Implementation and Evaluation of Urban Green Space Supply for Debre Berhan Town, Ethiopia

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Abstract

Urban green space (UGS) is part of urban land covered with vegetation which has an immense benefit for sustainable urban development. The main objective of this study was urban green space supply analysis and evaluation for Debre Berhan town, Ethiopia. To realize this objective, we generated UGSs information by using normalized difference vegetation index (NDVI) which was calculated from Sentinel 2 satellite image. Then, the result of NDVI calculation was classified as small vegetation and high vegetation with over all accuracy of 87.29% and kappa value of 0.808. According to the result, there are 15.85% and 1.55% supply of urban green space for small and high vegetation respectively. In addition, the UGS supply in inner and outer part of the town for each land use was quantified. The result showed that in the inner part of the town, service, green area, and vacant land uses have 30.12%, 30.06%, and 13.32% of UGS supply respectively. Conversely, recreation, commercial, and administration land uses are least supplied with 0.11%, 0.26%, and 0.40% share of UGS. Furthermore, the UGS supply was evaluated against the new urban planning strategy of Ethiopia (30% coverage) and World Health Organization standard (9m^2 per person). The coverage of small vegetation and high vegetation was 15.85% and 1.55% respectively. The UGS per capita for small vegetation was about 75.16m^2 while the value for high vegetation was 7.33m^2. The results of our analysis can be used as an input for urban planning and master plan revision.

1. Introduction

Rapid urbanization and booming population number caused problems like reduced ecosystem's capacity for providing ecosystem services and biodiversity (Milinium Ecosystem Assessment, 2005; Wu et al., 2011; Weng, 2012; McDonald et al., 2013; He et al., 2014; Bai et al., 2016), the increment of urban heat stress (Kweon et al., 1998; Chen and Jim, 2008; Lafortezza et al., 2009; Lee and Maheswaran, 2011; Nutsford et al., 2013; Krzyzanowski et al., 2014; Grêt-Regamey et al., 2013; Musango et al., 2017), noise pollution (Gidlöf-Gunnarsson and Öhrström, 2007), loss of spaces promoting public mental and physical health (Grahn and Stigsdotter, 2010; Hedblom et al., 2019), and poor air quality that caused acute diseases (Lovasi et al., 2008; Shah et al., 2011).

In order to solve the aforementioned urbanization driven problems, urban green infrastructure through establishment of interconnected network of green spaces is identified as an alternative nature-based solution (Benedict and McMahon, 2002; Gill et al., 2007; Grimm et al., 2008; Ramdani, 2013; Rakhshandehroo et al., 2017; Nikolic and Yang, 2020).

Urban green space (UGS) refers to part of urban land covered with vegetation (Rahimi, 2020), and is recognized solution for creating smart and resident friendly urban centers (Tan et al., 2013; Demuzere et al., 2014; Wolch et al., 2014; Jennings et al., 2016; Daniels et al., 2018; Woldesemayat and Genovese, 2021). UGS has multitude of social, economic, ecological, and planning benefits (Attwell, 2000; Kaczynski and Henderson, 2008; Baycan-Levent and Nijkamp, 2009; Sadeghian and Vardanyan, 2013; Kabisch et al., 2016; Pulighe et al., 2016; Anguluri and Narayanan, 2017).

UGS improves social cohesion and social capital (Zhou and Rana, 2012; Tabassum and Sharmin 2013; Bijker and Sijtsma, 2017; Kothencz et al 2017; Jennings and Bamkole, 2019; Elderbrock et al, 2020); and gives educational opportunities (Bolund and Hunhammar, 1999; Gee et al, 2009; Cameron et al., 2012; Smith et al., 2013; Kothencz et al 2017; Elderbrock et al, 2020). It reduce exposure to air pollutants, noise, and excess urban heat (Janhäll, 2015; WHO, 2016; Van Renterghem and Botteldooren, 2016; Margaritis and Kang, 2017; Ramaiah and Avtar, 2019). Maintaining ecological processes and resulting services like providing habitat for animals and plants, providing a beneficial city microclimate (*Tian, 2014; Niemela, 2014; McPhearson, 2015;* Elmqvist et al., 2015; de Jalón et al, 2020; *(*Daniels et al., 2018); enriching habitats and biodiversity (Benedict and McMahon, 2002; Gao et al, 2021), mitigating urban heat island effects via shading and evaporation (Kong et al, 2010; Zhibin et al, 2015); reducing high temperatures and urban heat effects (Gill et al, 2007) played a role in cooling effect (Aram et al, 2019); climate change mitigation (Fryd et al, 2011; Demuzere et al., 2014; ndersson-Sköld et al., 2015; Ramaiah and Avtar, 2019); providing a service of carbon sequestration (Strohbach and Haase, 2012); regulating or attenuating flooding (Dhakal & Chevalier, 2017; Zölch et al, 2017) and infiltrating storms (Livesley et al., 2016) are also momentous benefits of UGS.

Due to the environmental pressures of growing urban centers, many cities around the world have undertaken greening programs such as urban tree planting, enhancing parks, and providing incentives for green roofs to benefit from the amenities of urban green spaces (Li et al., 2015). In this respect, industrialized cities in the developed world have been trying to integrate sustainable ecological, social, and economic dimensions in all aspects of urban development (Bunce, 2009; Haase et al., 2010). However, in developing countries, the number of urban green spaces decreases, and there is unequal access to urban green space (Ramaiah and Avtar, 2019; Sabyrbekov et al., 2020; Rae, 2021). In sub-Saharan African countries, components of urban green infrastructure are depleting at an alarming rate in several cities across the continent (Mensah, 2014). However, there is a lack of empirical studies about the status, availability, and accessibility of urban green infrastructure in cities of African countries (Azagew and Worku, 2020). As part of the sub-Saharan Africa, Ethiopia is among the world's fast urbanizing countries even with more than population growth rate (Gulyani et al., 2001) but with unplanned urban growth (Zeluel et al., 2011).

Geospatial data and analysis techniques are very effective in urban greenery planning, their availability assessment, and evaluation. Many studies demonstrated the effectiveness of geospatial techniques for urban green space analysis and mapping (Hashim et al., 2019; Elderbrock et al., 2020; Woldesemayat and Genovese, 2021; Kumakoshi et al., 2020; Le Texier et al., 2018).

