A geospatial assessment of urban green space in Debre Markos City, Ethiopia

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Abstract

Urban Green Space (UGS) serves as a lung y for city dwellers to breathe. 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 the application remote sensing and GIS has a significant advantage in making residents more comfortable. This study, therefore, aimed to assess the existing UGS, quantify it, and identify a suitable area for UGS development. Hence, ten UGS influencing factors were selected. Each criterion was analyzed with the use of its proper algorithm. Multi-criteria decision-making (MCDM) analysis integrated with Analytical Hierarchy Process (AHP) method and RS 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 consistency ratio was 0.043, which is < 1 and acceptable. Results revealed that 13.12%, 25.47%, 30.89%, 22.49%, and 8.2% 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 1km radius distance, closer to the national standard of Ethiopia (i.e. 500m). However, in the existing UGS, a person enforced to walk or travel more than 8.4km distance to get the service. In conclusion, remote sensing and GIS can make life easy to access UGS in the study area with minimum distance and cost, and a short period. It is recommended that policy makers, planners and executive bodies in Ethiopia (highly urbanizing country) should consider future urban demand of the dwellers with proper studies earlier to other urban infrastructures.

1. Introduction

UGS refers to vegetation found in urban environments such as: parks, squares, open spaces, residential gardens or street trees (Kabisch and Haase, 2013). 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; Gelan, 2021; Amorim et al., 2021). 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 et al., 2017) and also provide important habitats for wildlife (Goddard et al., 2017). Well-planned, managed and funded cities have a strong commitment to creating economic, social, environmental and other non-quantifiable values that can significantly improve the quality of life for all. (Habitat. UN, 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 (UNDESA, 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. UN, 2016).

Ethiopia (a low-income country) has experienced rapid urbanization, emerged to create great challenges for planning and development decisions of UGS in cities. Therefore, UGS planning and development without a detailed analysis of considering multiple factors made mistakes and could not fulfill citizens' right to access for 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 (Sandstro¨ m, 2002). In Ethiopia, UGS is not well planned, allocated, and managed yet in most urban cities such as DMC.

As a result of rapid urbanization and future human advancement, very large and appealing UGS sites are required very soon. DMC, on the other hand, lacked natural attractions such as lakes, river beaches, caves, and other greenery areas, with the exception of the Yeraba natural forest, which is located in the city's south-eastern corner. Moreover, due to the oldness of the city, most of the 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 has recently expanded dramatically in all directions by incorporating free cultivated lands, grasslands, forest lands, and other open / bare land use types from surrounding rural districts for urban development. This opportunity will provide many benefits for UGS in terms of better structural planning and opportunities to review past problems. Hence, unplanned or 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 and Kállay, 2020). According to the structural plan (2021) of DMC, residents enforced to travel more than 8.4km (16.8times) and 5.4km (10.8times) more far 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 proposing 500m radius public green open spaces within city boundaries (Eshetu et al., 2021).

Globally, many researchers used remote sensing-based UGS site suitability analysis integrated with AHP method in different cities (Piran et al., 2013; Rasli et al., 2016; Saeedavi et al., 2017; Li *et al.*, 2018). However, in Ethiopia, even though, MCDM with AHP analysis is applied for many suitability analyses such as cropland suitability (Kahsay et al., 2018. Debesa, et al., 2020), environmental pollution (Dawit et al., 2020; Worqlul et al., 2017) and irrigation potential (Balew et al., 2020; Mussa and Suryabhagavan, 2021) and groundwater potential assessment (Abate *et al.*, 2022), its application for UGS assessment is very limited yet. Only a few researches are conducted in this area recently such as suitable site selection for UGS development using GIS and RS based on multi-criterion analysis (Hailemariam, 2021) and urban green spaces planning in Sululta town, Ethiopia (Gelan, 2021). However, no scientific research has previously been conducted in the study area (Debre Markos City) 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 of DMC, and remote sensing and GIS-based methods, to quantify and allocate the proper suitable site for UGS. As a result, this study demonstrated the importance of locating, planning, and developing UGS sites prior to their establishment with reasonable scientific justifications. 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 the residents.

2. Research Methods

2.1 Description of the study area

DMC, earlier named Menkorer, is the prior capital of Gojjam Province and is a regiopolitan city in northwestern Ethiopia. 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 a latitude of 10°21'30.271”N to 10°12’50.523”N and longitude 37°10’33.293”E to 37°18’46.995” E, and an elevation of 2446 m.a.s.l. DMC has located 300km to the North Western part of Addis Ababa City, the capital city of Ethiopia. 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.

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 (CSA, 2007) 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 (CSA, 2008)

2.2 Data source methods

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

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*30m spatial resolution.	Slope & elevation
2	Sentinel 2A	2022	https://scihub.copernicus.eu/	A geographical feature (that has 10m spatial resolution) can be used in diverse land features.	Preparing NDVI and land use and land cover map
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	Settlement data	2022	Sentinel 2A	The spatial location of settlements plan and supervised classification	Proximity to settlement
6	Religious institutions	2022	DMC Administration Plan Institution	How far are religious institutions from urban green space	Proximity to religious institutions
7	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

2.3 Methods

Multi-criteria decision analysis (MCDA) integrated with Analytical Hierarchy Process (AHP) were applied to determine an ideal place for UGS. 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 on the basis of its relevance and data availability. Finally, all these factors were analyzed with the ArcGIS environment with the application of 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:

$$NDVI = \frac{Band8\left(NIR\right) - Band4\left(R\right)}{Band8\left(NIR\right) + Band4\left(R\right)}$$

1

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

2.3.1 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 land use/ land cover map of the study 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 algorithm of image classification, 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;

$$OaUGS = \Sigma Xc / GCP * 100$$

2

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

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

3

Where; **TN** - total number of observations, f- number of rows in the matrix, $\mathbf{P}_{jj}$ is the number of observations in the row j, and the column j, $\mathbf{P}_{j+}$ is the marginal totals of the row j and $\mathbf{P}_{+j}$ the marginal totals of the column j.

2.3.2 Multi-Criteria Decision Analysis

The weights of all numerous UGS contribution items detected in the thematic map layers would have 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 decision making process can be reducing by using AHP which helps to capture objective assessment measures and it offers an appreciated method for confirming consistency (Ishizaka, 2003). In order 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.

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.

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).

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

$UGS_w = \lambda_{max}$ (UGS) W, with $W_j \geq 0$, j = 1, ….., n and $\sum_{j=1}^{n} wj = 1$ (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:

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

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:

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

6

Where, 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.

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

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

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

7

Where; **UGS**i, Urban Green Space identification, $\mathbf{fw_i}$, factor weight/Weight of criteria in the matrix, $\mathbf{Ap_i}$, Assigned normalization score of pixel value C, number of input factors/criteria that contribute for UGS_i.

2.3.3 Conceptual design

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

3. Results And Discussion

3.1 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). The slope of DMC ranges from 0 degrees (flat/gentle slope) to 70 degrees (steep-slope) (Table 4). Land slope having from zero to eight degrees has a very high to high suitability rating for UGS development. However, land slopes approaching to seventy degrees indicates that the study area consists of steep slopes, which makes urban greening difficult to establish and requires huge cost of investment (Newburn et al., 2006). According to Pokhrel (2019), earlier studies on UGS geospatial analysis show that areas having flat to gentle slope are very high suitable for the development of urban green space, particularly green parks. Moreover, the landscapes of the area determine the cost and design of the construction of UGS (Zhu, 2018).

