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Urban Neighborhood Green Index – A measure of green spaces in urban areas

Kshama Gupta[a,*], Pramod Kumar[a], S.K. Pathan[b], K.P. Sharma[a]

[a] Indian Institute of Remote Sensing, Indian Space Research Organization, 4, Kalidas Road, Dehradun, India
[b] Space Application Centre, Indian Space Research Organization, Satellite Road, Ahmedabad, India

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ABSTRACT

Urban green spaces (UGS) form an integral part of any urban area and quantity and quality of UGS is of prime concern for planners and city administrators. Objective measure of greenness using remote sensing images is percentage area of green, i.e., Green Index (GI), which is insensitive to spatial arrangement within the areal units. Measuring UGS at neighborhood level is important as neighborhood is the working level for application of greening strategies. Neighborhood (NH) is synonymous of nearness and can be defined as an area of homogeneous characteristics. The Urban Neighborhood Green Index (UNGI) aims to assess the greenness and can help in identifying the critical areas, which in turn can be used to identify action areas for improving the quality of green. For the development of UNGI, four parameters, i.e., GI, proximity to green, built up density and height of structures were used and weighted using Saaty's pair wise comparison method. Four different types of NH were compared and it was found that mean GI (0.44) is equal for high-rise low density and low-rise low density NH, i.e., both areas have same quality of urban green based on GI. But mean UNGI is higher for low-rise low-density NH (0.62), as compared to high-rise low-density NH (0.54), hence, area of highrise NH requires more amounts of good quality properly distributed green as compared to low-rise NH. The input for UNGI is easily derivable from RS images, besides the developed method is simple, and easily comprehendible by city administrators and planners.

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1. Introduction

Urban green spaces are an integral part of any urban area and their importance is very well known for maintaining the environmental quality and sustainability. Urban green spaces (UGS) constitute parks, gardens and recreation venues, informal green spaces such as river or sea fronts, green spaces surrounding historical sites, railway corridors and indigenous vegetation types. Urban habitats such as derelict industrial sites and overgrown gardens have also been considered as UGS (Venn & Niemelä, 2004). UGS provide numerous benefits to urban residents by acting as urban lungs – absorbing pollutants and releasing oxygen (Hough, 1984, cited in Haughton & Hunter, 1994), provide clean air, water and soil, and balances city's natural urban environment (Nijkamp & Leventa, 2004). These areas function as a visual screen and act as noise barriers and avoid too much spatial uniformity (Dole, 1989). It has been proved in many researches that green areas helps individuals to recuperate from physical and mental stress (De Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003; Grahn & Stigsdotter, 2010; Groenewegen, van de Berg, De Vries, & Verheij, 2006; Korpela & Hartig, 1996; Takano, Nakamura, & Watanabe, 2002). Mcpherson (1992) assessed the environmental and health benefits of UGS and found investment in UGS at par with monetary benefits of other capital investments. At neighborhood level, the availability of green spaces effects the environmental quality, helps in stress restoration, enhances feeling of social safety (Groenewegen et al., 2006; Maas et al., 2009; Troy & Grove, 2008), increases social interaction and property values (Jim & Chen, 2009) and also provides a play space for children's physical and mental development (Jacobs, 1961).

Despite the enormous benefits of UGS, dearth of information on its quantity and quality handicaps the planners responsible for managing the UGS. Assessment and quantification of greenness by subjective methods includes perceived, self-report method involving survey questions, such as perceived access to parks (Sugiyama, Leslie, Giles-Corti, & Owen, 2008; Tilt Jenna, Unfried Thomas, & Belen, 2007) and audit by trained raters who apply specific criteria (e.g., presence/absence of various features) to assess natural environments (Ellaway, Macintyre, & Bonnefoy, 2005; Giles-Corti et al., 2005; Hoenher, Brennan-Ramirez, Elliot, Handy, & Brownson, 2005). The subjective measure, i.e., surveys and audits are time and cost consuming and the assessment is much more subjective, for example access to parks is different for a children and an elderly person.

* Corresponding author. Tel.: +91 135 2742439; fax: +91 135 2745439.
E-mail address: gupta.kshama@gmail.com (K. Gupta).

