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URBAN GREEN SPACE PLANNING AND DEVELOPMENT IN URBAN CITIES USING GEOSPATIAL TECHNOLOGY: A CASE STUDY OF NOIDA

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ABSTRACT

Urban planning, with special attention to green space development, offers a relatively simple and low-cost solution to the impacts of climate change and urbanization faced by urban centres. The present work examines the spatial variability of availability of adequate sites for the development of urban green amenities in Noida city. Multi-criteria assessment of potential locations has been accomplished using Analytical Hierarchical Process coupled with geospatial technology. Urban land use, physiographic factors (slope and elevation), accessibility (proximity to roads), and presence of grey, green and blue amenities (Normalised Difference Built-up Index, Normalised Difference Vegetation Index and proximity to water bodies, respectively) are the seven key criteria used to derive the final green space suitability map. A total of 46.47 % of the land was found to be in the category of highly and moderately suitable for greening the city, highlighting the potential of developing different forms of green spaces in the area. Such holistic city scale analysis of availability of potential sites for green space development can be utilised by the city administrators and urban planners for future land use planning and improving the distribution and spatial connectivity of the green spaces in the city with the common goals of better health, a cleaner environment, and climate change mitigation.

Keywords: Analytical Hierarchy Process; Land use suitability; Pairwise comparison; Noida; Urban green spaces; Urban planning

INTRODUCTION

The urban green spaces (UGS) are the lungs of urban centers (Haq, 2001) and an essential component of a city’s environment. They are of critical significance as they are vital suppliers of multitude of ecosystem benefits and ameliorate the lives of the city dwellers (Velasco *et al.*, 2016). Therefore, UGS play a pivotal role in promoting urban dwellers' physical, social, and mental health.

Increasing urban population has threatened the existence of the urban green spaces (Roy, 2019). Other forms of urban land use compete with the existing green amenities leading to their encroachment and conversion (Brune, 2016; Ostoic *et al.*, 2017). Urban centers are usually warmer than their surrounding regions because of a number of factors like urban geometry, heat retaining construction material, and anthropogenic activities. These thermal anomalies are further amplified in the cities because of deficiency of natural cooling influences, such as water bodies and green spaces (IPCC, 2021). With present climatic changes, the significance and functionalities of the UGS have become all the more important. The first part of the solution to such increasing thermal aberrations in cities is to maintain the existing UGS and second is to augment them where ever possible (Gill *et al.*, 2007; Sturiale & Scuderi, 2019). Identifying appropriate locations within the city for developing and designing green spaces is the first important step towards this objective (Ramaiah, & Avtar, 2019). So, it is imperative that green spaces should be planned and designed at appropriate locations at accessible distances in order to make the most of the benefits provided by them to the urban residents and their environment (Giles Corti *et al*., 2005).

Land suitability analysis is a GIS based method of land assessment that aids in evaluating the adequacy of a specific location for a defined land use (Yohannes & Soromessa, 2018). The process involves a systematic and hierarchical approach taking into account multiple criteria such as geophysical, environmental and socio-economic factors. The results of the evaluation are visually presented on a map grading areas from acceptable to unacceptable levels of suitability and suggesting the most appropriate location for the specific land use (Parry *et al.*, 2018). The results of such land suitability analysis are used for site selection for designated use, conducting impact studies and are fundamental for future land use planning. Therefore, this tool can be utilized to identify areas suitable for green spaces' planning and development in urban centers in the most efficient manner (Govindarajulu, 2014).

A large body of work exists on land suitability analysis for various land uses such as crop suitability analysis for a region (Mugiyo *et al.*, 2021; Mistri & Sengupta, 2020), rangeland suitability (Jafari & Zaredar, 2010), finding suitable locations for developing public parks (Chandio, 2011), UGS planning (Uy & Nakagoshi, 2008; Gelan *et al.*, 2021; Pokhrel, 2019), suitability analysis for afforestation in arid regions (Kadam *et al.*, 2021), identifying potential irrigable land (Mandal *et al.*, 2018), studying sites for agroforestry (Nath *et al.*, 2021), determining suitable locations for wastewater treatment (Anagnostopoulos *et al.*, 2010), optimal site selection for sanitary landfills (Sk *et al.*, 2020), analyzing tourism sites (Liaghat *et al.*, 2013), etc. There are a number of approaches that are used for analyzing land suitability, such as weighted overlay land use suitability analysis, weight of evidence, logistic regression, Analytical Hierarchy Process (AHP), the Delphi process, fuzzy logic and simulation models.

Multi-criteria decision-making using Analytical Hierarchy Process (AHP) is widely used in regards to the suitability investigation of various land uses (Leal, 2020). AHP, developed by Thomas Saaty (1980), aids in decision-making when solving multiple criteria spatial problems. Weights or values are assigned to individual criteria and pairwise comparisons are then made to construct a hierarchical decision tree for evaluation of the adequacy of the land use for UGS planning and development (Aburas *et al.*, 2015). Therefore, AHP was selected as the best method for creating an UGS suitability map.

Although the benefits of green spaces in cities and the need to expand them to maximize their benefits is widely researched and documented in India (Singh, 2018; Ramaiah, & Avtar, 2019; Sen & Guchhait, 2021), but land suitability analysis particularly for UGS planning has not been done for many Indian cities except for Srinagar, Jammu & Kashmir (Parry *et al.*, 2018), and Ranchi, Jharkhand (Ahmad & Goparaju, 2016). Hence, this research gap calls for new research focusing towards UGS planning and development in fast urbanizing Indian cities. Therefore, this study attempts to quantify and identify potential locations for developing UGS in the Noida city using AHP, which is a multi-criteria suitability analysis for site selection.

