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GIS Based Multi-Criteria Analysis for Urban Green Space Development: A case Study of Daltonganj Town, Jharkhand

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Abstract

GIS based spatial analysis for urban green space for specific users is very difficult to determine the suitable land resources. City administrators and urban planners have been confronting challenges in providing facilities such as urban green space because of dynamic urban growth pattern and trends. To solve this problem and identification of suitable sites for urban green space, authors have developed a model which based on GIS based multi-criteria analysis (MCA) methods. Several spatial and non-spatial datasets i.e. land use / land cover, population density, road network, river, historical place, urban utilities, park, noise influence, slope, and soil type have been generated from various secondary sources data and satellite remote sensing data in GIS environment for suitable site selection process. By using the above stated data, GIS-based multi-criteria decision analysis has been done for suitable site for development of urban green space. Based on GIS-based MCA, 9.26%, 13.67%, and 24.98% of the study area has been identified as highly suitable, moderately suitable, and less suitable for green space development respectively.

Keywords

Urban Green Space, Remote Sensing, GIS, Multi-Criteria Analysis

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1. Introduction

Due to rapid urbanization in developing world, city administrators and urban planners are faced with difficulties in supplying basic services like green space, sanitation, water supply, transportation and primary health center. Urban planners must visualize such growth during planning, policy, and decision-making. Spontaneous construction of unplanned informal houses in and beyond the administrative boundaries of towns and cities is common in developing countries. These profound changes cause a change in land use patterns which makes urban planning inevitable. Urban planning does not only cover matters of the built environment such as housing and transportation network, but also the integration of green spaces into the physical urban landscape.

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

Green spaces are land uses that are covered with natural or man-made vegetation in the built-up areas and planning areas. The meaning of the green space system has also been continuously developing with the development of city theory,

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which mainly involves horticultural, ecological and spatial meanings.

2. Study Area

The project location is situated at Daltonganj town of Jharkhand state in India. Daltonganj is a headquarters of Palamu division and Palamu district. Daltonganj is located at 24.03°N and 84.07°E. It has an average elevation of 215m (705 feet). The town is situated on the banks of the north Koel River. At the confluence of the Koel River and the Auranga River, a picnic spot i.e. Kechki situated which is about 18 Kms from the city. The famous Betla national park is located about 26Kms from the town. This park is well known for Tigers and comes under the Palamu Tiger Project. The study area lies between 24°01'21"N Latitude to 24°03'28"N Latitude and 84°03'23"E Longitude to 84°04'54"E Longitude. The study area located within the municipal boundary of Daltonganj. The study area location map is shown in Figure 1.