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

Input factor	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
	2451–2548	5	Unsuitable
Proximity to road/ road type (m)	Primary road (60m,40m)	1	Very highly suitable
	Secondary road (30m, 25m)	2	Highly
	Tertiary road (20m,16m)	3	Moderately
	Quaternary (12m,10m)	4	Poorly
	Quinary (8m)	5	Unsuitable
Proximity to religious institutions (m)	< 500	1	Very highly suitable
	500–1000	2	Highly
	1000–1700	3	Moderately
	1700–2500	4	Poorly
	2500–3753	5	Unsuitable
Existing 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 (m)	0–220	5	Unsuitable
	220–580	4	Poorly
	580–1055	3	Moderately
	1055–1705	2	Highly
	1705–2854	1	Very highly

Input factor	Sub-factor	Normalization scores	Degree of suitability ranking
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 (m)	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 (m)	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	100–185	5	Unsuitable
	185–260	4	Poorly
	260–310	3	Moderately
	310–360	2	Highly
	360–485	1	Very highly

3.2 Proximity to the road

Road infrastructures such as road proximity and road width are one of the basic factors that make UGS more convenient for users. Main roads contribute a lot for this purpose owing to their nature of reducing traffic flow and serving as parking at the edge. As shown in Fig. 3, Fig. 4, and Fig. 5 (i) below DMC has proposed as well as existing roads that range from very wide to narrow road widths including 60m, 40m, 30m, 25m, 20m, 16m, 12m, 10m, and 8m 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 5025.58m showed that the area is very far from the 60m width main road.

3.3 Normalized Difference Vegetation Index

Results revealed that 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. As the NDVI vegetation prominence of a given environment is increased or becomes greater, the enhanced the level of urban green space adaptableness and NDVI value is approaching to + 1 (Wu et al., 2021). Moreover, as Li *et al.*, 2018, for UGS development, the calculated NDVI value should be greater than 0.1, that representing grasslands and shrubs.

3.4 Proximity to market place

Market places 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 pollutions and make it very clean, attractive and visit able by the residents. As shown Fig. 6 (n) proximity to market places ranges from 0 to 2853m distance, the nearest area are affected by pollutions from marketing and are not suitable for GS

3.5 Proximity to water source

The source of water is one of the key factors that regulate and make UGS development works ease because it is the heart for growth and development of green plants. Owing to, the above fact any UGS should be sited near to water source areas. However, the land should be out of flood risks since streams usually obtained at the lower relative elevation point in a given location. 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 used as an alternative/supporting mechanism to replace or support groundwater sources of the city to irrigate UGS.

3.6 Proximity to religious institutions

Places that are closer to religious sites, cultural and historical spaces are highly suitable for in good physical shape and spiritual lifestyles as related to places that are far away from these spaces (Pokhrel, 2019). These areas having a distance of < 500m are classified as very highly suitable, while, those areas > 2500m are unsuitable for the development of UGS (Table 4).

3.7 Proximity to residential/settlement areas

Globally, different countries have been 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 right to use to a green space within 15 minutes of time (*t*) of their dwelling and a maximum walking distance of approximately 900–1000metres (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 frontiers of the city, and every dweller living in the interior of 500m distance from public urban open green spaces (should have at least 3000m^2 area in size) (Eshetu et al., 2021).

3.8 Elevation of land surface

Elevation data was also obtained from DEM data. As the elevation of the land increases more, the suitability for UGS development is decreases. In the lower elevation associated with flat slope land areas demands less human intervention for design and construction, the more suitable the place for biological habitats to live and the advanced it's the suitability of UGS (Wu et al., 2021).

3.9 Land use/ land cover type

The land use/ land cover data of DMC was categorized into six main classes namely: cultivation land, grassland, forestland, settlement/ resident, water bodies, and urban open space/ bare land (Fig. 9). 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 (Li *et al*., 2018).

3.10 Flood Susceptibility

Flood susceptibility mapping development includes a slope, rainfall, distance to the river, and land use /land cover conditions of an area. Flood-susceptibility mapping has also been used as a parameter for UGS suitability study in DMC. Research studies indicate that the places within the lower flood-susceptibility has more suitable than the land with higher flood-susceptibility places for UGSs assessment and it also designated that urban green spaces has to be free from flood susceptibility areas as much as possible (Fotovatikhah et al., 2018; Zhao et al., 2019).

Accuracy assessment is the measurement of precision and error matrix 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.

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**		

Note: 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.

3.11 Criteria and sub-criteria for suitability analysis

All the selected causative input factors/criteria’s of UGS assessment pairwise comparison matrix has 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 settlement, proximity to road, 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 water source, proximity to religious area, flood susceptibility, and proximity to marketplace ranks from sixth to tenth, respectively.

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

Note: S_l- slope, Elv-elevation, P_{rx}.Reli – proximity to religious institution, $P_{rx}.R_o$-proximity to road, E_{xt}LU-existing land use, Prx.M_{kt}-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- weight of criteria.

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 was 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, that is less than 0.1, and deemed acceptable.

3.12 UGS spatial analysis

The most central part of DMC has very high and highly suitable UGS due to its proximity to 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, 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, 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 were used for the cultivation of crops 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 1.1km distance from seasonal and permanent flow streams. Within the center of the city too, there are areas suitable for UGS development activity as shown in Fig. 11.

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 would be 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.

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%

Based on area coverage, very high suitable, high suitable, moderate suitable, poor suitable, and unsuitable ratings accounts 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.

3.11 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, can be achieved the past (2012) projected population of the city.

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 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 study is conducted by the city planners per se, 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 500m 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 CSA (2008), 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 8.4km in the existing UGS and more than 5.4km in the proposed UGS to get the service as shown in Fig. 11 below. As shown in Table 8 below, on average the dwellers should travel 4.213km to get the existing UGS service for their entertainment within the city.

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 1.3km. Moreover, the maximum distance to reach in moderately and poorly suitable UGS is 675metres only (Fig. 13 above and Table 8 below). The average distance to access UGS in this geospatial analysis study was 656m and 337.5m from very high to a highly suitable area and moderate to a poor suitable area, respectively (as shown in Table 8). Overall, wherever UGS development activity doing in any corner of the city, a resident can access it within a maximum distance of a 1km radius, which is very close to the national standard.

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	4,213	8,426
2	Proposed UGS (newly proposed by the city per se)	0	2,710	5,420
3	Geospatial Assessment UGS (in this study)			
	3.1. distance to very high to high suitable UGS	0	656	1,312
	3.2. distance to moderate to poor suitable UGS	0	337.5	675

4. 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 is very highly suitable and high suitable for UGS, respectively. In the study, the average distance to get UGS service lowered to 656m from very high to highly suitable and 337m for moderate to poor UGS suitable areas. However, due to the city's undulating nature of 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 concern of the city to UGS planning development is very low under the proposed plan. It could not consider the future urbanization and urban population properly with scientific study.