Now a days Debre Berahn town is experiencing rapid growth of industrialization due to its proximity to Addis Ababa and its conducive climatic condition. With the expansion of industry, the town will be at high risk of emissions in the near future. To address this problem, expanding the supply of green space is an important task. Therefore, this research examines the nature of city's green space supply, identifies the underlying issues of UGS supply and provides accurate information to stakeholders.

2. Research Methods

2.1 Study area

Debre Berhan town is the administrative Centre of North Shewa Zone which is found in Amhara regional state of Ethiopia. Its astronomical location is in between $9^{0}36'30''$- $9^{0}42'32''$North and $39^{0}27'56''$-$39^{0}34'26''$ East (Fig. 1). In its relative location, it is found at 130 km road distance from Addis Ababa (Ethiopia's capital) in the Northeast direction. Presently, it is classified in to 9 administrative *kebeles (the smallest administrative unit in Ethiopia)*. The total area of Debre Berhan town is 5710ha. In this research, the town area is further classified as inner part

(1654ha), and outer part (4055ha) based on the level of urban development. Based on the population projection of Central Statistical Agency of Ethiopia, the current population size of the town is 120399 (CSA, 2019).

2.2 Data type and sources

In this study, we used band 4 and 8 of Sentinel 2 satellite image from official web site of Sentinel hub (https://scihub.copernicus.eu/). These two bands were used to calculate normalized difference vegetation index (NDVI) for Debre Berhan town. In addition, the land use plan of Debre Berhan town was obtained from town municipality. Ground control points (GCPs) were also collected from the field using hand held GPS (Table 1).

Table 1
Data type and source of data

Sn	Data	Source	Date	Spatial Resolution	Purpose
1	Sentinel 2 Satellite image	Sentinel Hub	18-Jan-21	10 m	NDVI calculation
2	Town land us plan	Town Municipality	2021		Land use composition analysis
3	Ground control points	GPS measurement	2021		To validate NDVI calculation and classification result

2.3 Methods

2.3.1 Normalized Difference Vegetation Index (NDVI) calculation and classification

The Sentinel 2 satellite image covering Debre Berhan area was downloaded from the official web site of Sentinel hub. To minimize the effect of haze and cloud, we downloaded the dry season image of 18th January 2021. Thereafter, the downloaded image was subseted by the shape-file of our study area in ERDAS IMAGINE software.

The normalized difference vegetation index (NDVI) is the ratio of the difference between the near-infrared band (NIR) & the red band (R) and the sum of these two bands (Rouse et al., 1974)

NDVI = NIR-RED/NIR + RED…………………………………………………………….1

Where, NIR is near-infrared reflectance, RED is red reflectance. In this research work, sentinel 2 image was used to calculate NDVI. When calculating the NDVI, band 8 and band 4 were used for near-infrared and red bands respectively.

NDVI value for a given pixel always ranges from −1 to + 1. A zero NDVI value corresponds to no vegetation while closer to + 1 indicates the highest density of green leaves. In addition to NDVI calculation, we classified NDVI result in to three classes with overall accuracy of 87.29 % and Kappa value of 0.808 (Table 2). While classifying the NDVI image, NDVI value of 0.25 was used as a minimum threshold for vegetation (Elderbrock et al., 2020). The NDVI raster data was then classified in to three classes of urban green space as: non-vegetation, small vegetation, and high vegetation (Hashim et al., 2019). The classification was done based on NDVI threshold value of < 0.25 for non-vegetation, 0. 25 to 0.5 for low vegetation, and > 0.5 for high vegetation using reclassify tool of Arc GIS software (Table 3).

Table 2
Accuracy assessment report

		Reference						
		None vegetation	Small vegetation	High vegetation	Total	User accuracy	Over all accuracy	Kappa
Classified image	None vegetation	**42**	6	1	49	85.7143	87.2994	0.808
	Small vegetation	5	**45**	4	54	83.3333		
	High vegetation	3	4	**47**	54	87.037		
	Total	50	55	52	157			
	Producer accuracy	84	81.8182	90.3846				

Table 3
Urban vegetation class and NDVI value

SN	Vegetation class	Description	NDVI value
1	Non- vegetation	Barren areas, built up area and road network	< 0.25
2	Small vegetation	Shrub & grass land areas	0.25–0.5
3	High vegetation	Temperate and tropical urban forest	> 0.5
Adopted from Hashim et al 2019			

2.3.2 Availability of urban green space

The availability index of urban green space is calculated by the share of land allocated to urban green space per area of a given reference surface (Le Texier et al., 2018). In this research work, availability index was computed for both the inner and outer urban areas of Debre Berhan town. The inner areas are the developed part of the town, and the outer areas are those which are currently being used for urban agriculture. The availability was also analyzed using distance from the Central Business District (CBD). In the study, the area around Semayawi (Blue) building was selected as a CBD.

2.3.3 Land use composition

The share of each land use classes in the land use plan of Debre Berhan town was used as an input to quantify land use composition. The composition analysis was computed for both inner and outer areas of the town.

2.3.4 Urban green space supply evaluation

Urban green space supply evaluation was analyzed according to the new national urban planning strategy of Ethiopia (30% coverage) and WHO (9m^2 per person) standards. This analysis helps us to examine the performance of study area in the provision of urban green space for its residents.

3. Results And Discussion

3.1 Urban green space composition

According to the land use plan of Debre Berhan town, there are 13 land use types which cover a total area of 5710ha. From these land use classes, urban agriculture covers the largest area of the town with 71.02% of land. The smallest land use type is mixed use with 0.23% of the town. The share of green space in the land use plan of the town is about 2.19% which is by far below the national green space supply standard (30% coverage) (Table 4).