STUDY AREA

The present work is focused on NOIDA (New Okhla Industrial Development Authority) which is one of the biggest Industrial Townships of Asia and situated very close to the national capital Delhi (Fig. 1). Also called the satellite city of Delhi, it was shaped under the U.P. Industrial Area Development Act, 1976 with the primary motive to decongest the national capital and set up an industrial area. Today, it remains as an advantageous landmark with smooth and wide roads, well developed infrastructure, excellent amenities, and tall skyscrapers surrounded with greenery. Other than these, presence of several industries, MNCs and educational institutions attract more and more people to this city which is one of the primary contributing factor for the unplanned urban growth in Noida. With such fast paced urbanization and migration, there is a colossal burden on the existing green spaces in the city (Sharma *et al.*, 2021).

DATA AND METHODS

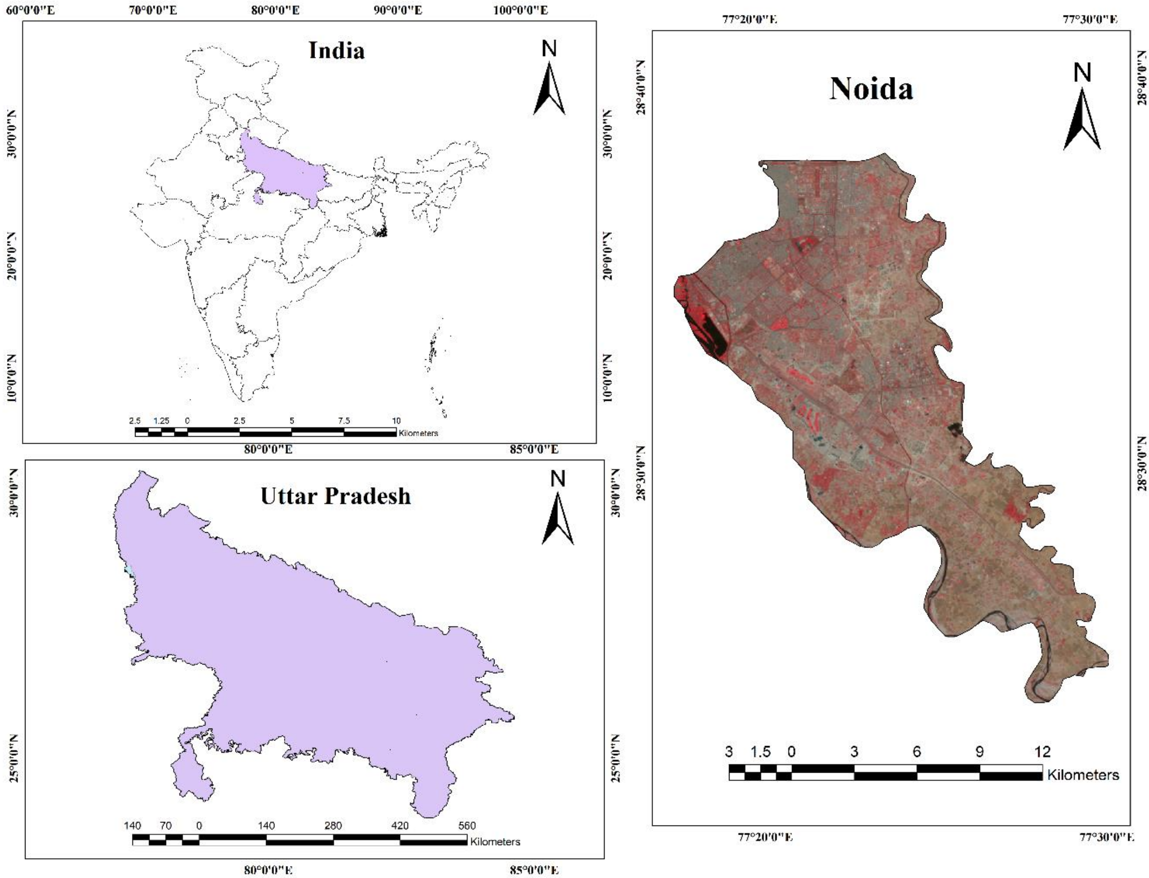
Data procuring and pre-processing

Remote sensed datasets of the year 2000 and 2019 were procured from United States Geological Survey (USGS), in Geo TIFF format having UTM projection with zone number 43 and WGS 84 datum. Detailed information of the satellite data is presented in Table 1 below. The radiometric calibration, atmospheric correction, and other pre-processing steps were done to prepare the satellite images for LULC classification and other processes.

Table 1: Imagery specifications

S. N.	Acquisition Date	Resolution (m)	Satellite	Sensor	Path	Row
1.	28.04.2019	30/100	Landsat 8	Operational land Imager LI/Thermal Infra-Red Sensor	146	40
2.		30	ASTER DEM	Global Digital Elevation Model V3		