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Figures

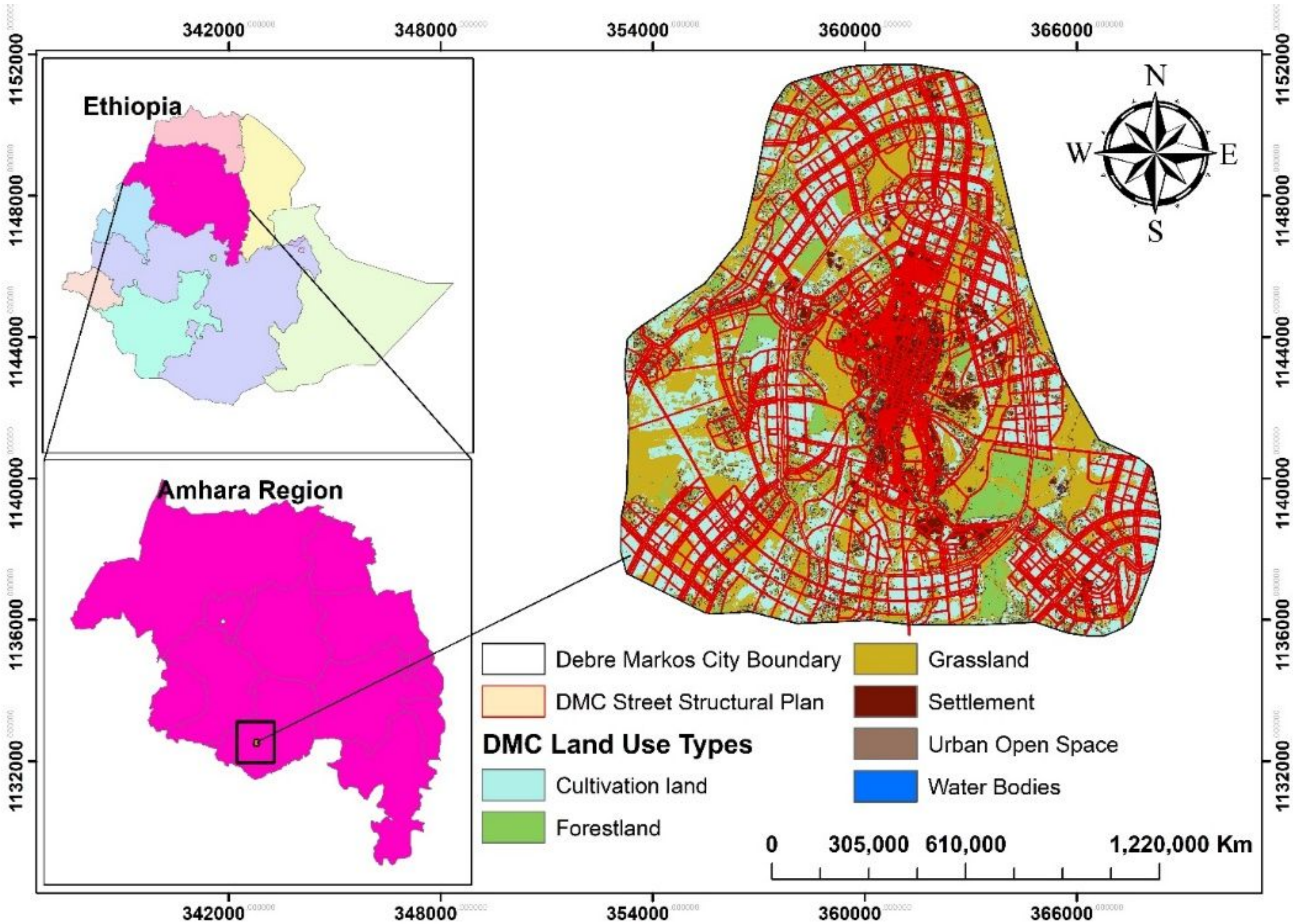

Figure 1

Location map of DMC

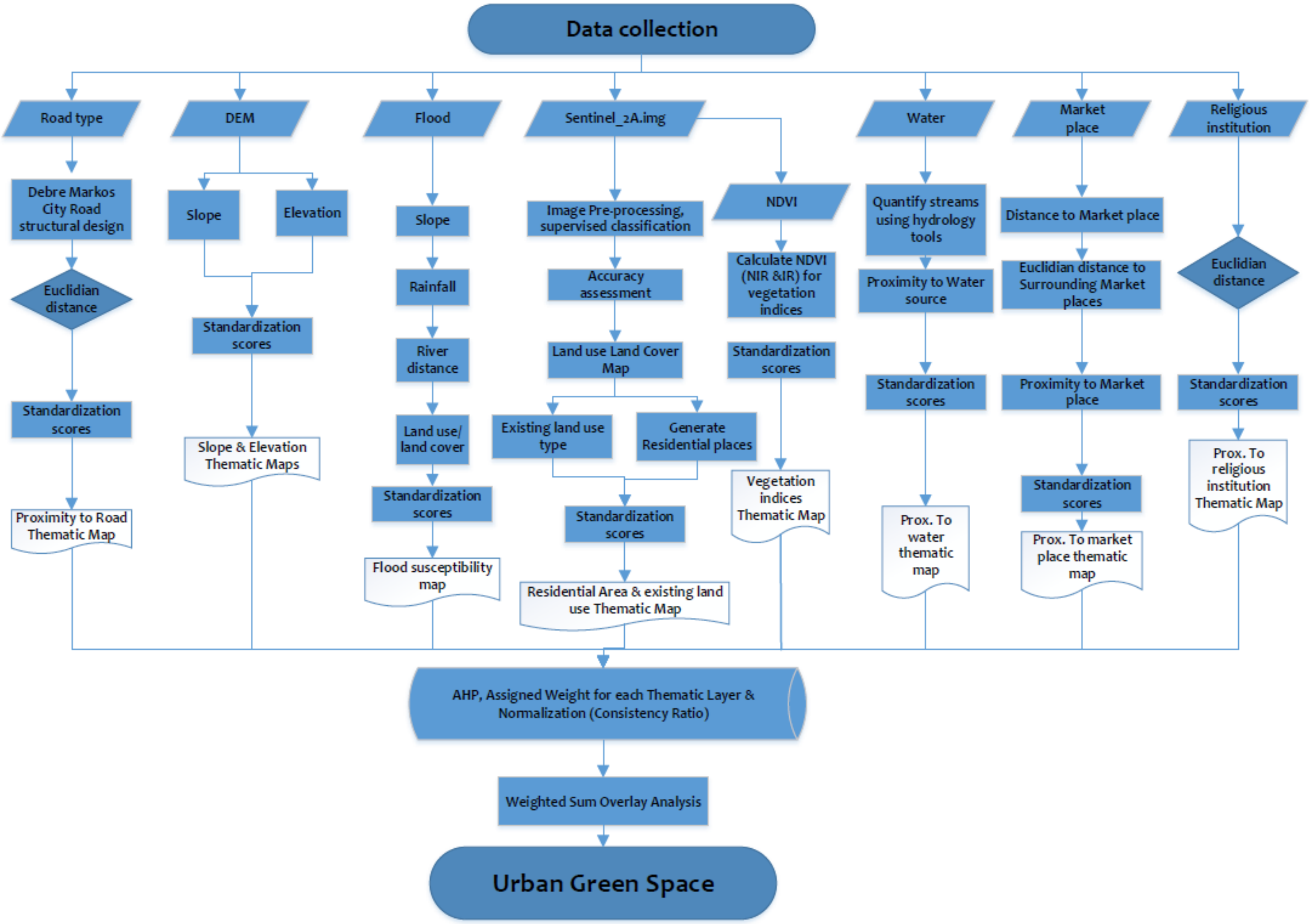

Figure 2

Conceptual design of UGS in DMC

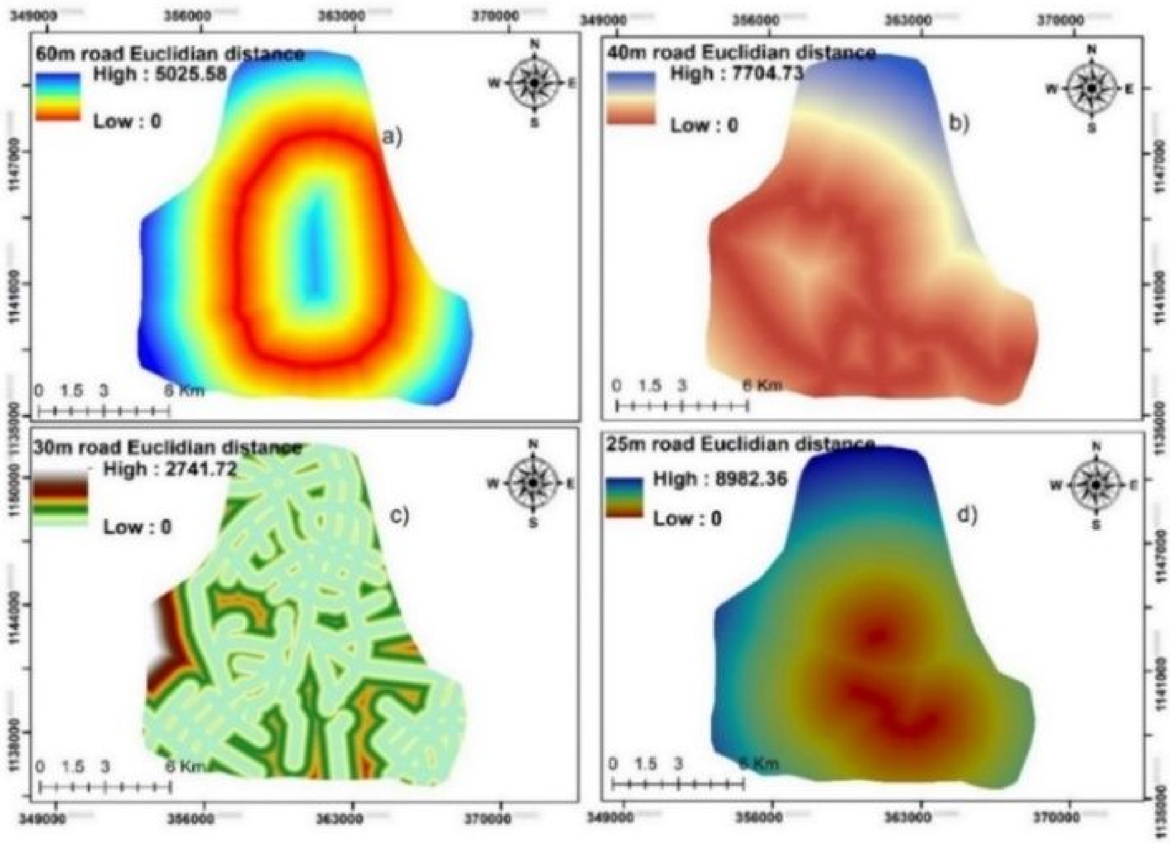

Figure 3