Table 4
Land use composition of Debre Berhan Town

		General		**Inner**		**Peripheral part**	
SN	Land Use	Area	%	Area	%	Area	%
1	Administration	17.72	0.31	17.72	1.07	0.00	0.00
2	Commercial	30.00	0.53	30.00	1.81	0.00	0.00
3	Manufacturing & Storage	180.82	3.17	180.82	10.93	0.00	0.00
4	Mixed	13.32	0.23	13.32	0.81	0.00	0.00
5	Residence	463.71	8.12	463.71	28.02	0.00	0.00
6	Road	181.81	3.18	181.81	10.99	0.00	0.00
7	Service	365.55	6.40	365.55	22.09	0.00	0.00
8	Special Function	14.11	0.25	14.11	0.85	0.00	0.00
9	Water body	16.66	0.29	16.66	1.01	0.00	0.00
10	Vacant land	220.01	3.85	220.01	13.30	0.00	0.00
11	Urban Agriculture	4055.63	71.02	0.00	0.00	4055.63	100.00
12	Recreation	25.82	0.45	25.82	1.56	0.00	0.00
13	Green Space	125.16	2.19	125.16	7.56	0.00	0.00
14	Total	5710.33	100.00	1654.70	100.00	4055.63	100.00
Source: Debre Berhan town land management office							

In this research work, we classified our study area in to two. These are the inner city which is purely nonagricultural land use and its periphery which is purely urban agricultural land use. In the inner city, residential land use is the largest followed by service and vacant land with 463.71ha (28.02%), 365.55ha (22.09) and vacant land 220.01ha (13.3%) respectively (Table 5). Urban agriculture is the only land use in the peripheral area of inner city. The small share of urban green space (2.19%) in the land use plan of the town indicates overlooking of UGS allocation in the town. Generally, the existing UGSs are not evenly distributed and planned properly considering the national and WHO standards of green space provision (Fig. 2).

Table 5
Urban green space availability for Inner and peripheral part

	Inner part		Peripheral part	
Land use	UGS (ha)	%	UGS (ha)	%
Admin	1.29	0.40	0.00	0.00
Manufacturing	29.35	9.13	0.00	0.00
Mixed	1.38	0.43	0.00	0.00
Residence	34.42	10.70	0.00	0.00
Road	11.53	3.59	0.00	0.00
Service	96.87	30.12	0.00	0.00
Special function	2.37	0.74	0.00	0.00
Water Body	3.67	1.14	0.00	0.00
Vacant land	42.83	13.32	0.00	0.00
Urban Agriculture	0.00	0.00	671.95	100.00
Recreation	0.36	0.11	0.00	0.00
Green area	96.68	30.06	0.00	0.00
Commercial	0.84	0.26	0.00	0.00
Total	321.60	100.00	671.95	100.00

3.2 Urban Green space availability

Green space availability is a measure of green space provision of an area. It is quantified by using availability index which is the ratio of urban green space and total reference surface (Le Texier et al., 2018). The NDVI calculation from Sentinel 2 and its classification result shows the availability of green space which is not incorporated in the land use plan of the town. Thus, the result suggests a mismatch between UGS on the land use plan and UGS in reality (Fig. 3). The availability analysis was done considering the minimum NDVI threshold value of 0.25 for small vegetation and 0.5 for high vegetation. According to the result of our analysis, kebele 05 has the largest availability of UGS with a share of 32.18% followed by kebele 07 and kebele 03 having 21.24% and 20.81% respectively. The UGS availability analysis result asserted that the old part of the town (kebele 01 and 02) have a minimum supply while the recently developed part of the town has better provision of urban green space (Table 6 and Fig. 4). In line with this, Azagew and Worku (2020) found that the inner sub-cities of Addis Ababa city have a small amount of urban green infrastructure. However, in developed countries, studies revealed that the availability of higher green space in the inner city (Dobbs et al., 2014). The distribution of UGS was mapped for the town in general, the inner city, and its outer part (Fig. 5a, 5b, and 5c).

Table 6
Urban green space availability per Kebele

Kebele	Name	Area	%	Kebele	Area	%
1	None-Vegetated	853.04	89.61	2	231.07	87.68
	Small Shrubs	92.47	9.71		29.6	11.23
	Green Space	6.44	0.68		2.88	1.09
	Total	951.95	100		263.54	100
3	Non-Vegetated	148.7	79.19	4	255.3	84.72
	Small Shrubs	33.62	17.9		43.95	14.58
	Green Space	5.45	2.91		2.1	0.7
	Total	187.77	100		301.35	100
5	None-Vegetated	126.89	67.81	6	202.13	84.54
	Small Shrubs	56.32	30.09		29.93	12.52
	Green Space	3.93	2.1		7.03	2.94
	Total	187.14	100		239.09	100
7	None-Vegetated	1712.41	78.76	8	419.79	87.45
	Small Shrubs	415.12	19.08		51.48	10.72
	Green Space	46.9	2.16		8.79	1.83
	Total	2174.43	100		480.05	100
9	Non- Vegetated	767.3	82.92	Town	4716.6	82.6
	Small Shrubs	152.93	16.56		905.12	15.85
	Green Space	4.78	0.52		88.31	1.55
	Total	925.01	100		5710.33	100

The comparative analysis of UGS for the inner part of the town and its periphery shows a continuous increment of small vegetation towards the town boundary. In contrast, the coverage of high vegetation shows insignificant reduction towards the periphery (Fig. 5d). Likewise a study by Woldesemayat and Genovese (2021) affirmed that inner parts of the urban centers in developing countries have low supply of UGS, which increases towards the peripheries.

Furthermore, green space density was calculated for each kebele. Green space density is the ratio of green space and the total area of reference surface. The result revealed that kebeles 05, 07, and 03 have higher urban green space density with respective values of 0.32, 0.21, and 0.21 (Fig. 6, Table 7). The high UGS density in Kebele 05 is mainly ascribed to its less suitability for urban development due to the rugged topography of the area. In this regard, slope steepness and terrain irregularity positively influences the extent of green space coverage and their quality (Davies et al., 2008).