Fig. 1: Study area



Methodology

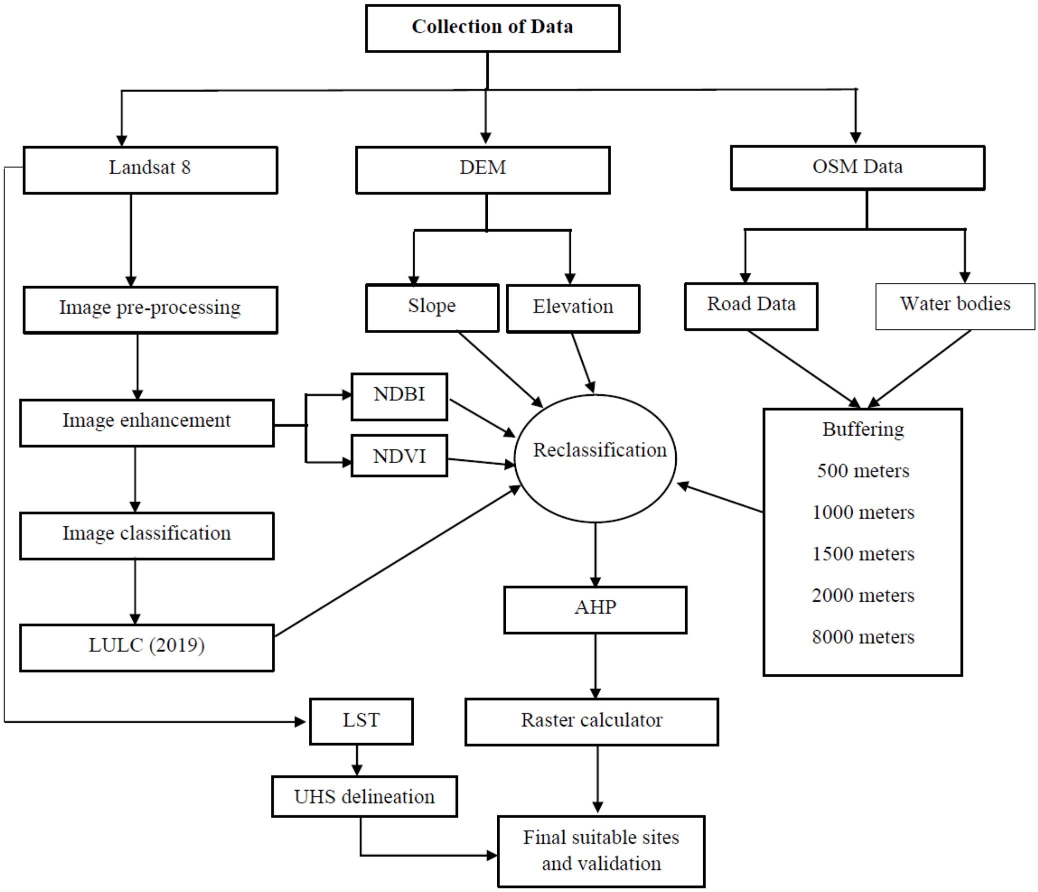
The methodology of the work is detailed in Fig. 2.

Analytic Hierarchy Process (AHP)

AHP model is one of the most popularly used method of Multi Criteria Decision Analysis (MCDA) that aids in evaluating and comparing multiple criteria (Table 2) to arrive at the best possible selection or decision. It is a systematic and structured approach that helps in solving various spatial problems by combining and restructuring geographical dataset with value judgments. The scale value and their definitions are shown in Table 3.

The AHP model uses different quantitative and qualitative factors obtained from the GIS analysis and ranks different choices on the basis of priority. Figure 3 illustrates the systematic heirarchical decision tree that is used for the identification of the potential UGS sites. The first level of the decision tree outlines the main objective which is the identecation and mapping of potential sites for UGS development in Noida. The second level lists the different quantitative and qualtitative factors weighed in the site selection process obtained from the remotely sensed data and secondary sources. The bottom most level (level 3) elucidates the different choices or the alternatives to decide upon the main objective.

Fig. 2: Methodology Flowchart



The AHP assigns rank to a large set of plausible decision alternatives derived by transforming multiple criteria onto a relative scale of evaluation. Ratio scales are derived from paired comparisons among individual as well as between the different factors. The comparisons are made using a nine point scale, where 9 represents extreme orientation, 7 represents very strong orientation, 5 represents strong orientation, and so on as shown in Table 3 until it gets down to 1, which signifies no orientation towards the alternative. Individual scores to each of the factor on the basis of pairwise comparison simplifies the decision-making process. The pair-wise comparisons of different criteria are usually arranged into a square matrix with the diagonal elements of the matrix equal to 1.

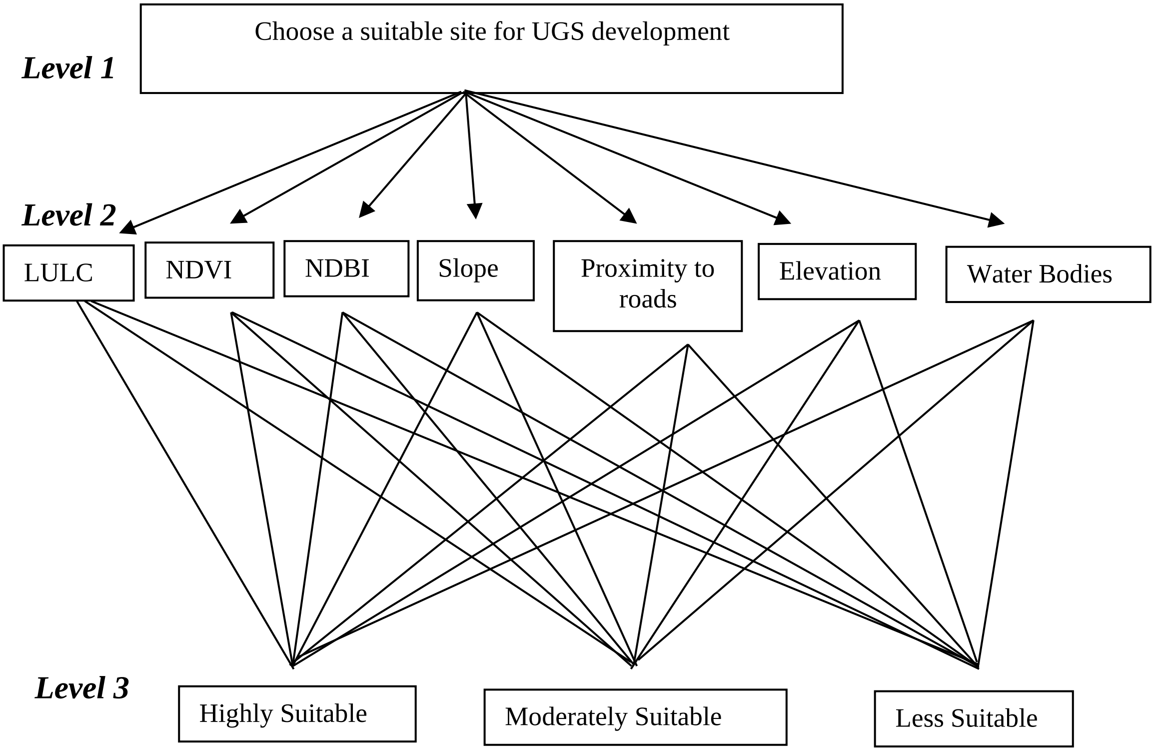
Table 2: Derivation of different criterion for AHP