Proximity to road maps (a) 60m (b) 40m (c) 30m (d) 25m

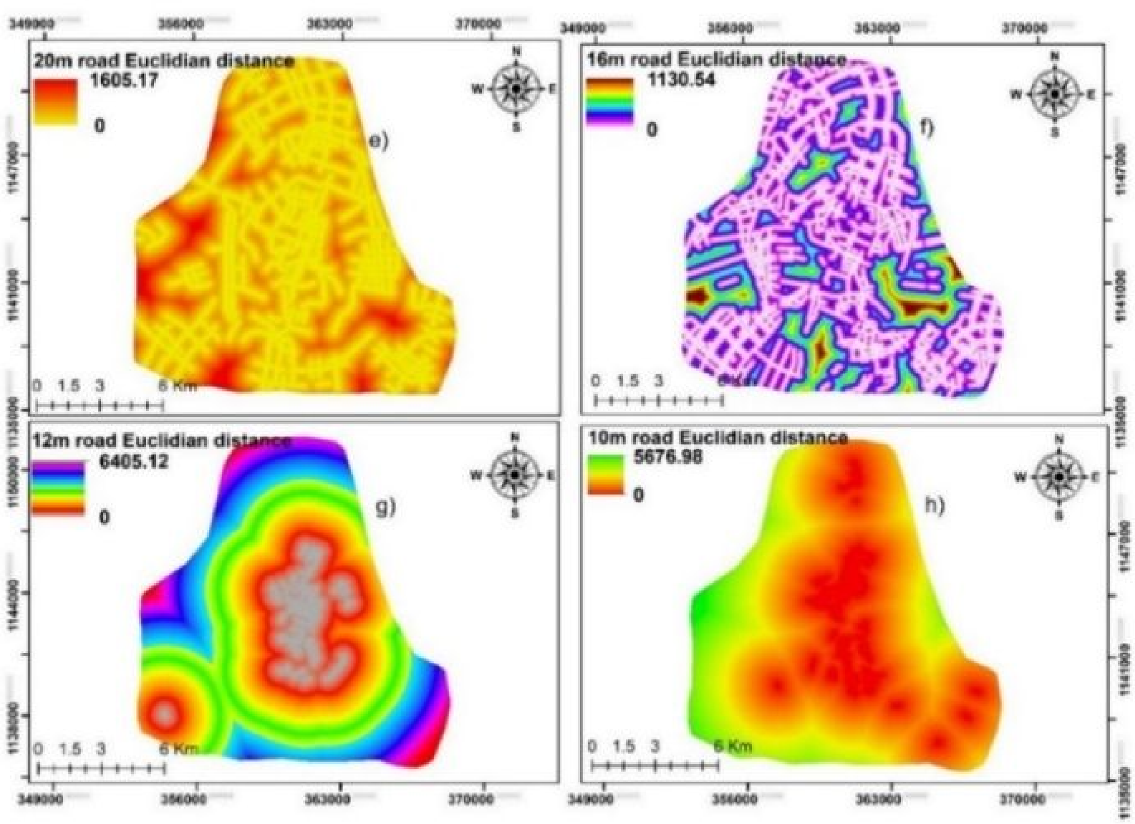

Figure 4

Proximity to road maps (e) 20m (f) 16m (g) 12m (h) 10m

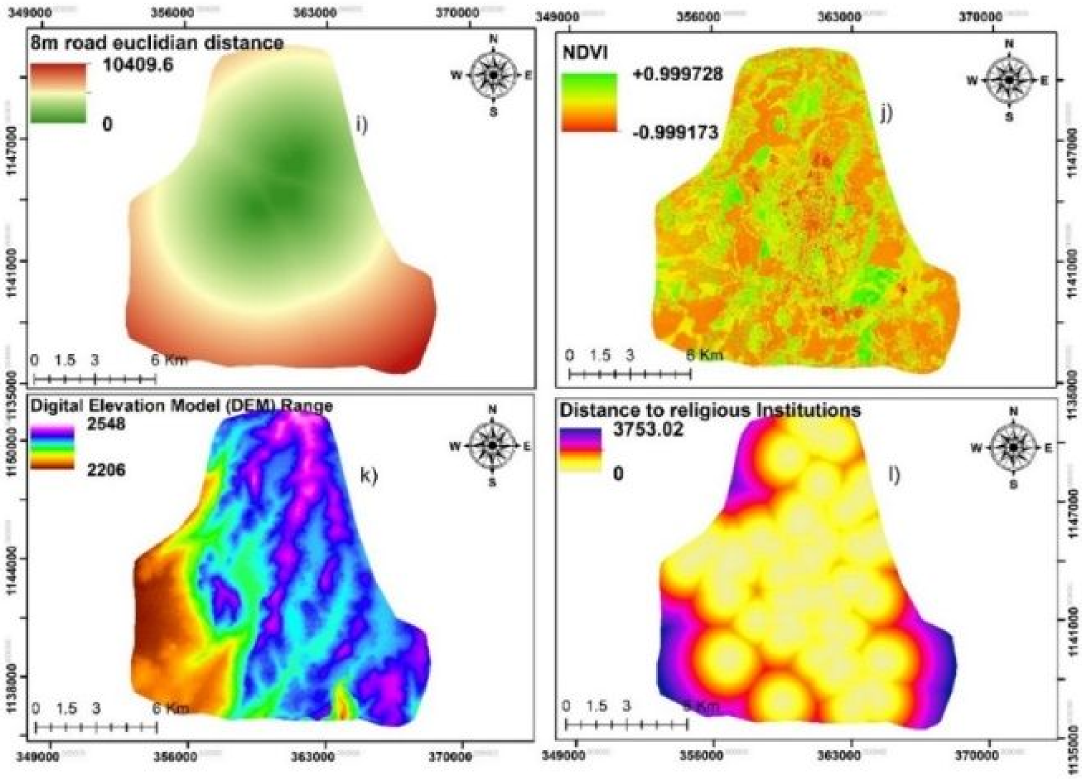

Figure 5

Proximity to road distance (i) 8m (j) NDVI (k) the