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The objective measures of greenness are distance or green space per inhabitant or percentage of green area which can be identified using remote sensing (RS) (Leslie, Sugiyama, Ierodiaconou, & Kremer, 2010). RS by virtue of its repetivity, synoptic view and larger area coverage, has become an indispensable tool for study and management of natural resources and land use/land cover. In an early attempt to relate remotely sensed data to socio-economic parameters, Forster (1983) devised a classification scheme for Landsat imagery that could be applied to urban areas to produce a residential quality index (Venugopal, Ramesh, Bhavani, & Kamini, 2010). Normalized Difference Vegetation Index (NDVI) derived from remote sensing images has been used in various studies to distinguish between vegetated and non-vegetated areas (Hur, Nasar, & Bumseok, 2010; Saied, Syed, & Heshmi, 2005; Tilt et al., 2007). Ruangrit and Sokhi (2004) has used pixel based classification for mapping urban green spaces of Jaipur city, India from remote sensing images and analyzed availability of green spaces in various administrative units based on percentage green space, green space per 1000 persons and green space/built up area ratio. Faryadi and Taheri (2009) has considered area and green space per capita and vegetation cover density of the Tehran regions as ecological indices to evaluate the urban environment quality based on NDVI derived measurement of green space. Guobin, Fuling, and Mu (2003) proposed Vegetation Cover Index (VCI) based on segmentation techniques and classification approach using ASTER data. The VCI map divided the whole area in 10 classes based on the amount of vegetation in each object identified keeping in view the scale of the study.

2. Conceptual framework

NDVI based measures do not account for the proximity and spatial arrangement of green spaces within the areal units besides; it does not address the vertical dimension and density of urban built-up. Using geographic area and NDVI based measures, a big patch of green available in the vicinity or within the residential neighborhood can be termed as area with high amount of green space. But the question arises, is it sufficient to have a big green patch in the vicinity? Or the green space should be properly distributed over the neighborhood? Area based measures such as green space per capita has limitation as the population data is available as best at ward level which consists of number of neighborhoods. This data is insufficient to assess the distribution and quality of green spaces as per different neighborhood characteristics. The question arises about the methods those could be used for assessing the quality of green spaces below ward level using remote sensing images which are a continuous source of information. Is the NDVI based measures, i.e., percentage of green, sufficient to assess the quality of green in any area? Whether urban areas of high-rise development or low-rise development, really has same quality of green? How to address the impact of vertical dimension and built-up density on the quality of green in any area using information from RS images?

Schöpfer, Lang, and Blaschke (2004), Schöpfer and Lang (2006) and Lang et al. (2008) using high resolution satellite data and ortho-photo have assessed the urban environmental quality in Salzburg, Austria. Object based classification approach on Quickbird data was followed to estimate percentage of green, percentage of multi storey buildings and distance between buildings to develop a weighted index. Although, methodology adopted addresses spatial distribution of UGS and is independent of the grid size, the implementation of this method in India, where built up density is very high, is not feasible. Absence of information on parameters such as percentage of multi storey buildings and distance between buildings prevents the use of above methodology in its original form.

The 74th constitution amendment act of India places more importance on urban local bodies (ULBs) for urban area management as well to cater to the urban renewal programs to be implemented by ULBs. Hence, demand for techniques and methods, which are easily comprehendible by urban planners and city administrators for implementation on ground, are urgently required.

Keeping this in view, the study aims to develop a simple technique/tool to objectively measure the quality of green spaces in urban neighborhoods using RS and Geographic Information System (GIS) technology. The developed index is based on basic types of urban vegetation and built up characteristics which can be derived from RS images and spatial measures to differentiate between areas which may have same share of green as visible on satellite image.