S. No.	Criterion	Technique	References
1.	LULC Mapping	Maximum Likelihood Technique of Supervised classificfation	Jog and Dixit, 2016
2.	River	Open Street Map data	www.openstreetmap.org
3.	Road	Open Street Map data	www.openstreetmap.org
4.	NDVI	$\text{NDVI} = (\text{NIR} - \text{Red})/(\text{NIR} + \text{Red})$	Zha et al., 2003
5.	NDBI	$\text{NDBI} = \big((\text{SWIR} - \text{NIR})\big)/(\text{SWIR} + \text{NIR})$	Zha et al., 2003
6.	Slope	$\text{Slope} = arctan\sqrt{(fx)^2 + (fy)^2}$	(AlFanatseh, 2021).
7.	Elevation	Extract value to points from DEM Data	(Ustaoglu & Aydınoglu, 2020).
8.	LST Estimation	Mono-Window algorithm	Kumari et al., 2017
9.	Urban Hot Spot Delineation	LST > μ+2∗σ where, μ is the average and σ =Standard deviation LST (°C).	Guha et al., 2017

Table 3: Scale of Relative Importance (Saaty, 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak of one over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgement	When compromised is needed
Reciprocals of above nonzero	If activity I has one of the above nonzero number assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

Fig. 3: Hierarchical decision tree for identification of appropriate location of UGS development



Estimation of the Consistency Ratio (CR)

Consistency Ratio (CR) is defined as the ratio of Consistency Index (CI) to Random Consistency Index (RI). The value of CR shows the level of uniformity in the pair-wise comparisons. CR less than 0.10, indicates a rational level of consistency. CR greater than or equal to 0.10, indicates inconsistent judgments. In such cases, the revision of the original values in the pairwise comparison matrix is necessary. CI offers a measure of deviation from consistency given by:

$$CI = (\boldsymbol{\lambda} - \mathbf{n})/(\mathbf{n} - \mathbf{1})$$

Where $\boldsymbol{\lambda}$ is the average consistency vector and n represents number of factors. RI is referred from the statistical table that is given in Table 4.

Table 4: Random Consistency Index (RI)

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Computation of Suitable locations for Urban Green Space development

Each of the criteria considered for the UGS suitability map in this study has multiple variations within it that needs to be given specific ratings or individual weights. Determination of weight of each class is the most crucial step in the integrated analysis, as the output is mostly dependent on the assignment of appropriate weights. The weighted sum overlay approach using Arc Map Spatial Analyst is adapted for integration of input data layers where the data layers are multiplied by their corresponding weights obtained from Saaty's pair-wise comparison matrix, and the same are summed up together to achieve the suitability map. Based on the total scores computed for all the parameters, the complete study area is categorized into four zones of suitability by assigning appropriate ranges of the aggregate score to each suitability zone. The output is then displayed in the form of a suitability map for green space development showing four zones indicating the highly suitable, moderately suitable, less suitable, and not suitable zones, respectively.

RESULTS

Land use/land cover (LULC)

Supervised classification has been carried out on the satellite dataset by taking appropriate training signatures for broad LU/LC classes viz., built-up (50.47 %), vegetation (28.18 %), agriculture (13.08 %), barren (6.07 %), and water (2.19 %). The classified outputs and the results of the land use/land cover are given in Figure 4. Accuracy was assessed and the classified dataset has overall accuracy of 94 % in 2019. The highest kappa coefficient is observed as 0.90.

Fig. 4: LULC map of Noida for year 2019

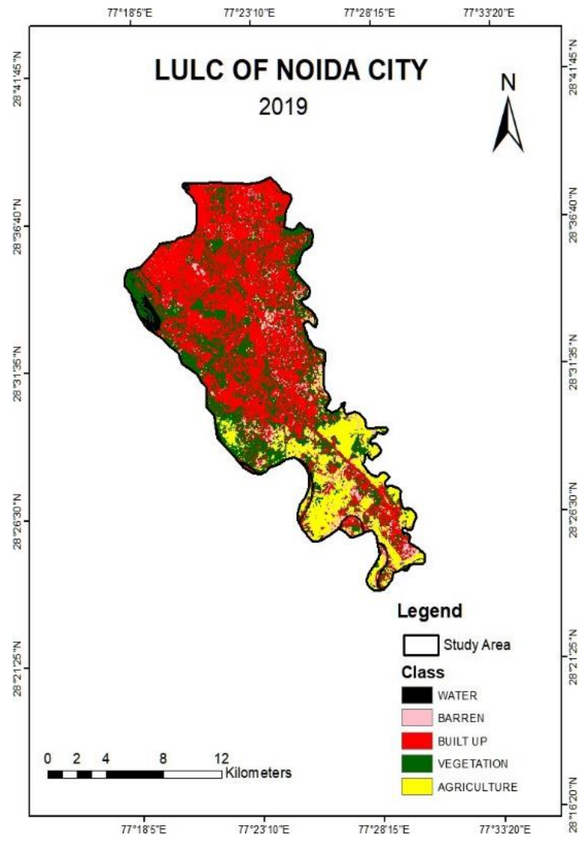


Table 5: LULC of Noida

S. N.	Classes	Area in sq.km.	% of total area
1	Agriculture	27.68	13.08
2	Barren	12.84	6.07
3	Water	4.64	2.19
4	Built Up	106.77	50.47
5	Vegetation	59.61	28.18
	TOTAL	**211.54**	**100**