minimum and maximum value of digital elevation model (DEM) (l) distance to the religious institution

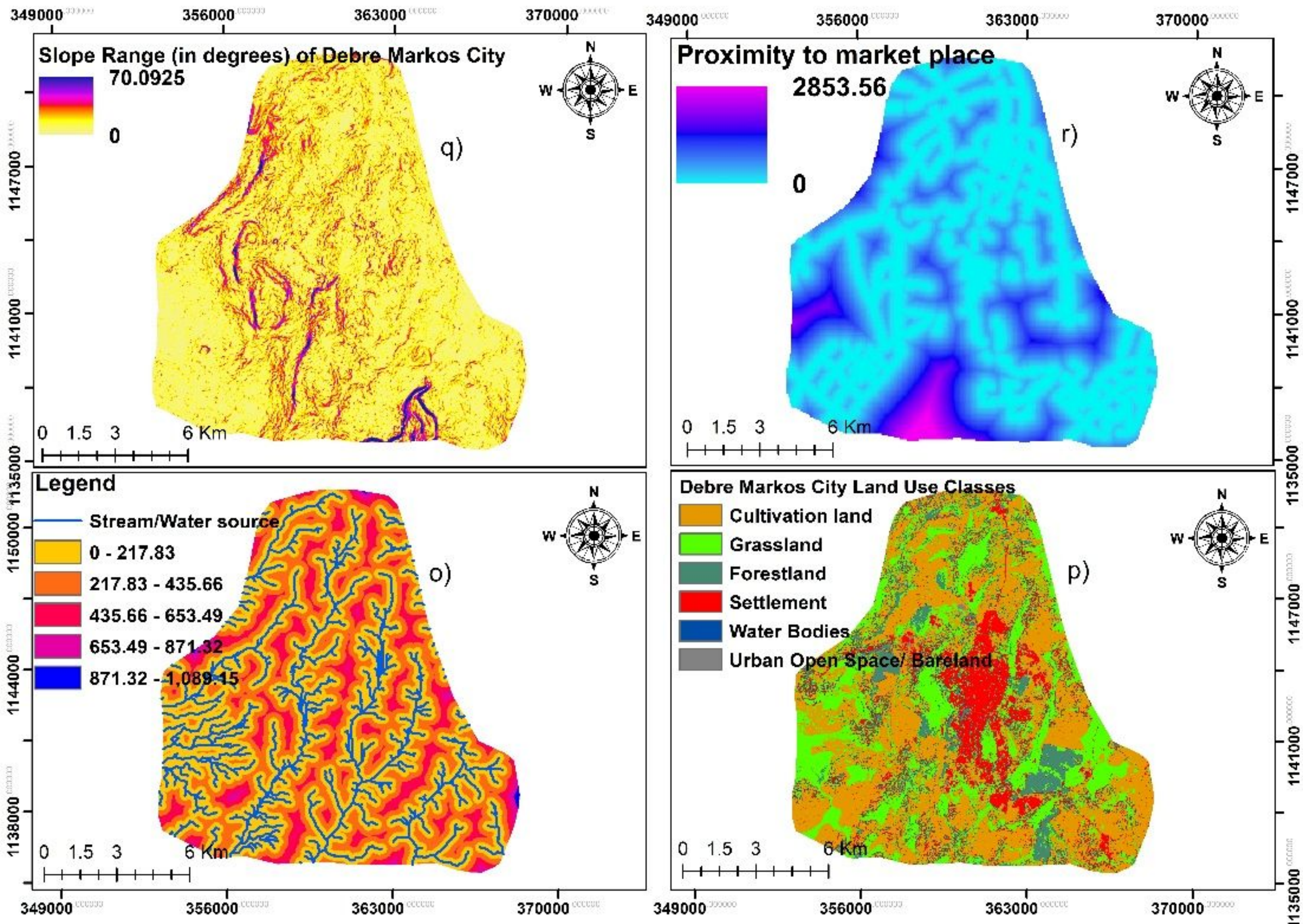

Figure 6

Thematic maps of DMC (m) slope in degrees (n) proximity to marketplace (o) streams (p) land use /land cover map