Table 7
UGS density per kebele

Kebele	Kebele area (ha)	Urban Green Space (ha)	Green Space Density
1	951.95	98.91	0.1
2	263.54	32.46	0.12
3	187.77	39.07	0.21
4	301.35	46.02	0.15
5	187.14	60.25	0.32
6	239.09	36.96	0.15
7	2174.43	462.02	0.21
8	480.05	60.27	0.13
9	925.01	157.59	0.17
Total	5710.33	993.55	0.17

3.3 Urban green space availability in terms of land use

The amount of urban green space in each land use was analyzed using land use plan of the town and the NDVI classification result. According to this analysis, in the inner part of the town the service, green area, and vacant land are the first three largest land uses with 30.12%, 30.06%, and 13.2% of UGS coverage respectively. In this part of the town recreation, commercial, and administration land uses are least supplied with a UGS share of 0.11%, 0.26%, and 0.40% correspondingly (Table). Although recreation land use is expected to have better UGS supply, unexpectedly it has the smallest (0.11%) UGS share. In addition, there is only 30% agreement between green area on the land use plan and our NDVI analysis result. Thus, 70% of green space on the land use plan has not yet developed as of planned (Table 8). This exposes the seriousness of the problem on land use planning and its implementation. Moreover, it indicates underperformance of the town municipality in UGS supply and development.

Table 8
UGS availability in each land uses

	General		Inner		Outer	
Land use name	UGS Area(ha)	%	UGS Area(ha)	%	UGS Area(ha)	%
Admin	1.29	0.13	1.29	0.40	0.00	0.00
Manufacturing	29.35	2.95	29.35	9.13	0.00	0.00
Mixed	1.38	0.14	1.38	0.43	0.00	0.00
Residence	34.42	3.46	34.42	10.70	0.00	0.00
Road	11.53	1.16	11.53	3.59	0.00	0.00
Service	96.87	9.75	96.87	30.12	0.00	0.00
Special function	2.37	0.24	2.37	0.74	0.00	0.00
Water Body	3.67	0.37	3.67	1.14	0.00	0.00
Vacant land	42.83	4.31	42.83	13.32	0.00	0.00
Urban Agriculture	671.95	67.63	0.00	0.00	671.95	100.00
Recreation	0.36	0.04	0.36	0.11	0.00	0.00
Green area	96.68	9.73	96.68	30.06	0.00	0.00
Commercial	0.84	0.08	0.84	0.26	0.00	0.00
Total	993.55	100.00	321.60	100.00	671.95	100.00

Furthermore, most of the green areas in our finding are informal greenery. Hence, our evaluation of UGS supply shows significant amount of informal greenery which is planned as vacant land (13.32% of the vacant land is informal green) (Table 8). Those informal greens will be converted to other land uses such as commercial, residential, manufacturing etc. Hence, the current informal green space may not be available in the near future with the horizontal expansion of the town. In agreement with this, in most cases there is reduction of green spaces when urban centers expand towards the peripheries (Shen et al., 2017; Azagew and Worku, 2020). Similarly, continuous urbanization and suburbanization together with the growing infrastructure development causes a constant decrease and severe fragmentation of green landscapes (Van Herzele and Wiedemann, 2003).

3.4 Urban Green space supply evaluation

The performance of town municipality in UGS supply was evaluated against the new urban planning strategy of Ethiopia (30% coverage) and World Health Organization standard (9m^2 per person). In terms of areal coverage, small vegetation covers 15.85% while the share of high vegetation is about 1.55%. This finding indicates under performance of Debre Berhan town in realizing the new urban planning strategy of the country. Our UGS supply evaluation was done for both small vegetation (Shrub & grass land areas) and high vegetation (Temperate and tropical urban forest). According to our analysis result, the UGS per capita for small vegetation was about 75.16m^2 while the value for high vegetation was 7.33m^2. With reference to the WHO standard, the UGS supply in the town is below the expected amount for high vegetation whereas the per capita for small vegetation is above the WHO standard (Table 9).

Table 9
UGS per capita

SN	UGS class	UGS m^2	UGS per Capita
1	Small Vegetation	9050088	75.1675
2	High vegetation	883165	7.33532
3	Total	9933253	82.5028
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In this research work we also evaluated the change in UGS supply by generating buffer distance from the CBD. According to the result, the first 1km^2 buffer areas from the CBD has the smallest share of UGS availability and the largest UGS supply gap. Generally with some irregularities there is an increment of UGS supply from the CBD towards the peripheries. (Fig. 7).

4. Conclusion

Based on the land use plan of the town, in its inner part Debre Berhan has 13 land use types of which residential land use covers the highest share (28.02%). The share of green space in the town land use plan is about 2.19% which is by far below the new urban planning strategy of Ethiopia (30%). The small share of urban green space in the land use plan of the town indicates planning gap in UGS provision and development. The NDVI calculation from Sentinel 2 and its classification result shows the availability of informal green space which is not incorporated in the land use plan of the town. Thus, the result suggests a mismatch between UGS on the land use plan and UGS in reality. The UGS availability analysis result asserted that the old part of the town (kebele 01 and 02) has a minimum supply while the recently developed part of the town has relatively better provision of urban green space.

In the inner part of the town the service, green area, and vacant land uses are the first three largest land uses with 30.12%, 30.06%, and 13.2% of UGS coverage respectively. In this part of the town recreation, commercial, and administration land uses are least supplied with a UGS share of 0.11%, 0.26%, and 0.40% correspondingly. Although recreation land use is expected to have better UGS supply, unexpectedly it has the smallest (0.11%) UGS share. In addition, there is only 30% agreement between green area on the land use plan and our analysis result. Furthermore, most of the green areas in our finding are informal greenery which will be converted to other land uses in the near future. UGS supply evaluation result based on the national and WHO standards affirmed underperformance of the town municipality in achieving expected UGS provision and development. Thus, considering all these issues the concerned planning department is expected to revise the existing land use plan specifically in relation to urban green space provision and supply.

