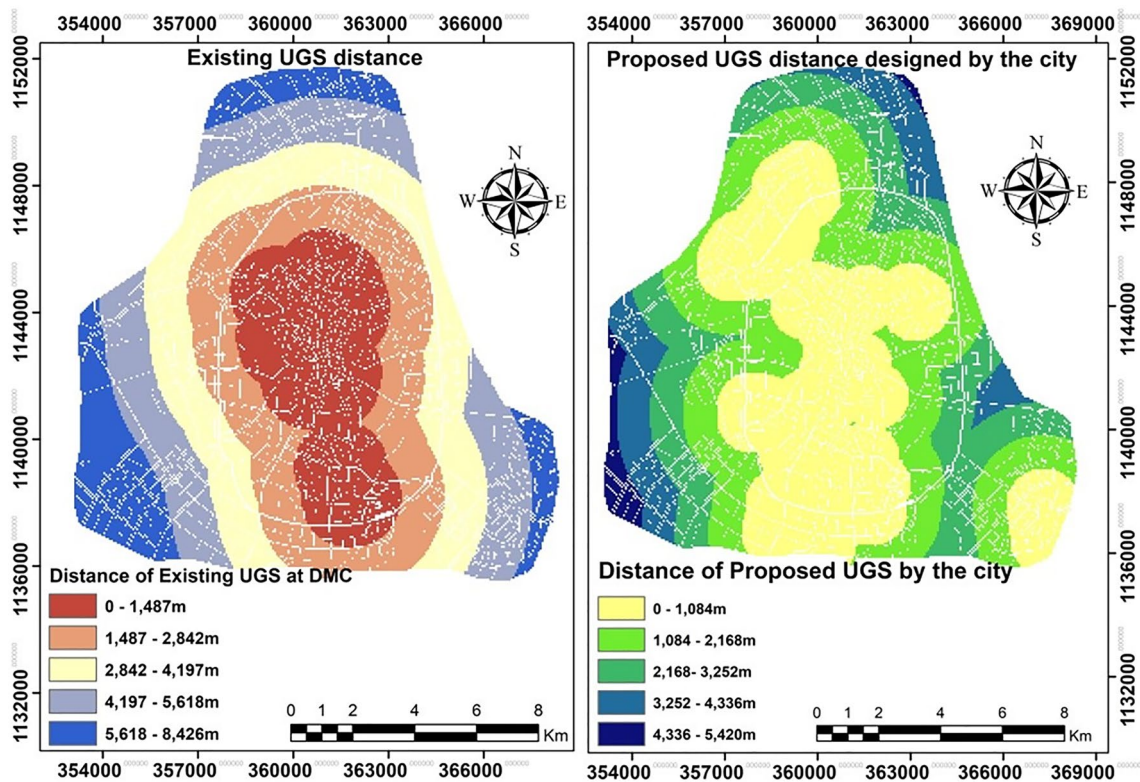
Fig. 12 Existing and Proposed UGS distance
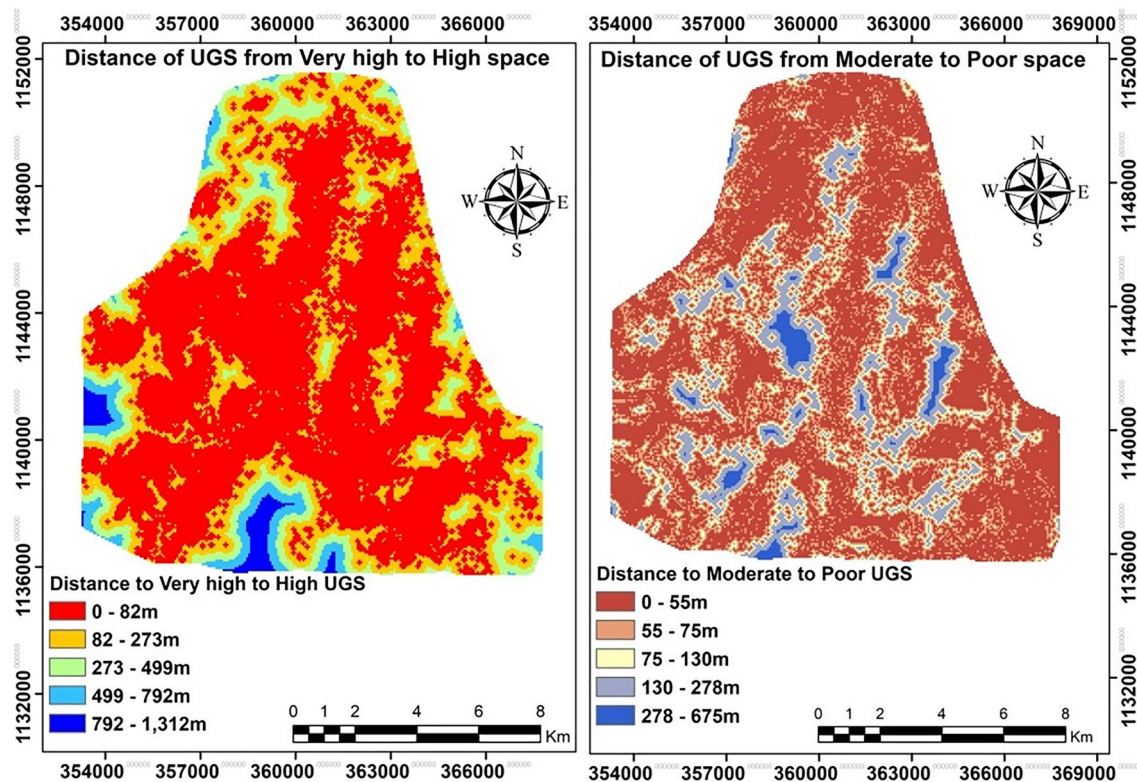
Fig. 13 Distance from Very high- to high and Moderate to poor UGS area

access it within a maximum distance of a 1 km radius, which is very close to the national standard.

Conclusion

The study has a profound benefit for the fastest expansion of DMC. UGS assessment should include many factors as input into consideration because it needs safety placed ahead of its establishment. The application of Remote sensing and GIS can save time and cost of study for the assessment of recreational areas such as UGS at DMC. It also contributes input to the high demand for UGS assessment results for planners and decision-makers in the city.

In conclusion, 13.12% and 25.47% of the city land are highly and highly suitable for UGS, respectively. In the study, the average distance to get UGS service was lowered to 656 m from very high to highly suitable and 337 m for moderate to poor UGS suitable areas. However, due to the city's undulating nature of the topography and other constraints, about 30.5% of its land is poorly suitable and unsuitable for urban green spacing activities. However, this does not mean that these areas are not completely rejected for an urban green spacing development program, but it needs high investment cost and special design for development. The city's concern

for UGS planning development is very low under the proposed plan. It could not properly consider future urbanization and urban population with scientific study.

Availability of data and materials
All of the materials are owned by the authors and/or no permissions are required.

Declarations

Ethics approval and consent to participate
All authors respect the ethics of the publisher.

Consent for publication
This manuscript has not been published elsewhere, nor are they under consideration (from you or one of your Contributing Authors) by another publisher.

Competing interests
The authors' declares no competing interests.

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