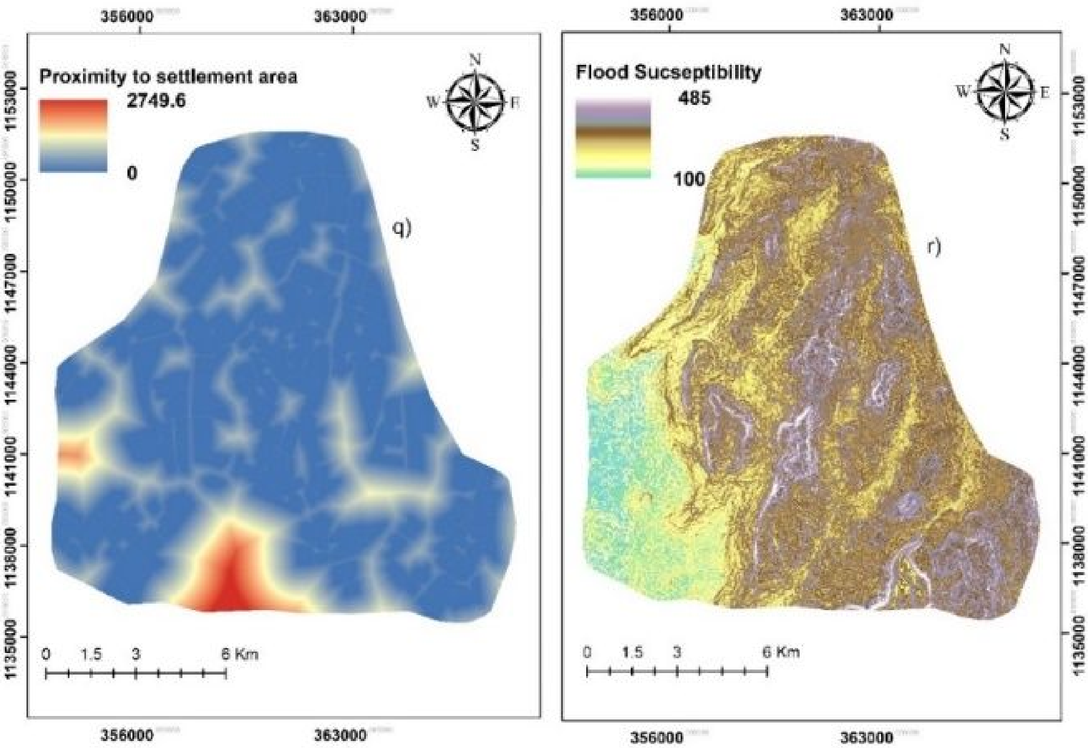

Figure 7

(q) proximity to settlement (r) flood susceptibility map

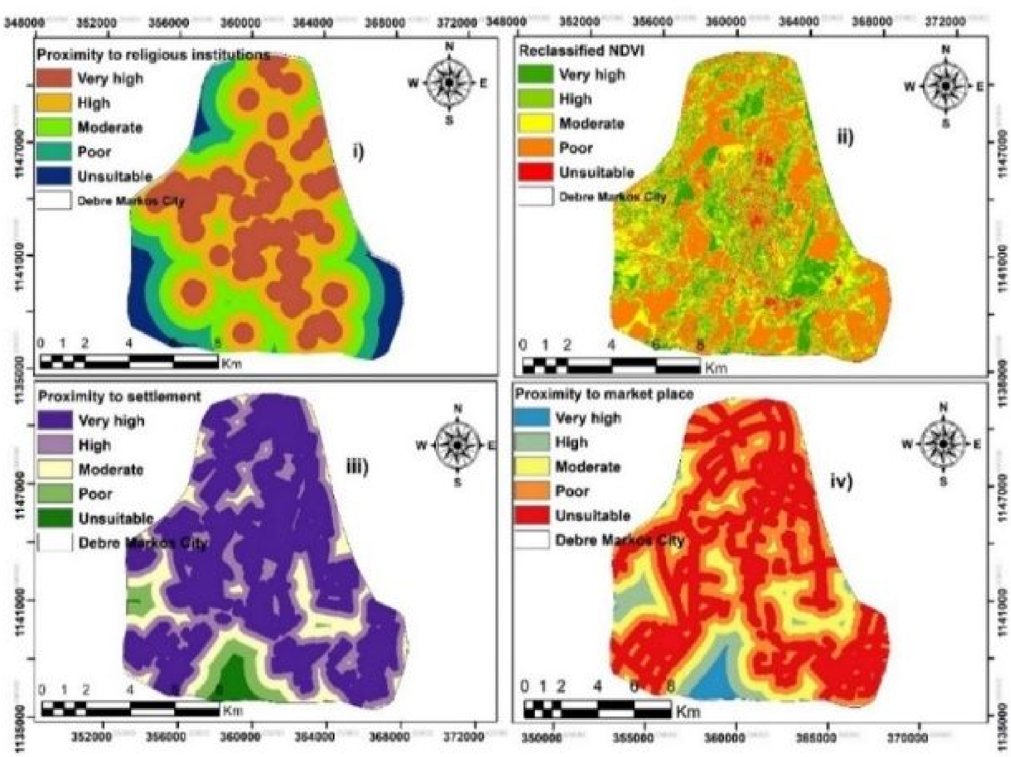

Figure 8

reclassified maps of (i) proximity to the religious institution (ii) NDVI (iii) proximity to settlement (iv) Proximity to marketplace