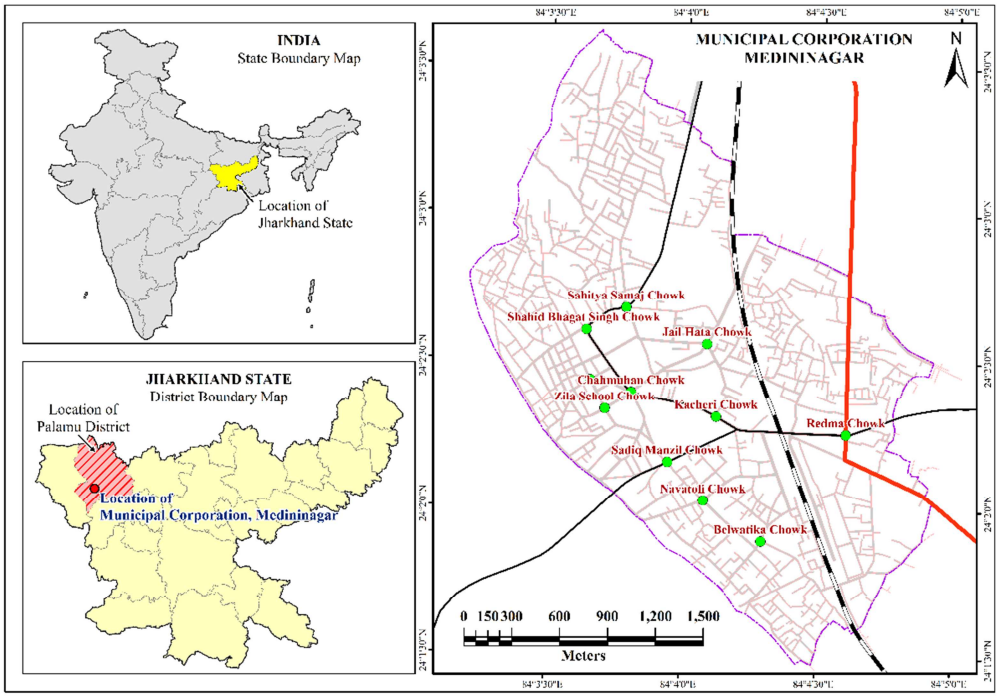

Figure 1. Location Map of Study Area.

3. Methods and Materials

As presented in Table 1, various spatial and non-spatial datasets were obtained from different organizations and processed using multiple GIS tools for mapping and analysis purposes.

Table 1. Dataset and Data Sources.

S. No.	Dataset	Sources
1.	Topographical Map	Topographical Map, Survey of India (1: 50,000) [15] 72D / 04
2.	Remote Sensing Data	Land Use Land Cover, Urban Expansion and Sprawl Mapping (2017) ResourceSAT-2 LISS-III satellite imagery [10] with 23.5m spatial resolution LandSAT-8 OLI & PAM merge satellite imagery [17] with 15m spatial resolution Digital Terrain Model / Slope Analysis CartoSAT-1 DEM [11] with 30m (re-sampled) data
3.	Geological Map	Palamu district Geological map has been collected from CGWB [3] and updated through IRS LISS-III & LandSAT-8 satellite remote sensing data with limited field check
4.	Topography	Slope map has been created using Spatial Analyst Extension in ArcGIS-10.5 software, and CartoSAT-1 (DEM) data with 30m spatial resolution
5.	Ward Boundary / Other Administrative Boundaries	Ward Gazette Notification Documents collected from Municipal Corporation, Medininagar Ward boundary has been demarked with the help of GPS and satellite imagery as well as Municipal Officers from Municipal Corporation, Medininagar
6.	Demographic Map	Census of India [2] - 2001 and 2011
7.	Soil Map	Soil map of Palamu district has been collected from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) [9] & updated through IRS LISS-III / LandSAT-8 satellite remote sensing data with limited field check

The 1st step was to set the goal or define the problem. The main aim of this study is GIS based Multi-Criteria Analysis

(MCA) to produce a map showing suitable sites for green space in the Daltonganj town of Jharkhand state.

The 2nd step is determining factors / criteria that are important for green space development. The factors used for site selection process for a green space were selected based on different literatures and prior knowledge of that area. Based on the literature and previous related studies conducted by different researchers (e.g. Jain, 1979 [7]; Heshmat et al. [6], 2013; Pareta, 2013 [13]; Pantalone, 2010 [12]; Ahmed et. al., 2011 [1] and Elahe, 2014 [4]), LULC, population density, soil type, slope, proximity to existing road, distance to existing park, distance to noisy influence, distance to historical place and distance to stream were selected as factors that are important for the green space development in Daltonganj town. These datasets were collected from various sources and processed using ArcGIS software for multi-criteria analysis.

The 3rd step was standardizing each factor / criterion scores. It is important to set the suitability values of the factors to a common scale to make comparisons possible. Therefore, all input datasets were changed into a raster at 23 m resolution and to a common measurement scale using conversion. Based on FAO [5] land suitability classification, the datasets were reclassified from Highly Suitable (S1) to permanently unsuitable (N2); where S1 represents the highly suitable, S2 moderate, S3 less suitable, N1 not suitable and N2 represents permanently unsuitable conditions for green space.

The 4th step was defining weights for each criterion based on its importance for the green space development. Several methods are available to determine the weight like Analytical Hierarchy Process (AHP), ranking and rating.

In this study the Analytical Hierarchy Process (AHP) method was adopted to assign weight for each factor because, AHP uses a hierarchical structure; it enables decision makers to define high level strategic objectives and specific metrics for a better assessment of strategic alignment and it can be applied in any organization with any level of maturity because the inputs are normalized using either numerical data or subjective judgments when metrics are not available and the process gives itself to sensitivity analysis (Saaty, 1980) [14].