Table 6: Different Variables and their Suitability

S. No.	Variables	Classes	Value	Level of Suitability
1	Road Buffer (km)	1	1	S_3
		2	2	S_2
		3	3	S_1
		>4	4	S_0
2	River Buffer (km)	1	1	S_3
		2	2	S_2
		3	3	S_1
		>4	4	S_0
3	NDBI	-0.483 - -0.182	1	S_3
		-0.182 - -0.104	2	S_2
		-0.104 - -0.041	3	S_1
		-0.041 - 0.254	4	S_0
4	NDVI	0.610 – 0.295	1	S_3
		0.295 – 0.202	2	S_2
		0.202 – 0.112	3	S_1
		0.112 - -0.155	4	S_0
5	Slope	0-2.07	1	S_3
		2.07-3.92	2	S_2
		3.92-6.86	3	S_1
		6.86-27.77	4	S_0
6	Elevation	168-195	1	S_3
		195-199	2	S_2
		199-203	3	S_1
		203-232	4	S_0
7	LULC	Vegetation	1	S_3
		Barren	2	S_2
		Agriculture	3	S_1
		Water/ Built Up	4	S_0
*S_0 Not suitable; S_1 Less Suitable; S_2 Moderately Suitable; S_3 Highly Suitable				

Reclassified parameters

Reclassification of the different thematic parameters considered for site suitability to generate four classes was done through histogram equalization, and each class was assigned suitable importance value on the scale of 1 to 4 (Table 6). The importance values were assigned to different classes of the various thematic parameters based on their influence in UGS development. For example, the area in close proximity to road, river, built-up and vegetation are highly suitable for UGS development and, conversely locations distant to these indicate comparatively less suitable sites. Following this logic, for the slope and elevation, the area with high slope and elevation is considered as less suitable in comparison to the region with less slope and elevation. The intermediate parameter values were assigned weights of 2 and 3 to the various subgroups determined through the application of histogram equalization technique.

Parameter Weights

Considering the factors favoring UGS of the area, pairwise comparison was performed using the pairwise comparison matrix (Table 7). The obtained CR value indicates a reasonable level of consistency in the pairwise comparisons (Table 8). Using this method, the weightings are interpreted as the average of all possible ways of comparing the criteria. The weightage allotted for each parameter for the study area is presented in Table 9 with NDVI having the highest weightage followed by LULC, NDBI, Proximity to Roads, Slope, Elevation, and Proximity to Waterbodies having the least weight.

Table 7: Pairwise Comparison Matrix

FACTORS	LULC	PR	SLOPE	ELEVATION	PWB	NDBI	NDVI
LULC	1	3	5	6	6	3	0.5
PR	0.333	1	2	3	3	1	0.333
SLOPE	0.2	0.5	1	2	2	0.5	0.2
ELEVATION	0.167	0.333	0.5	1	1	0.5	0.167
PWB	0.143	0.333	0.5	1	1	0.333	0.167
NDBI	0.333	1	2	2	3	1	0.5
NDVI	2	3	5	6	6	2	1

Table 8: Consistency Index and Ratio

λ	7.139
CI	0.03
CR	0.017
RI	1.32

Table 9: Computation of the Criterion Weighting

Layer Name	Weight
NDVI	0.323
LULC	0.282
NDBI	0.12
PR	0.118
SLOPE	0.069
ELEVATION	0.045
PWB	0.043

Overall suitability map

As per the overall suitability map (Figure 5), there are small patches of high suitable zones throughout the study area, with larger patches around the western boundary, southern and south-eastern part of the city for UGS expansion. Based on the Figure 6, out of the total area of Noida, about 24.62 % (59.92 sq. km) and 21.85 % (46.22 sq. km) of the city area falls under the highly suitable and moderately suitable category, respectively. On the other hand, approximately 27.04 % (58.04 sq. km) and 26.09 % (55.20 sq. km) of the city is categorized as less suitable and not suitable for UGS development. There is large scope of UGS development in the city with ample availability of space (46.47 % of the city's land area) suitable for greening the city.

DISCUSSION

Noida city has witnessed fast paced conurbation during the last two decades. The city master plan of 2011 (revised in 2006) for the perspective year of 2021 proposed a total of 14,964-ha land for the development of urban activities, of which 61.61 % of total proposed land is reported to have been already developed. For example, construction of Yamuna Expressway, Noida metro, Indian motor racing circuit, Faridabad–Noida–Ghaziabad Expressway, the Rashtriya Dalit Prerna Sthal and Green Garden, and a number of residential and commercial spaces. Such rampant urbanization in the city has left little room for green area development in the recent past. Therefore, multi-criteria decision analysis using GIS based AHP is a potential tool for proposing suitable sites for the planning and development of green spaces in urban centers.

Urban Land use based Suitability

The present land use land cover is an important criterion when deciding for an adequate location for the development of UGS (Liu *et al.*, 2014). In this study, the suitability of different land uses has been identified based on their use type. Land under vegetation were considered to be highly suitable followed by barren land being moderately suitable, agricultural land less suitable and, built up and water bodies combined were considered not suitable for green space allocation. A large area of the city is less suitable for green space development in the existing situation, which covers 27.44 % of the area and 26.09 % is unsuitable for UGS development, respectively. The selected areas are mostly categorized under the barren land, agricultural area, roadside and bank of the waterbodies in the LULC map of the city.

Physiographic suitability

Low-incline zones are profoundly appropriate for the advancement of UGS as it will determine the soil characteristics and rate of erosion. Accordingly, gentle slope is regarded as highly suitable than the land with a steep slope (AlFanatseh, 2021). The slope value 0 to 2.0 is considered as flat and highly suitable (18.37 %) and up to 3.92 as gentle slope and moderately suitable (38.55 %). Whereas 3.92 to 6.86 is considered as less suitable (39.11 %) and lastly 6.86 to 27.77 and above is marked as steep slope and not suitable for developing green spaces (3.97 %). Although the city has a gentle slope from north west to south east, still high suitability regions are mostly observed in the southern parts as a number of patches of agricultural and barren lands are available in this zone of the city only.