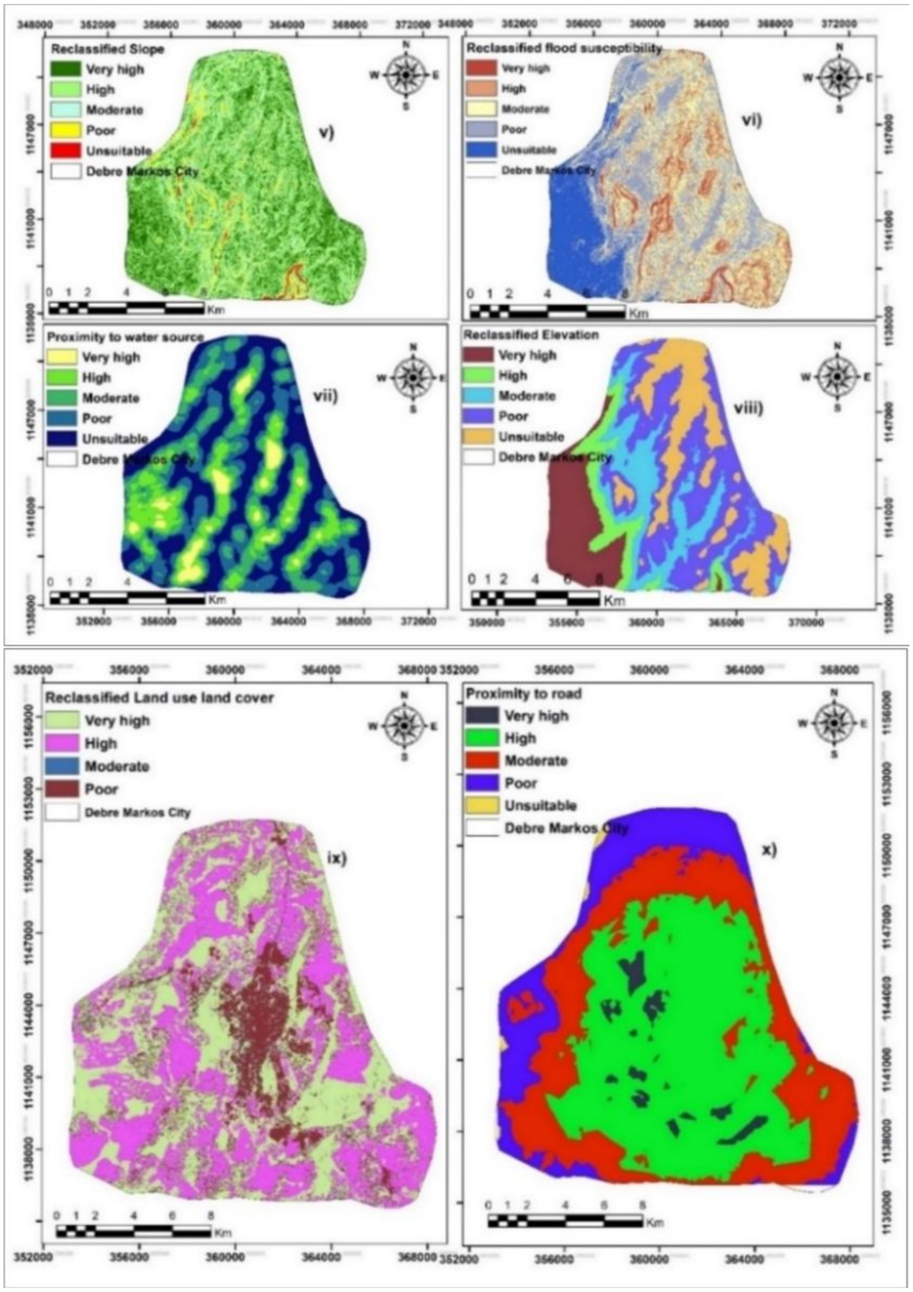

Figure 9

Reclassified maps of (v) slope, (vi) flood susceptibility, (vii) proximity to water source and (viii) elevation (ix) land use land cover map (x) proximity to road