AHP and GIS are integrated techniques used to assess suitable land use for UGS (Urban Green Space) in Daltonganj town. A pairwise comparison matrix was constructed, where each criterion was compared with the other criteria, relative to its importance, on a scale from 1 to 9.

Priority vector is also called normalized principal Eigen vector. To normalize the values, divided the cell value by its column total and calculated the priority vector or weight to determine the mean value of the rows (Saaty, 1980) [14]. 0.31, 0.20, 0.11, 0.04, 0.03, 0.09, 0.04, 0.07 and 0.11 was obtained as a weight value for the LULC, population density, distance from the road, distance from the stream, distance from the historical place, noise influence, distance from the existing park, and, slope and soil type respectively with 0.01 of consistency ratio (Table 2).

Table 2. Pairwise Comparison Matrix.

Criteria	LULC	Population Density	Road	River	Historical Place	Noise Influence	Park	Slope	Soil Type	Weight
LULC	1.00	2.00	3.00	7.00	9.00	3.00	7.00	5.00	3.00	0.31
Population Density	0.50	1.00	2.00	5.00	7.00	2.00	5.00	3.00	2.00	0.20
Road	0.33	0.50	1.00	3.00	5.00	1.00	3.00	2.00	1.00	0.11
River	0.14	0.20	0.33	1.00	2.00	0.33	1.00	0.50	0.33	0.04
Historical Place	0.11	0.14	0.20	0.50	1.00	0.20	0.50	0.33	0.20	0.03
Noise Influence	0.33	0.50	1.00	3.00	5.00	1.00	3.00	0.50	1.00	0.09
Park	0.14	0.20	0.33	1.00	2.00	0.33	1.00	0.50	0.33	0.04
Slope	0.20	0.33	0.50	2.00	3.00	2.00	2.00	1.00	0.50	0.07
Soil type	0.33	0.50	1.00	3.00	5.00	1.00	3.00	2.00	1.00	0.11

A consistency ratio of less than 0.1 shows a consistent comparison between the criteria and it was considered as acceptable (Saaty, 1980) [14].

CR = Consistency index (CI) / Random Consistency Index (RI) (Table 3)

$CI = (\lambda max - n) / n - 1$

Where λ max is the Principal Eigen Value; n is the number of factors.

λmax = Σ of the products between each element of the priority vector and column totals.

Table 3. Random Consistency Index (RI).

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

Source: Saaty (1980) [14].

5th step was to aggregate the criteria using weighted linear combination and apply it in the ArcGIS raster calculator. Validating or verifying the result was the final step. It helps to assess the reliability of the output and usually assessed by ground truth verification and sensitivity analysis. Sensitivity analysis was performed by changing the weight of criteria and field survey were conducted for ground truth verification.

In weighted linear combination (WLC) procedure, factors or parameters (Vi) multiplied by the weight of the suitability parameters (Wi) to get composite weights and then summed. WLC is a straightforward linear method calculating composite weights. This function multiplies and sums up the layers to produce suitability maps for green space. Therefore, the weighted linear technique (Mendoza, 1997) [8] was applied to generate a suitable site map for green space.

$$E = \sum_{i=1}^{n} (wi \times vi)$$

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

4. Results and Discussions

4.1. Suitability of Land Use / Land Cover

A detailed land cover classification schema was prepared. Visual interpretation key corresponding to the land cover classification scheme was also created to assist the process of classification. The classification was implemented in hierarchical manner with level I classes: built-up, Transportation, Vegetation and Open Surfaces. The level II Rural, Urban (high, medium and low density), industrial, recreational, agriculture, forest, plantation and open area, were separated using visual interpretation with the help of spectral and shape information. Transportation land cover including railway station, railway lines and roads were extracted at level III. Finally, data was subjected to clean up. LULC statistics were generated for the year 2017.

The LULC of the study area was analyzed using latest available ResourceSAT-2 LISS-III (23.5 m) and LandSAT-8 OLI & PAN merge (15 m) satellite imagery, land use plan of the town and ground truth verification. By reviewing different literature (e.g. Heshmat et al. [6], 2013; Pareta, 2013 [13] and Ahmed et al., 2011 [1]), it was advisable to select land, which was occupied by green urban (vegetation) for green space development. In the study area, major LULC classes were Built-up (56.34%), open area (14.28%), vegetation (9.97%), road (9.29%), scrub land (5.47%), and railway area (2.30%) (Table 4 and Figure 2).