Fig. 5: Final Suitability Map for Urban Green Spaces

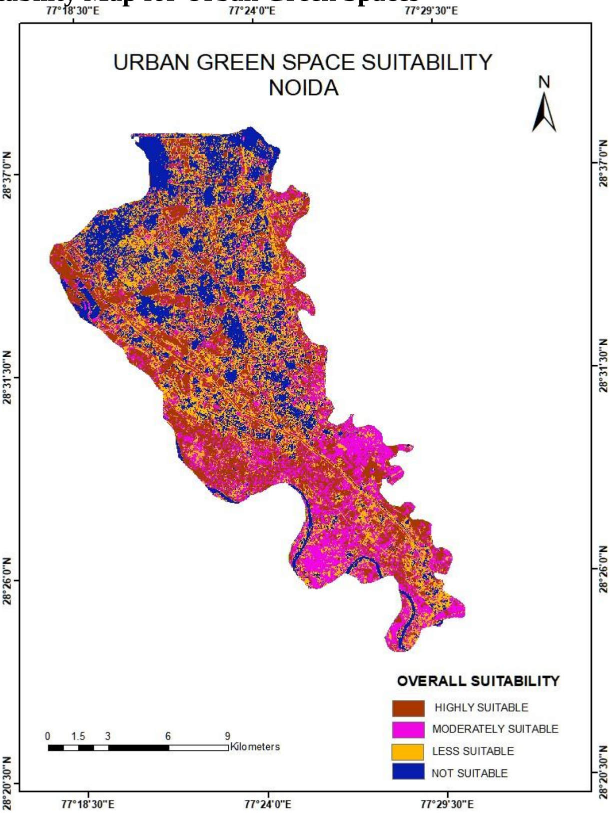
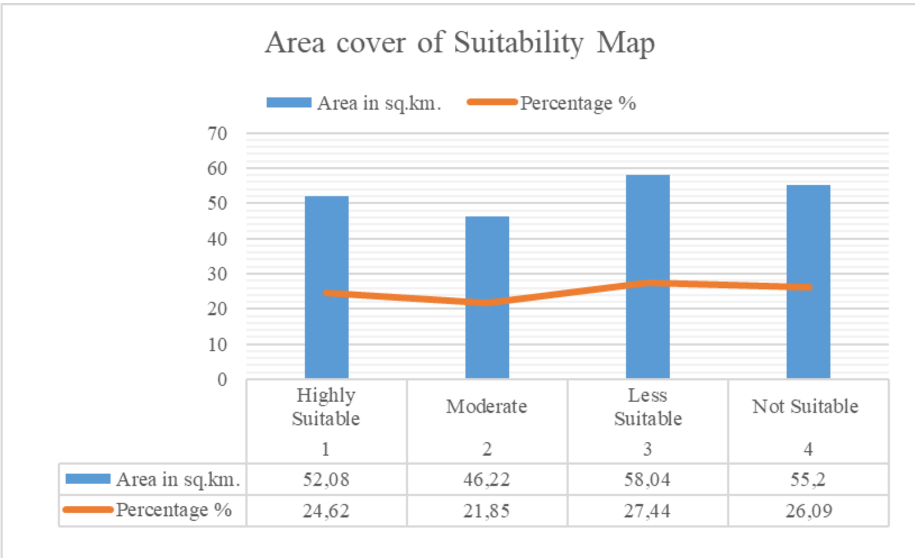


Fig. 6: Area cover of suitability map for Noida city

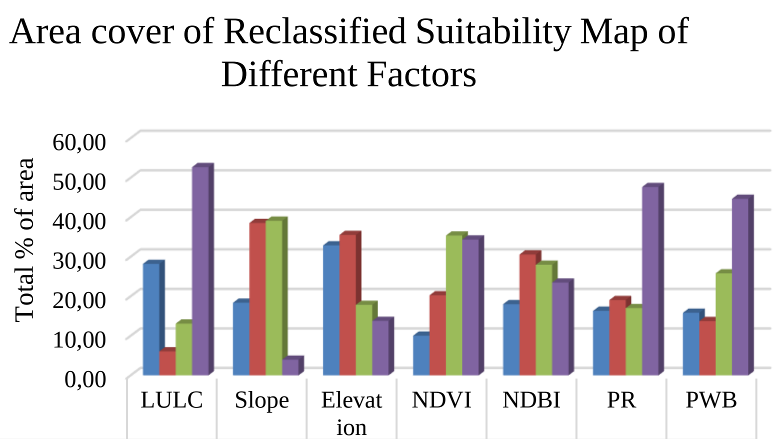


In choosing appropriate site for UGS, elevation also has a likewise important contribution and ought to be considered as one of the factors. Elevation affects the amount of solar insolation, temperature, and wind in the region (Ustaoglu & Aydınoglu, 2020). Based on the data obtained from literature reviews of different research papers, the heights between 168-195 m, 195-199 m, 199-203 m, and 203-232 m in this study area were considered as highly suitable (32.88 %), moderately suitable (35.52 %), less suitable (17.84 %) and not suitable (13.77 %), respectively (Fig. 8). Most part of Noida territory is under 200 meters mean ocean level as Noida is situated at the absolute bottom corresponding to its encompassing regions and the overall level of the space is lower than the high flood level of river Yamuna.

Accessibility based suitability

The road proximity assumes an indispensable part in giving the green space users the access to the nearby green territories around them (Abebe *et al.*, 2017). Green spaces having close proximity to roads within 1-2 km are preferable and ideal. Approximately 47 % of land was unsuitable for green space development with distance from roads equal to or more than 4 km (Fig. 7).

Fig. 7: Area Cover of Reclassified Suitability Map of Different Factors



	LULC	Slope	Elevat ion	NDVI	NDBI	PR	PWB
Highly Suitable	28,18	18,37	32,88	10,04	18,00	16,33	15,83
Moderately suitable	6,07	38,55	35,52	20,26	30,57	19,05	13,73
Less Suitable	13,08	39,11	17,84	35,36	27,97	17,01	25,79
Not Suitable	52,67	3,97	13,77	34,34	23,47	47,62	44,65

Grey, green and blue amenities based suitability

Presence of grey, green and blue amenities is also one of the most important determining factor for UGS siting. Sites with low NDBI values were re-classified in the image as suitable (48.56 %), and regions with higher percentage of built-up (NDBI close to 1) were marked as not suitable areas (51.44 %) for green spaces. Northern part of the city has a very high concentration of built up, and therefore highly unsuitable for any further green space augmentation.