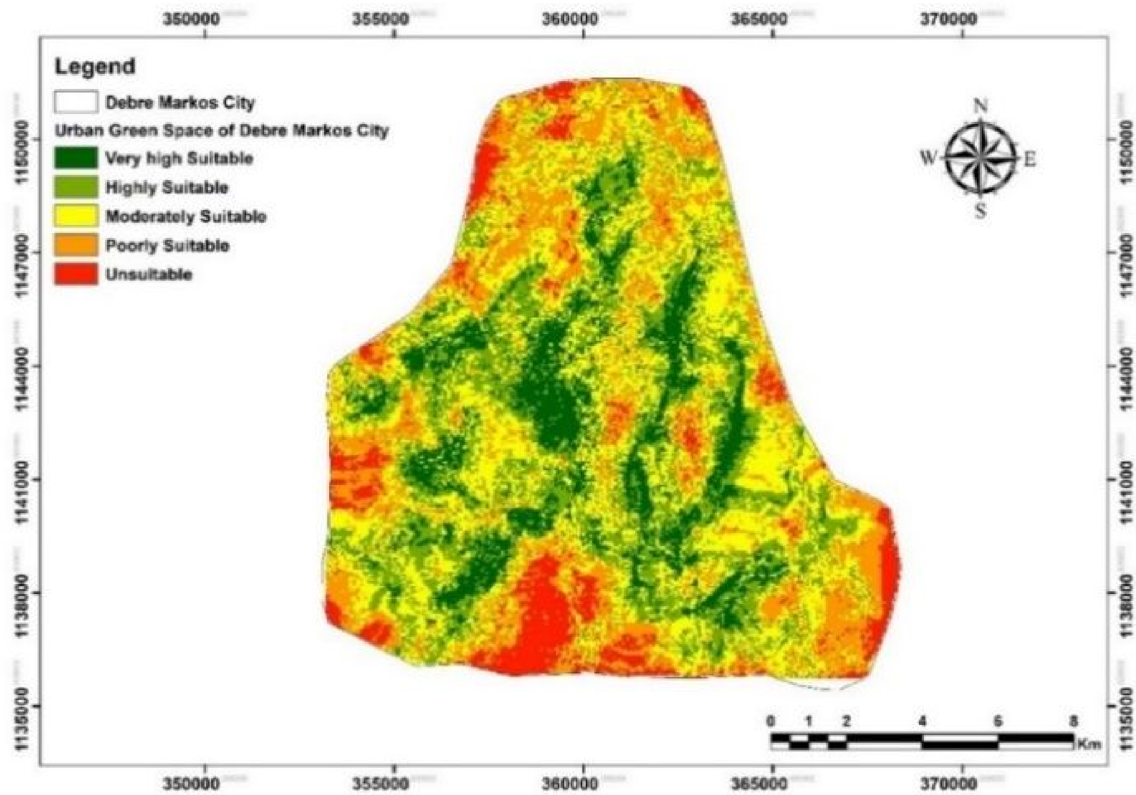

Figure 10

UGS suitability map of DMC

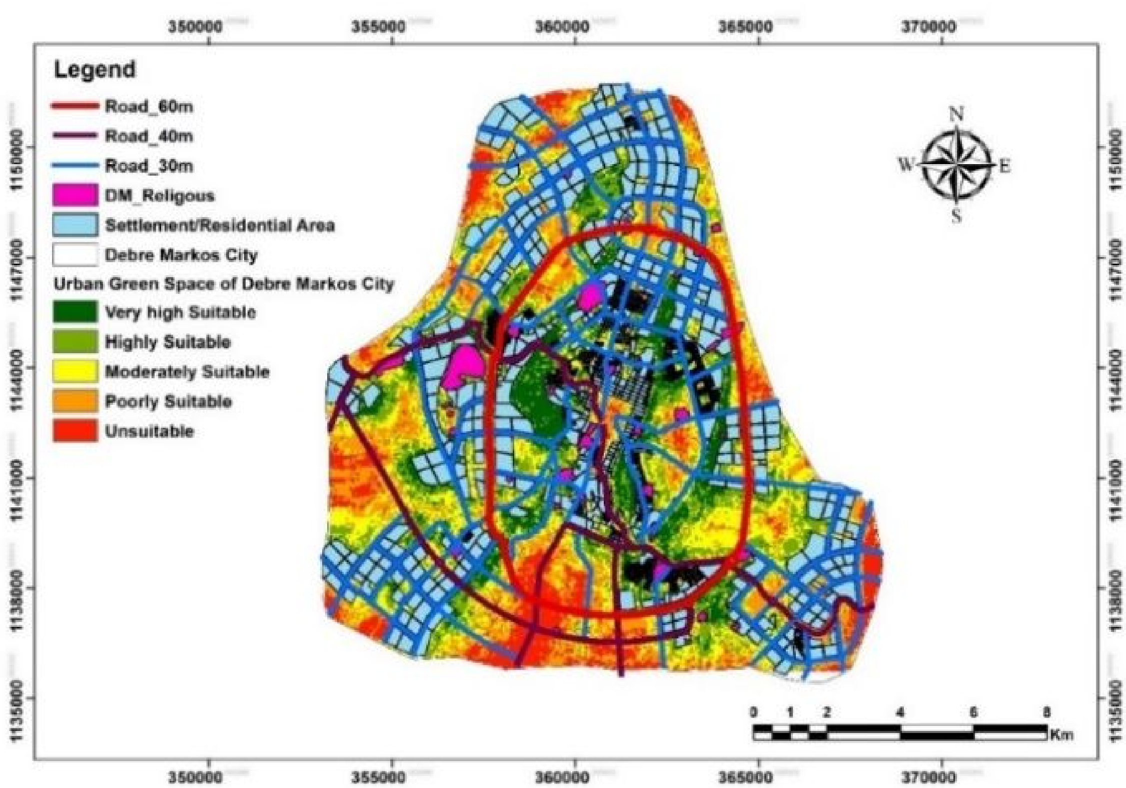

Figure 11

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

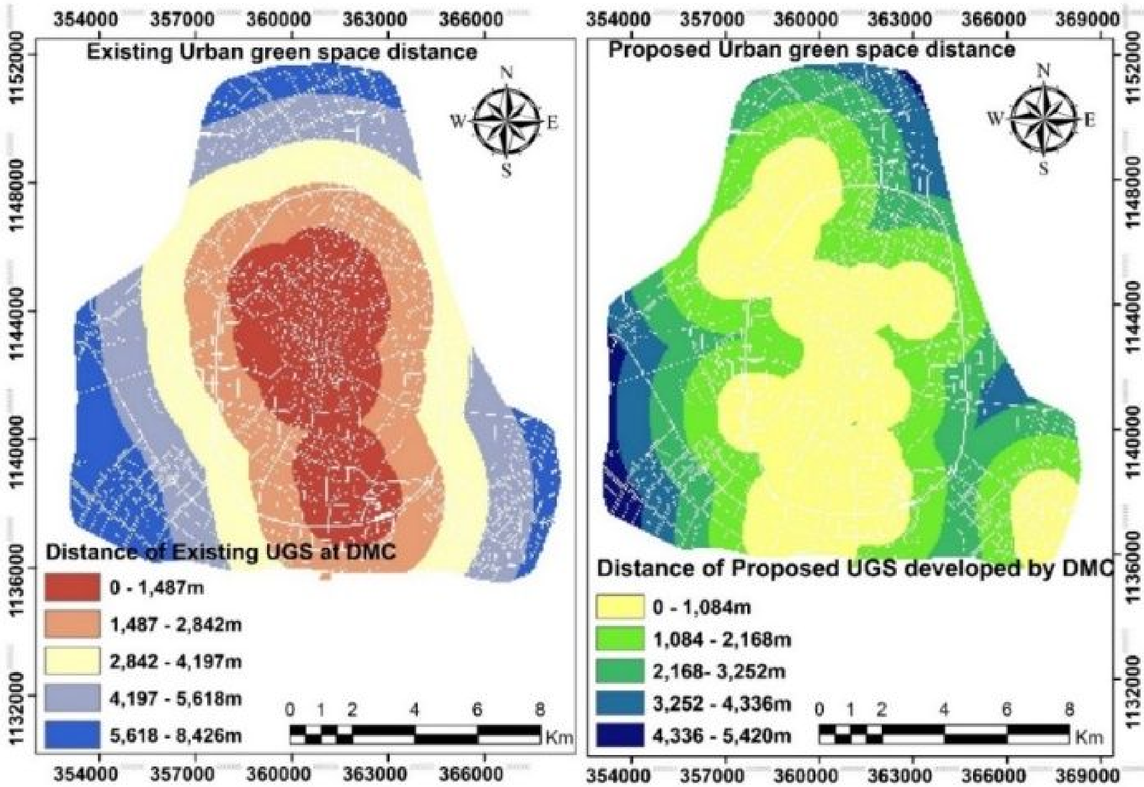

Figure 12

Existing and Proposed UGS distance

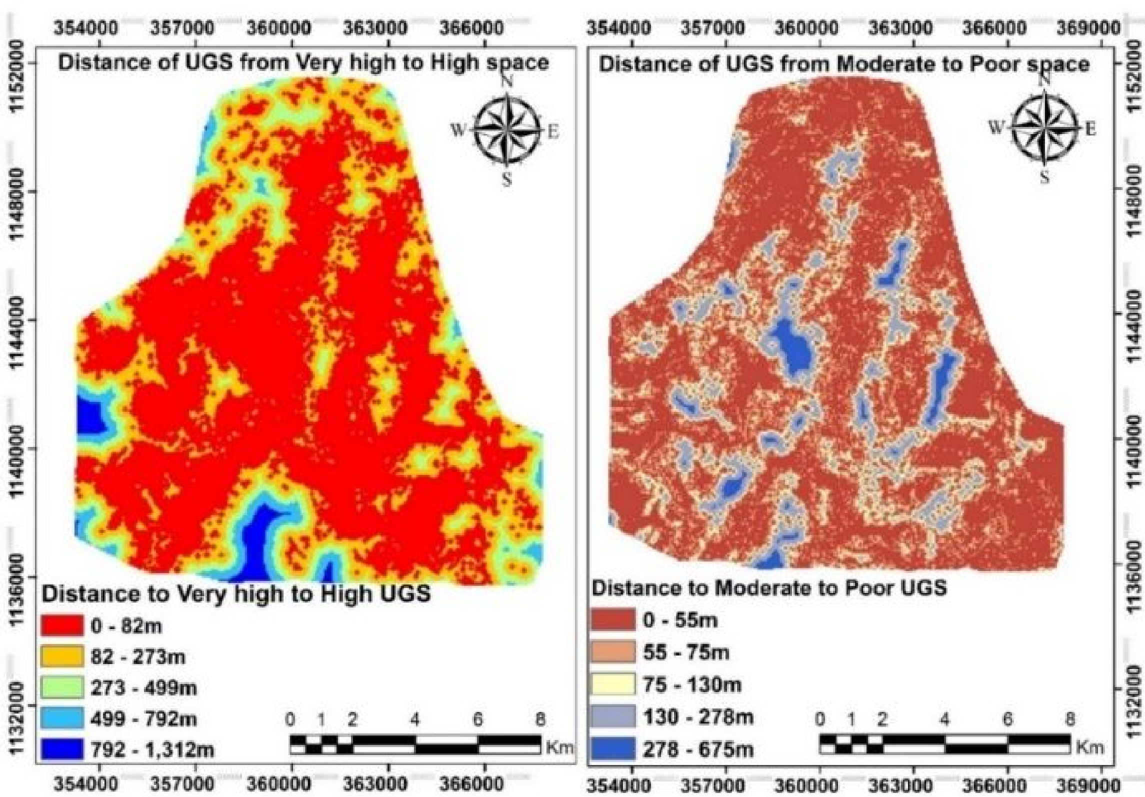

Figure 13

Distance from Very high- to high and Moderate to poor UGS area