4.2. Distance from Roads

20 feet and more than 20 feet wide roads have been selected for this study. Arterial road with 6.73Km length, sub-arterial road with 10.79Km length, and feeder collector road with 5.98 Km has been considered. Elah (2014) and Ahmed et al (2011) [1] suggested that the green space site is preferable when it is located at a suitable distance from roads in order to access transportation. It was reclassified as unsuitable road greater than 200m relatively compared to the other. The distance starting from 50m up to 100m was considered as moderately suitable and highly suitable is distance less than 50m. The result indicated that about 32.15% from the total area is highly suitable with the class value 5 and 19.76% is moderately suitable for green space development. The land that is unsuitable for green space constitutes 27.55% only (Table 4 and Figure 2).

4.3. Distance from the Stream

A detail drainage map of the study area has been prepared by using the ResourceSAT-2 LISS-III (23.5m) on 1:250,000 scales, ASTER (DEM) with 30m spatial resolution, and IRS-P5 CartoSAT-1 DEM with 30m spatial resolution. Drainage maps also created from published Survey of India toposheet (1965-1978) at 1:50,000 scales, but this is very old maps, therefore in-order-to get the updated river network, latest drainage network map has been generated the through DEM and ArcGIS-10.3 Software-Spatial Analysis tools-Hydrology Toolset.

The closer lands to the stream banks got more preferences and it used to maintain the environmental health of the area (Pareta, 2013) [13]. Heshmat (2013) [6] also noted that lands closest to water resources like rivers, lakes and reservoirs are highly suitable for green space development. Therefore, based on this argument, distance from the stream less than 50m (70.56% of the area) is highly suitable relative to the other and in between 50m and 100m is moderately suitable (27.67% of the area). Whereas 0.02% of the area is relatively considered as totally unsuitable which is greater than 200m from the stream (Table 4 and Figure 2).

4.4. Distance from Historical Place

Developing of green space closer to historical place can maintain and preserve the historical place in the case of maintaining ecological balance. Therefore, the land which is closer to historical place is more suitable than the further land. Distance from the historical place less than 200m and in between 200 and 400m are highly suitable and moderately suitable respectively, and greater than 800m is relatively

considered as totally unsuitable. 5.05% is highly suitable from the total area whereas 40.13% is totally unsuitable (Table 4 and Figure 2).