NDVI is one of the most commonly used index to study vegetation of an area. This criterion has the highest weightage and one of the key factor to assess the suitability of land for green space development. In reference to Fig 4 and 5, it is evident that a large part of the highly suitable locations for potential green space development lies in the vicinity of existing green areas in the city. Of the total area of the city, only 10.04 % of land was found to be highly suitable for development of urban green amenities. 30.30 % is classified as suitable and 69.70 % is regarded as unsuitable for UGS development.

Presence of blue amenities near to green spaces influence the overall quality of the soil and in turn the green space. It also reduces the overall cost incurred on irrigation of such spaces. Distances less than 1 km and 1-2 km from the water bodies considered to be highly and moderately suitable, respectively were found to be only 29.56 % around the north-western boundary as the city is surrounded by Yamuna River in the north and northwest periphery (Fig. 7).

Overall land suitability

For a total area of around 211.54 km^2, approximately 46.47 % of the land was found to be suitable for developing UGS. Different forms green infrastructure can be designed in these identified locations for augmenting overall ecological health of the city. The northern part of the city is mostly covered with not suitable land patches as it is highly urbanized with very little or no scope for any further land use planning. Therefore, attention is needed to conserve the existing UGS in such regions to sustain the benefits obtained from them. Agricultural and barren land are available in the southern part of the city, and hence is allocated as highly suitable for green space development.

Similar study was done for Aqaba development area in Jordan city which is experiencing huge pressure of urbanization and increasing population (AlFanatseh, 2021). Land suitability analysis of Pendik district in Turkey also highlighted 24 % of land as highly suitable for green space development (Ustaoglu & Aydınoglu, 2020). Hui & Guang (2016) reported also 49.2 % of the area of a rapidly urbanizing Haikou city in southern China as suitable for UGS expansion and optimization. Another work from Changzhou city in China, also demonstrated that the high suitability region accounts for 24.14 % of the total area for urban green space augmentation (Mingrui *et al.*, 2012).

Validation and Recommendation for UGS development

To further validate the obtained suitable sites of UGS development in the city, urban hotspots were delineated using LST values, derived using mono window algorithm. The UGS site suitability image was overlaid by delineated urban hotspots (UHS). It was very evident that the identified suitable locations overlapped with the areas of high LST values or hotspots.

To visually depict the phenomenon, four land use patches were identified – barren land, agricultural land, road and water body. In figure 8A, C, E and G, the blue pixels show the urban hotspots areas while the pink pixels highlight the areas highly suitable for setting up UGS. Figures 8B, D, F and H are the corresponding Google Earth Images of the identified land patches.

Recommendations for UGS development for different land use are as follows -

i. In Figure 8B, the polygon shows a barren land patch highly suitable for UGS development and a potential UHS. Developing urban green infrastructure on such barren lands is the most optimum use of the land as it will also help in reducing the local temperature of the area.

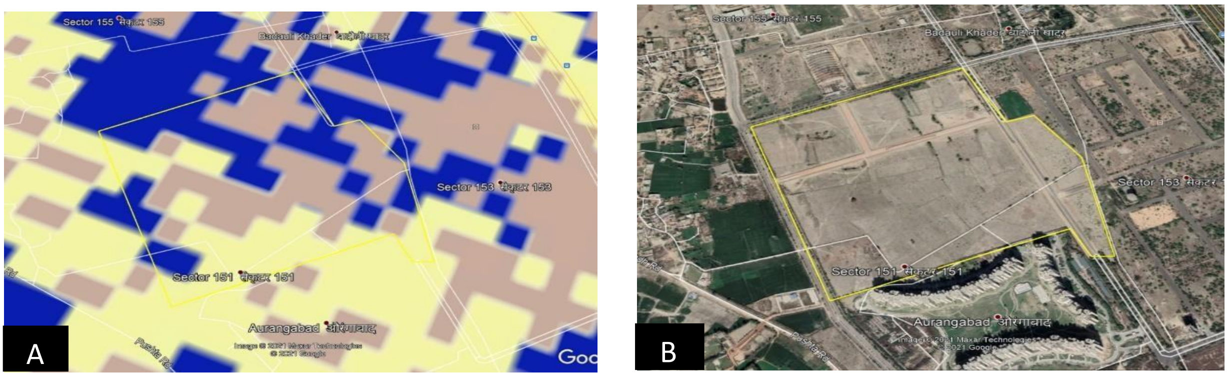
ii. In Figure 8D, the polygon shows a part of the road and its surrounding areas. The periphery and the boundary of the road can be used for avenue plantation which will add some green cover and help in reducing the local temperatures as well through shade and evapotranspiration.

iii. In Figure 8F, the polygon shows a part of the river and its surrounding areas. The periphery area of the river is one of the best sites for planting perennial trees adding to the total green cover of the city.