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Availability of data and material (Not applicable)

Code availability (Not applicable)

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Figures

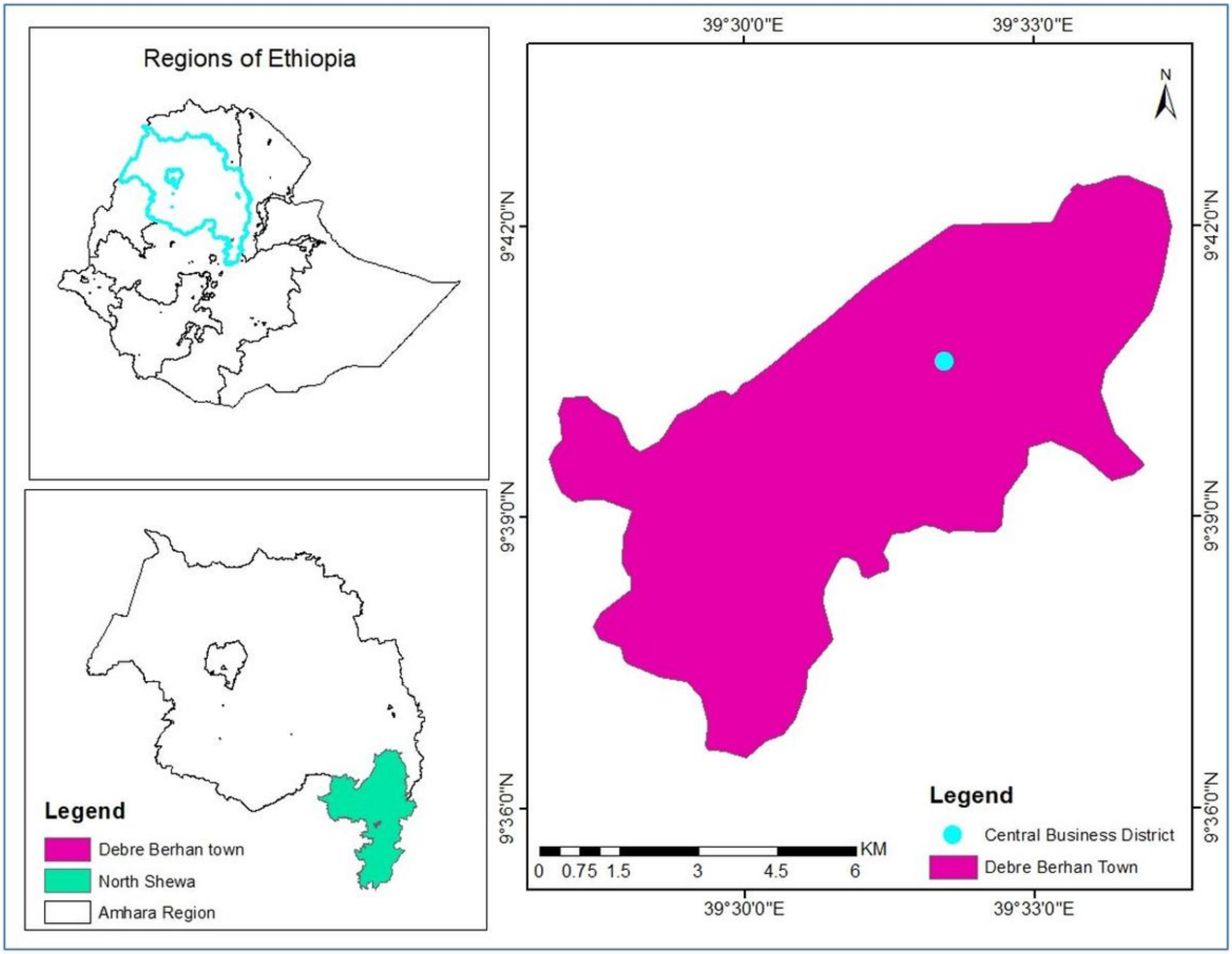


Figure 1

Location Map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

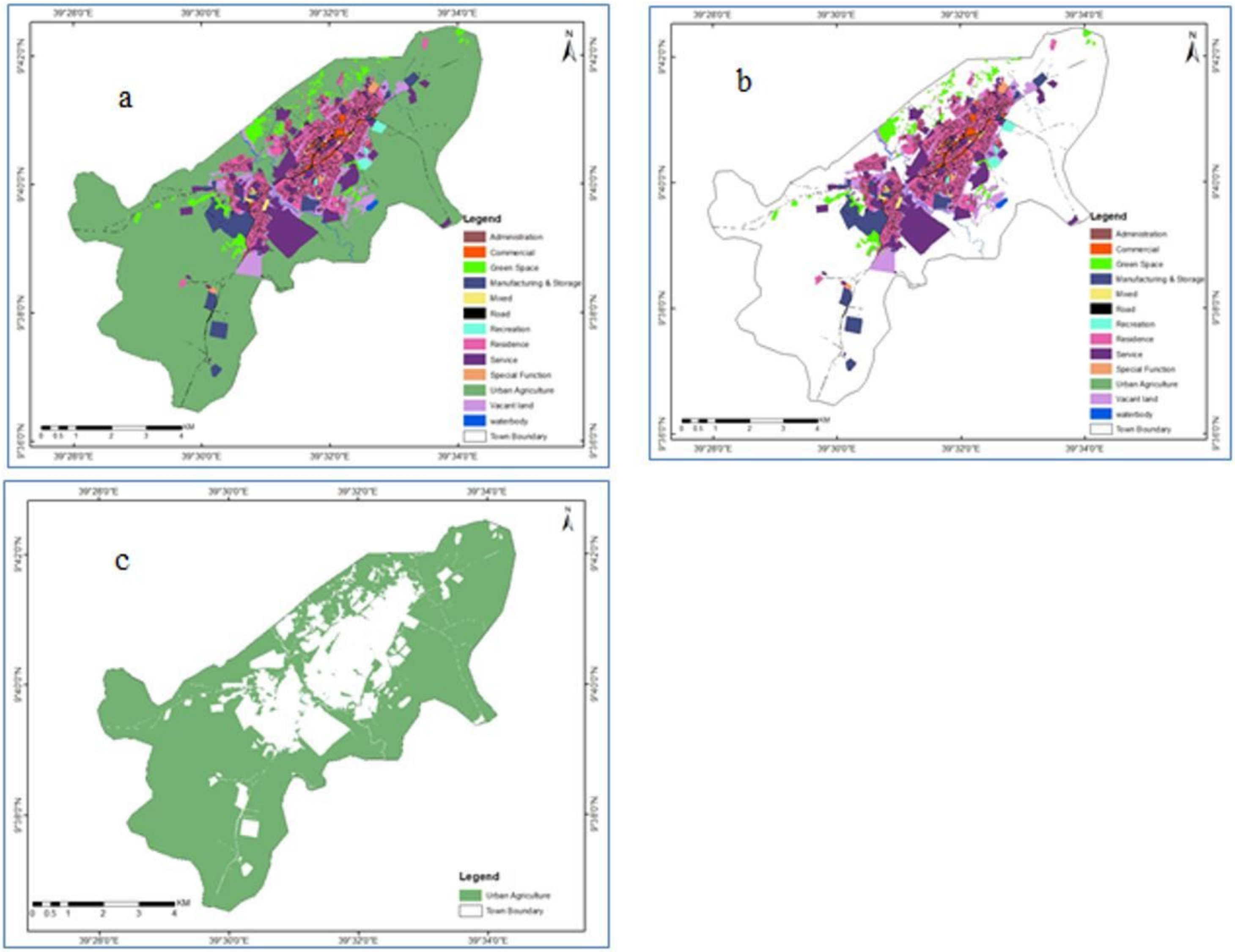


Figure 2

Land use composition (a is general composition, b is inner composition and c is outer composition). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