4.5. Distance from Noise Influence

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

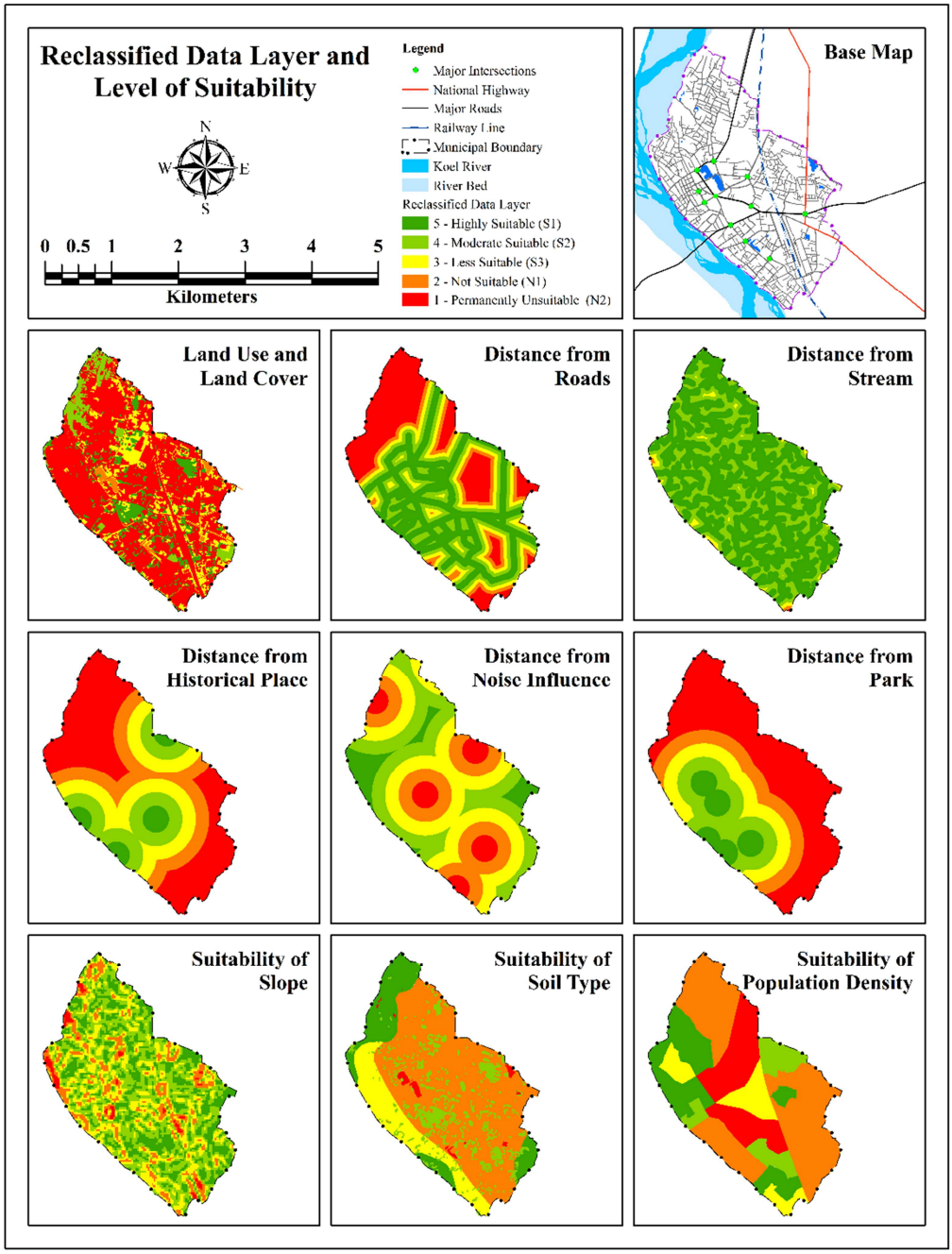

Figure 2. Reclassified Data Layer and Level of Suitability.

4.6. Distance from the Park

In the study area, there are five main parks such as Ambedkar Park, Nawatoli Park, DTG Garden, CRPF Park and Heritage Genie Garden. The area which is the farthest from the existing park highly requires the green space because that

area lacked green space or vegetation (Pantalone, 2010) [12]. Therefore, if distance from the park is greater than 800 m, it will be considered as highly suitable; 600-800m, moderately suitable; and less than 200m, permanently not suitable for developing parks. 7.61% is highly suitable from the total area whereas 8.49% is totally unsuitable (Table 4 and Figure 2).

4.7. Suitability of Slope

Different researchers show that areas with low slopes are highly suitable for developing park (e.g. Heshmat, 2013) [6]. Based on FAO [5], the slope value 0 to 0.2% is considered as flat and up to 5 gently slope. 5 to 10% and 10 to 15% is called sloping and strongly sloping respectively. Whereas 15 to 30% and above 30% is moderately steep and steep respectively. Therefore, this study considered the gently slope as more highly suitable than the land with steep slope. The majority of the study area falls under the slope class of less than 5 to 10%, which covers 35.45% of the total study area. The slope value greater than 30%, which has the least coverage about 3.52% is steep slope totally unsuitable compared to the other (Table 4 and Figure 2).

4.8. Suitability of Soil Type

Soil map of the district has been collected from NBSS & LUP and updated through the IRS ResourceSAT-2 LISS-III & PAN, and IRS-P5 CartoSAT-1 DEM Data. Soil of Daltonganj is classified into five categories, chromic (i) Haplustalfs, Paleustalfs, Rhodustalfs (red gravelly soils), (ii) Paleustalfs, Haplaquents (older alluvial soils), (iii) Ochraquults, Rhodustults, Haplustults (red & yellow soils), (iv) Haplustalfs, Paleustalfs, Rhodustalfs (red loamy soils) and Paleustalfs, Haplaquents (clay soils). Based on the UNEP (2005) [16] soil suitability standards, red gravelly soils and red & yellow soils are considered as suitable soil because it is a high natural fertility and covers large area (27.90%) (Table 4 and Figure 2).