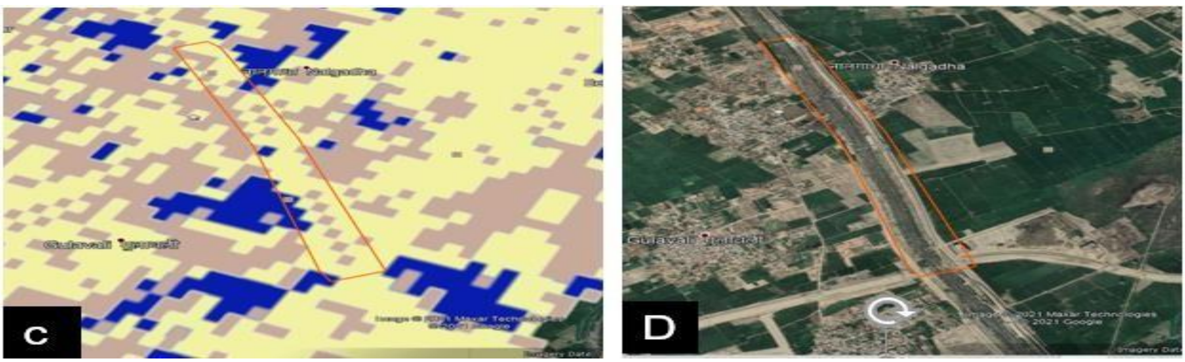
iv. In the figure 8H, polygon shows an agricultural land patch. It is suggested that agroforestry practices should be adopted on such agriculture lands so that land is not left fallow when the crops are harvested. The standing trees provide shade altering the microclimate, reduce rate of erosion, increase biodiversity and increase the overall verdancy of the region.

Fig. 8: A, C, E and G - Overlay image of sites identified for UGS development and UHS; B, D, F and H - Google Earth Images of the identified land patches

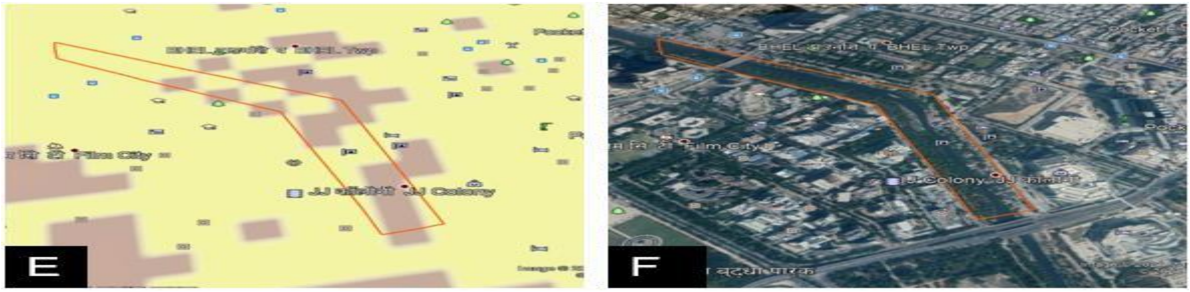
Overlay image of sites identified for UGS development and UHS **Google Earth Image**



Patch of Barren Land



Part of Road



Part of River

Patch of Agricultural land

Significance of the study

Such analyses hold great importance for city administrators and urban planners given the fact that Indian cities are rapidly expanding incessantly at the cost of degrading existing green spaces (Haaland & Bosch, 2015). The findings of the study highlight the efficiency of GIS based methods in being cost and time effective for better land use planning of a city, and aiding in the identification of adequate sites for the development of green amenities. Another advantage is that both qualitative as well as quantitative parameters are considered for site selection with objectivity and precision. Such holistic city scale analysis of available sites for UGS development is first of its kind for Noida city and the methodology provides base for such future analyses for other cities within and outside India. The methodological framework can be further modified or adapted according to the needs of either other rapidly growing cities or new towns to identify adequate locations for green space allocation.

For populous city like Noida, one of the major factors for better living quality is a greater share of land earmarked as urban green spaces. With proper planning and examination of the identified locations for potential urban green development, the urban planners and city administrators can utilize the obtained results for optimizing green space planning of the city and make decisions about allocation of land for green spaces amongst several other conflicting and competing land uses, avoiding any type of physical infrastructure development in the areas found to be highly suitable for the development of green amenities. Grey infrastructure development can be strategically apportioned in the locations identified as unsuitable for development of UGS.

Future scope

The present work can be expanded further and improved by consideration of other qualitative and quantitative parameters into hierarchical decision making. The ecological factor threshold method can also be applied to quantify the amount of green spaces required to maintain the ecological balance of the city (Mahmoud & El-Sayed, 2011). As suggested by Li *et al.* (2018), after inspecting the present status of green spaces of Noida and integrating the output of the green space suitability analysis, a network of UGS should be designed in the city, especially in regions having thermal aberrations and overall poor ecological quality. Development of UGS networks can aid in recognizing potential corridors for the improvement of ecological conditions in the city and provide a better framework for future green space planning (Kong *et al.*, 2010). Any uncertainties or limitations associated with data sources and interpretation of land cover classes due to human factor can also be addressed in future analyses (Brus *et al*.,2018).

CONCLUSION

The present work examines the spatial variability of adequate sites for the development of urban green amenities in Noida city. The composite suitability map highlights that there are several small pockets of high suitability, with larger pockets around the western boundary, southern and south-eastern part of the city for UGS augmentation. Existing green spaces in the city are mostly isolated and fragmented, limiting the cumulative benefits that can be derived from large interconnected green spaces. There is a large scope of green space development with ample availability of space (46.47 % of the city's land area) and possibility of designing interconnected network of green spaces in the sites identified as highly suitable. Such multi criteria analysis coupled with AHP and GIS provide an important tool of spatial analysis for assessing land use suitability for UGS designing and planning.

The results of the present work provide a framework of potential spatial planning of UGS development in cities worldwide especially, which are facing the challenges of inadvertent urbanization and are in need of an effective plan for incorporation of UGS in their urban planning. The findings will also aid in augmenting the resiliency and sustainability of the city by providing input to the city administrators and urban planners for future land use planning and further improve the spatial connectivity of the existing green spaces in the city, ultimately contributing to the Sustainable Development Goal (SDG) – 11. Regardless of the reality that the population of the urban centers in developing countries is expanding exponentially, there is paucity of such analyses directed towards efficient land-use planning and land suitability analysis focusing particularly on UGS development. A complete and comprehensive urban planning is in a need of a paradigm shift, focusing not only on grey infrastructure development, but all inclusive of green space development too. Such intergrated city development will provide environmental, socio-cultural, and economic benefits to its dwellers (Turaga *et al*.., 2020).

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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