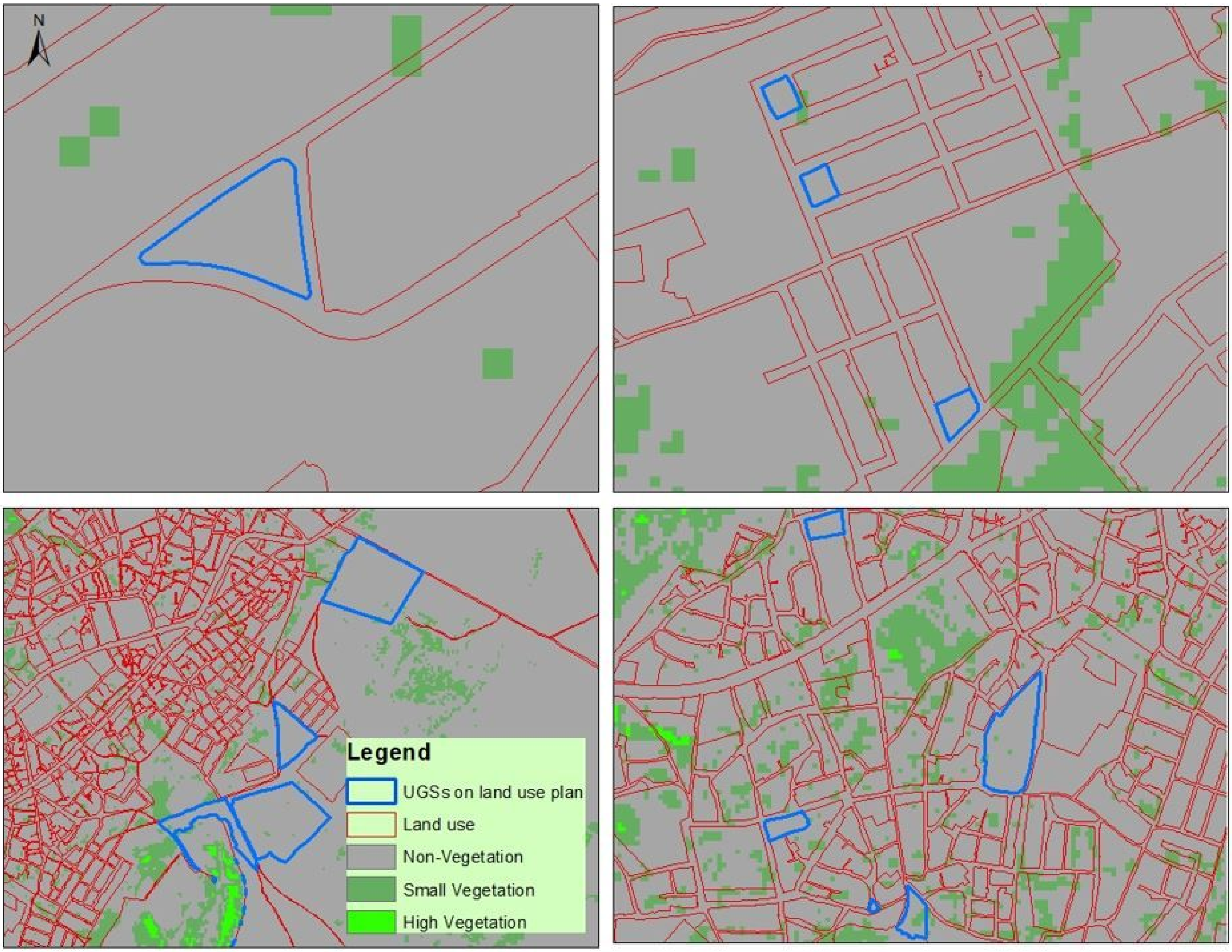


Figure 3

Mismatch between UGS on the land use plan and reality

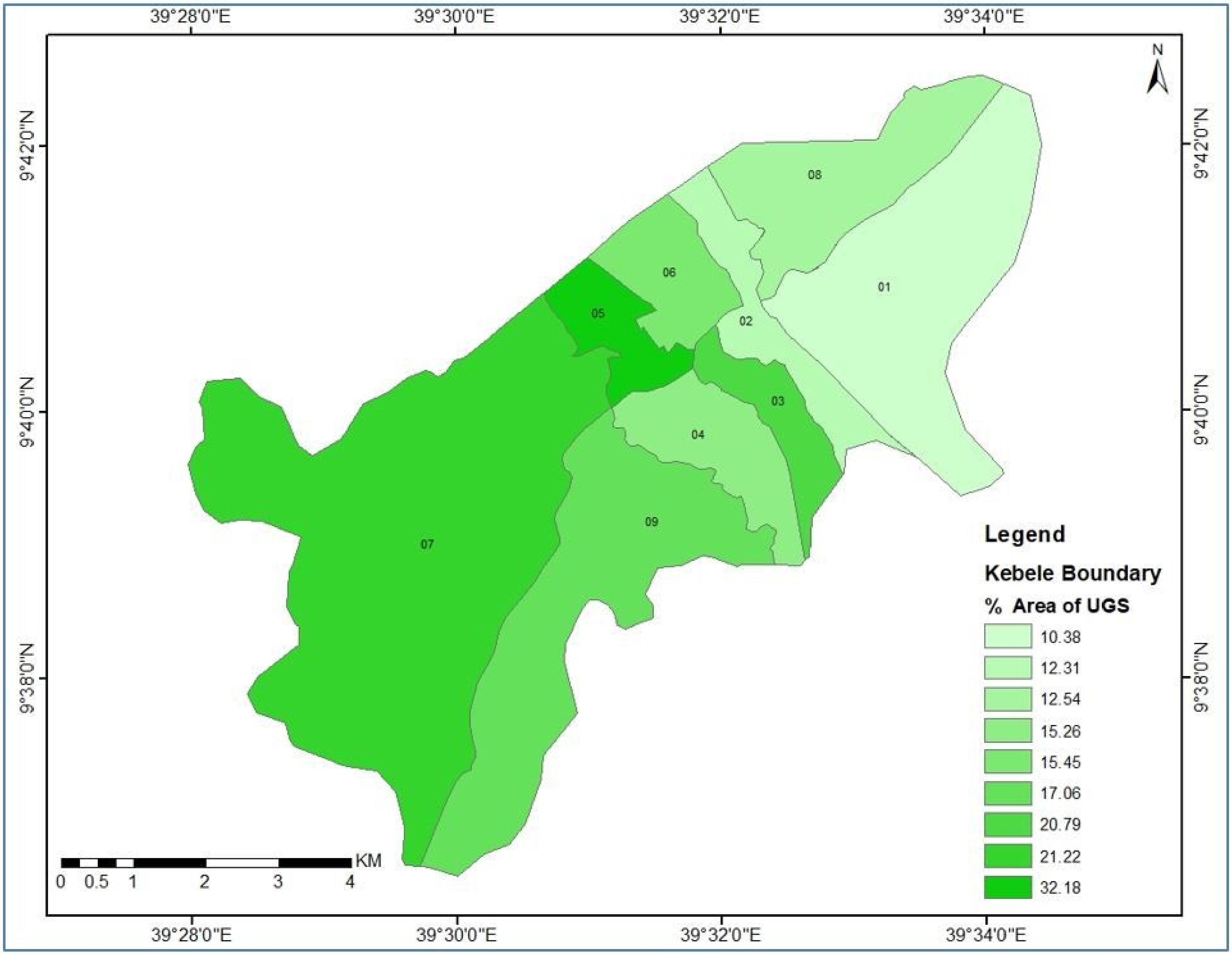
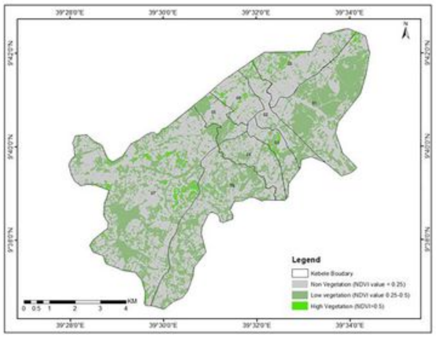
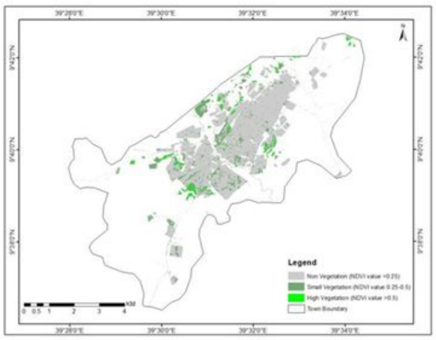


Figure 4

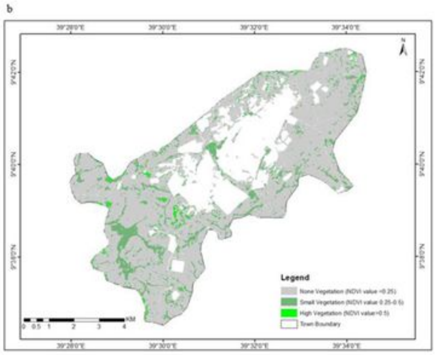
UGS availability index map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



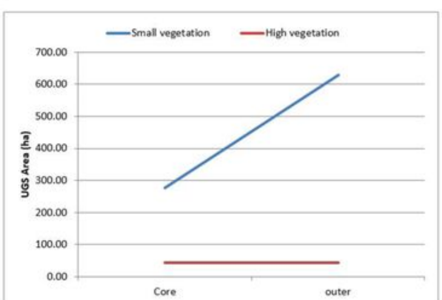
a



b



c



d

Figure 5

Green space availability; where a is general availability map, b is core availability map , c is outer availability map, and d is change of UGS availability from core to outer areas. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