4.9. Suitability of Population Density

Population density is one of the major criteria for suitable site selection of green space. Some researchers [1, 2, 7, 3, 6] recommend that areas closer to residential areas are highly suitable for developing green space. The north-west and southern part of the study area is highly populated and suitable areas for developing green space. The north-eastern and south-eastern part is sparsely populated and hence unsuitable for green area. With respect to population density, highly suitable and moderately suitable areas cover 18.20% and 9.66% of the total area respectively (Table 4 and Figure 2).

Table 4. Reclassified Data Layer and Level of Suitability.

S. No.	Reclassified Items	Level of Suitability	Value
	Land Use and Land Cover Classes		
	Green Urban (Vegetation) - VG	S1	5
	Scrub Land - SL	S2	4
	Agricultural Area - AG	S2	3
	Recreational Urban (Ground) - GR	S2	4
A	Open Area - OA	S3	3
	Drain / River / Streams - RV	N1	2
	Ponds / Lakes - WB	N1	2
	Urban Settlement - BU	N2	1
	Railway Area - RA	N2	1
	Roads - RD	N2	1
	Distance from Road (m)		
	Less than 50	S1	5
B	50 - 100	S2	4
	100 - 150	S3	3
	150 - 200	N1	2
	More than 200	N2	1
	Distance from Stream (m)		
	Less than 50	S1	5
C	50 - 100	S2	4
	100 - 150	S3	3
	150 - 200	N1	2
	More than 200	N2	1
	Distance from Historical Place (m)		
	Less than 200	S1	5
D	200 - 400	S2	4
	400 - 600	S3	3
	600 - 800	N1	2
	More than 800	N2	1
	Distance from Park (m)		
E	Less than 200	S1	5
	200 - 400	S2	4

S. No.	Reclassified Items	Level of Suitability	Value
	400 - 600	S3	3
	600 - 800	N1	2
	More than 800	N2	1
	Distance from Factory (m)		
	More than 800	S1	5
F	600 - 800	S2	4
	400 - 600	S3	3
	200 - 400	N1	2
	Less than 200	N2	1
	Slope (%)		
	Less than 5	S1	5
G	5 - 10	S2	4
	10 - 15	S3	3
	15 - 30	N1	2
	More than 30	N2	1
	Soil Type		
	Red Gravelly Soils - RGS	S1	5
H	Red & Yellow Soils - RYS	S2	4
	Older Alluvial Soils - OAS	S3	3
	Red Loamy Soils - RLS	N1	2
	Clay - CLY	N2	1
	Population Density (Pop / Ha)		
	More than 200	S1	5
I	150 - 200	S2	4
	100 - 150	S3	3
	50 - 100	N1	2
	Less than 50	N2	1

Analytical Hierarchy Process (AHP) pairwise comparison matrix was created, and criteria weights were calculated for each factor by comparing factors on a scale from 1 to 9. The reclassified input datasets were assigned a weight value to express the importance of each criterion to the other criteria for suitable site selection for green space (Table 2). In-order-to select suitable sites for green space development all the reclassified input datasets were overlaid using the Weighted Overlay tool or a raster calculator in ArcGIS (Table 5 & Figure 3).