3. Study area

The city of Delhi is the capital of India and fast growing metro city with approximately 12.8 million population (Census of India, 2001). The city is located on the banks of Yamuna River. Out of its nine districts, two districts, i.e., North east Delhi and East Delhi districts are located on other bank of Yamuna River, generally referred as Trans-Yamuna area. The east Delhi is characterized by unauthorized colonies which sprang up due to high influx of migrants just after the independence of India. The unauthorized and unplanned development has characteristics of narrow closely packed lanes, where it is difficult even for small cars to enter. Distinction between buildings using satellite images is out of question as buildings are just adjacent to each other. After the economic boom of 1990s, there is an increase in high-rise buildings (more than 7 storeys) in the study area. At present, the east district of Delhi (http://www.delhiinformation.org/districts/eastdelhi.html) is a mix of unauthorized high-density development (mostly of 2–3 storey buildings), planned low-rise low-density development (again of 2–3 storey buildings) and high-rise residential apartments (more than 7 storeys). For the last few years, there is a drive to regularize the unauthorized development, which calls for the quantification of facilities and green space requirements.

The study area of 320 ha, a part of East Delhi, represents a mix of unauthorized development, i.e., high density and unplanned development, planned low-rise (2–3 storey buildings) and high-rise apartments (7–8 story buildings) and a non-residential railway corridor area (Figs. 1 and 2).

4. Urban Neighborhood Green Index model

Neighborhood (NH) is defined as an area of homogeneous or same distinguishing characteristics whether in terms of ethnicity, housing, type of development, etc. (http://www.merriam-webster.com/dictionary/neighborhood). Neighborhood term is also synonymous of vicinity, i.e., quality of green space nearby a built-up area and its distribution. The Urban Neighborhood Green Index (UNGI) assesses the spatial distribution of UGS in the vicinity of urban built-up. Here, the term neighborhood is used as a spatial concept as the analysis is partly based on neighborhood characteristics. Fig. 3 illustrates the model for measuring neighborhood greenness. The characteristics of urban vegetation have been defined by two parameters, i.e., amount of green and type of green (basic type of urban vegetation, i.e., dense, low/grass vegetation, etc.). Characteristics of urban built-up at neighborhood level have been defined by parameters, i.e., proximity to green, built-up density and height of structures. Amount of green is the percentage of green in unit area and a widely used measure of urban green and has been refereed thereafter as Green Index (GI) (Faryadi & Taheri, 2009; Hur et al., 2010; Leslie et al., 2010; Schöpfer & Lang,

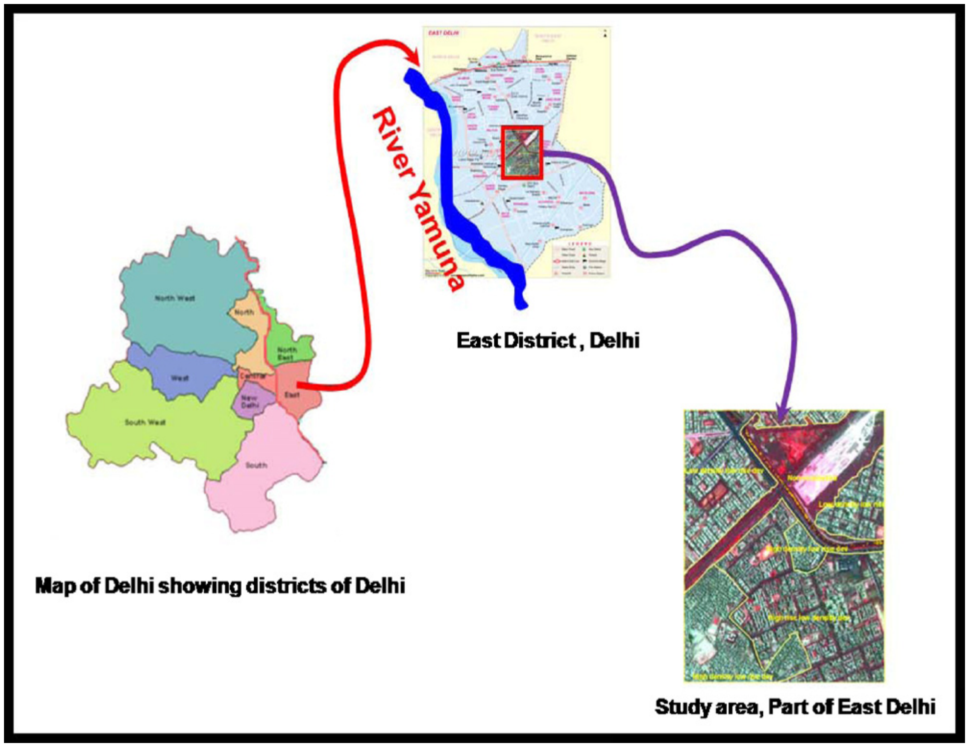

Fig. 1. Location map of study area.