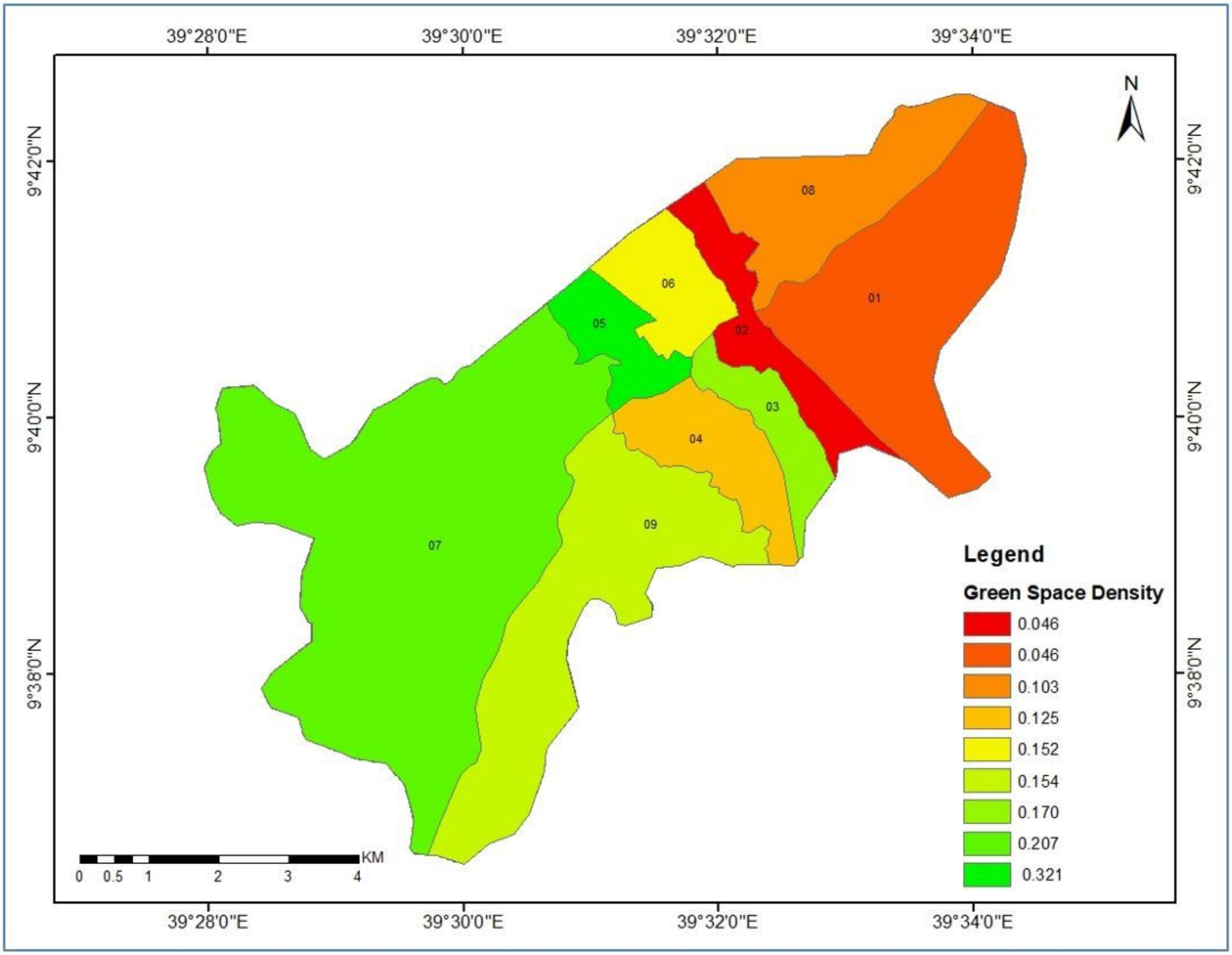


Figure 6

UGS density map. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

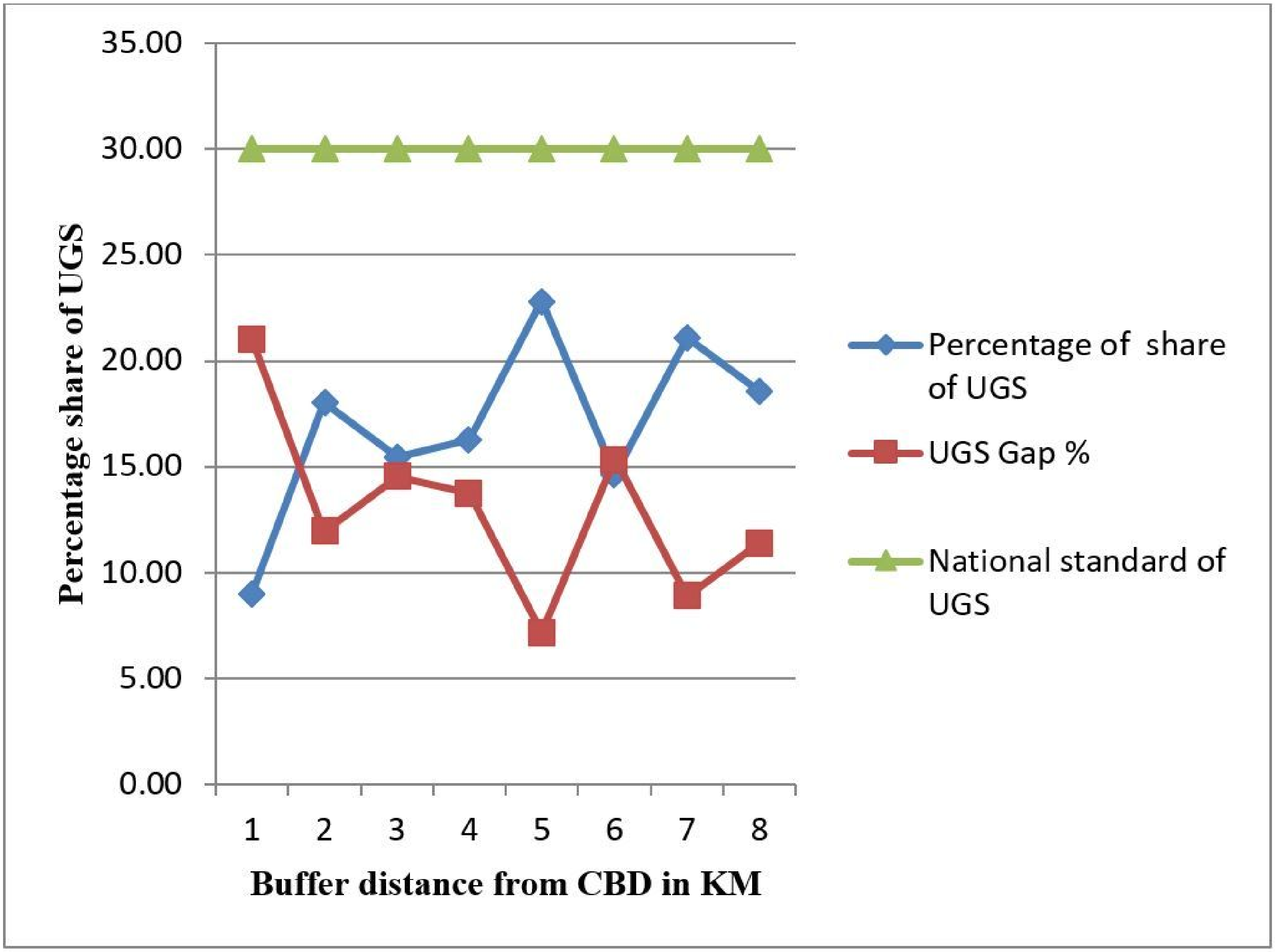


Figure 7

Availability and gap of UGS