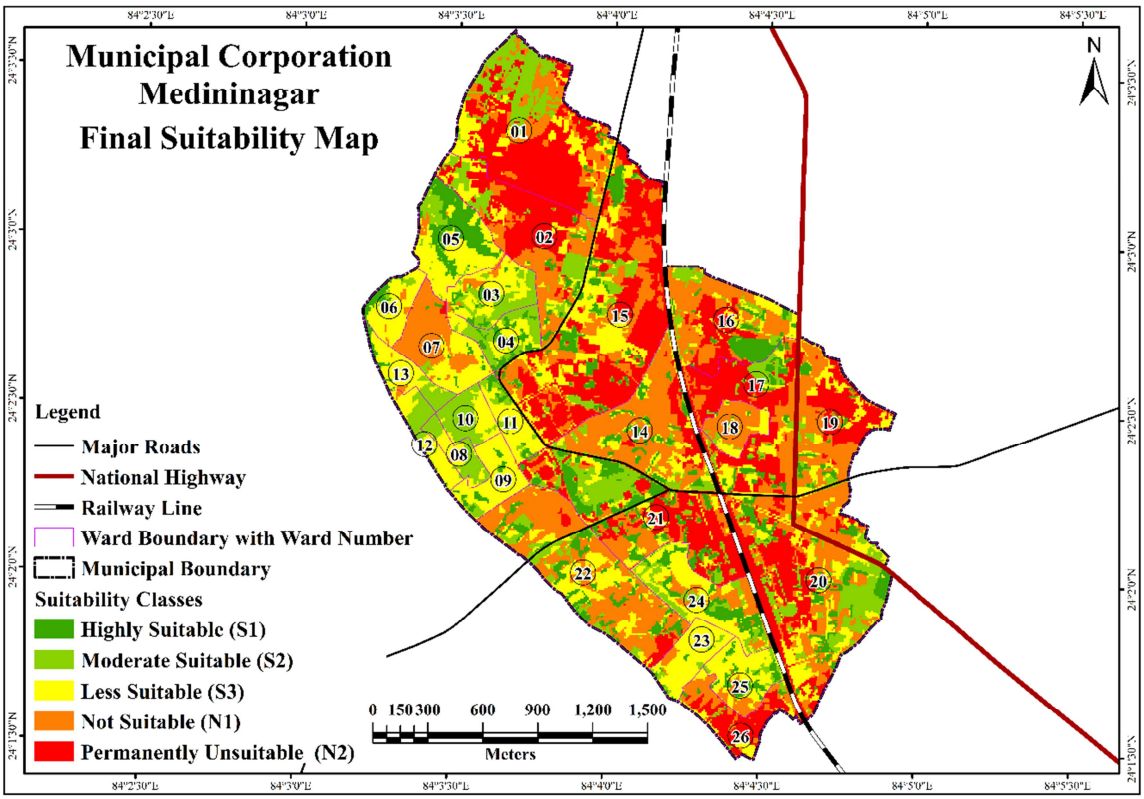

Figure 3. Final Suitability Map.

Table 5. Suitability Level per Criteria for Park Site Selection.

Criteria	Measurement Unit	Suitability Level					Weight (%)
		5	4	3	2	1	
		S1	S2	S3	N1	N2	
LULC	Class	VG	SL, AG, GR	OA	RV, WB	BU, RA, RB	31
Population Density	Pop./Ha	> 200	150 - 200	100 - 150	50 - 100	< 50	20
Distance to Road	m	< 50	50 - 100	100 - 150	150 - 200	> 200	11
Distance to Stream	m	< 50	50 - 100	100 - 150	150 - 200	> 200	4
Distance to HP	m	< 200	200 - 400	400 - 600	600 - 800	> 800	3
Distance to Factory	m	> 800	600 - 800	400 - 600	200 - 400	< 200	9
Distance to Park	m	< 200	200 - 400	400 - 600	600 - 800	> 800	4
Slope	%	< 5.0	5.0 - 1.0	10.0 - 15.0	15.0 - 30.0	> 30.0	7
Soil	Class	RGS	RYS	OAS	RLS	CLY	11

According to GIS-based MCA, 9.26% and 13.67% are highly suitable and moderately suitable for green space development. The large area is less suitable for green space development in the existing situation which covers 24.49% of the area. The remaining 27.80% and 24.98% are unsuitable and permanently unsuitable for park development respectively. In the land use plan, the selected areas are mostly categorized under riverine, recreational, built-up area and open space.

5. Conclusion

The urban / built-up areas in Daltonganj town have expanded dramatically, while green areas declined. The town has currently consumed more than 68% of its areas for development. This unprecedented growth is beyond the town's bearing capacity within its current socioeconomic, physical and administrative situation. Added to these prime problems, the town is challenged by expanding squatter settlements, rising traffic congestion and more pollution, lack of green spaces and inadequate water supply and sanitation.

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

The classification achieved in this study indicates that large area is not suitable for park development in the existing situation (52.78% of the area). As demonstrated in this study remote sensing and GIS technologies can play a crucial role in urban research and help to get up-to-date information about the urban LULC dynamics with frequent coverage and low cost.

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