2006; Schöpfer et al., 2004; Tilt et al., 2007). The type of green has its importance as dense vegetation offers more ecological benefits than grass lawns. Jansson and Persson (2010) reported that an area with natural open space or dense vegetation is preferred by children to play as it provides the variety of play methods. Grahn and Stigsdotter (2010) discuss that an area which is a combination of refuge, nature and rich in species, i.e., area with dense vegetation is the most restorative environment for stressed individuals.

Type of green map was used to define the characteristics of urban built-up, i.e., proximity to green. Researchers have found that proximity to green space leads to an increase in the value of the property as it increases the environmental quality (Jim & Chen, 2009; Troy & Grove, 2008). Other characteristic parameters of urban built-up, i.e., built-up density and height of structures are constituent parts of urban density and indirectly denote the number of people living in a particular neighborhood. Schöpfer and Lang (2006) used percentage of multi storey buildings and distance between buildings to assess the environmental quality. Hur et al. (2010) although could not establish a link between building density and perceived openness but discussed that to calculate building density, volume and height of buildings was not considered which in turn effected the perceived density. Inclusion of height of buildings for assessing urban greenness has been suggested for

Fig. 2. Various neighborhood types.

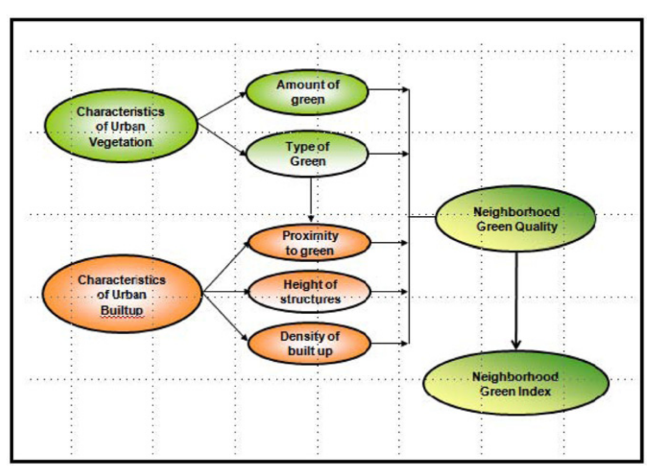

Fig. 3. Conceptual model for Urban Neighborhood Green Index (UNGI).

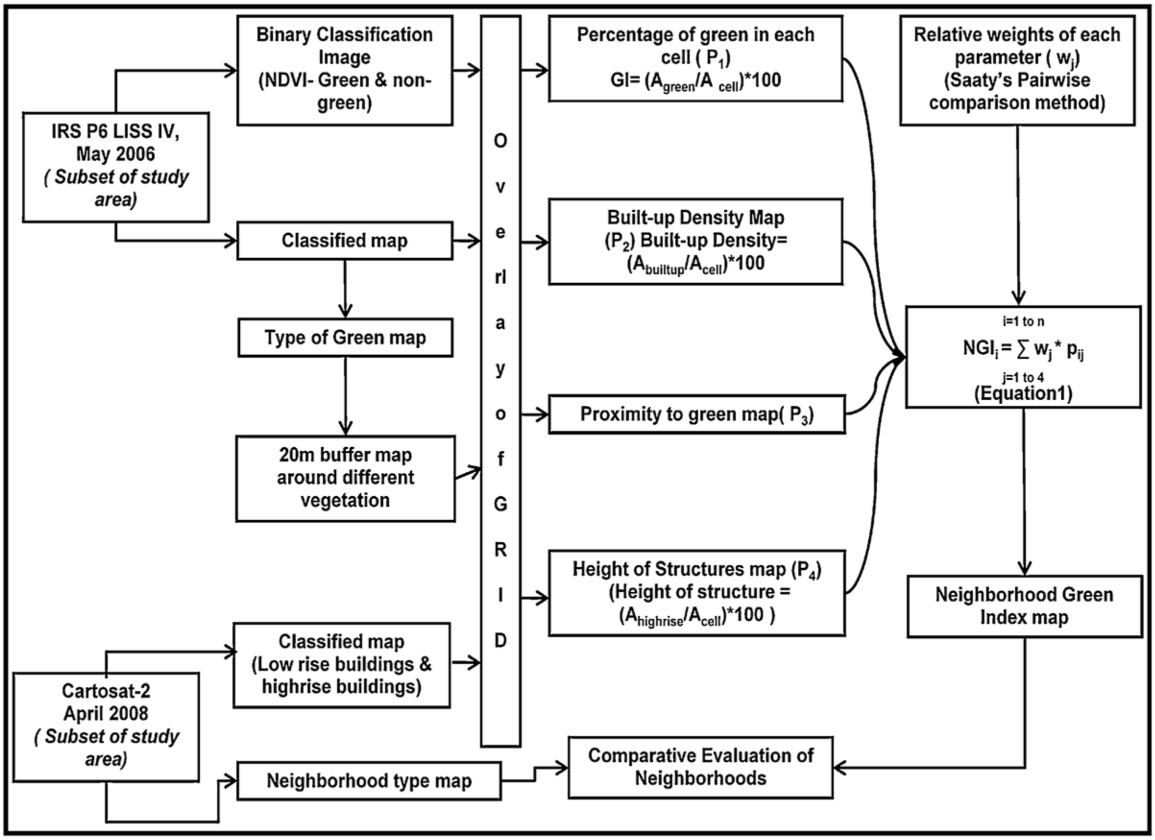

Fig. 4. Methodology chart.

future research. All the layers then transformed to neighborhood green quality gradation and then combined to finally derive the UNGI.

5. Methodology

5.1. Data used

To derive the various parameters to measure quality of neighborhood green, Indian Remote Sensing satellite data IRS P6 LISS IV (May 10, 2006) data has been used as base data for quantifying the amount of vegetation and broad characterization of vegetation, i.e., dense, low/grass vegetation, open space without vegetation and built-up area. LISS-IV is a multispectral high resolution sensor with a spatial resolution of 5.8 m at nadir and operating in three spectral bands 0.52–0.59 μm, 0.62–0.68 μm and 0.76–0.86 μm (Kshama & Jain, 2005). Due to imaging in multispectral domain, i.e., green, red and Near Infrared (NIR band) region, it is useful in vegetation identification and characterization. Cartosat-2 data (April 23, 2008) has been used for deriving the neighborhood types and height of buildings as well as reference data. Cartosat-2 is a polar sun synchronous cartographic satellite launched by Indian Space Research Organization (ISRO). It has advantages of high resolution of less than 1 m and repetivity of 5 days (Amitabh, Gopala Krishna, Srinivasan, & Srivastava, 2008). When these two data sets have been used in combination, the benefits of both multi-spectral and high spatial resolution can be fully utilized.

The detailed methodology is illustrated in Fig. 4. A grid cell of 20 m × 20 m was overlaid over the study area to capture the spatial arrangement of green spaces and to derive an index. 20 m × 20 m grid cells has been chosen by considering 3 pixel by 3 pixel minimum mapping unit of LISS IV data (Knight & Lunetta, 2003) that comes to approximately 18 m × 18 m and also to capture the spatial variability at finer resolution.

5.2. Derivation of Green Index Map

The Green Index (GI) i.e., percentage of green in each cell, is based on binary classification (green and non-green classes) of NDVI measurements. The NDVI image was generated using IRS P6 LISS IV data of study area. The negative values of NDVI measurement were classified as built up area and positive values were classified as green class. The 20 m × 20 m grid was overlaid over the binary image and percentage of green in each cell was calculated.

Based on the percentage, the each cell had been classified in four green quality classes' i.e., low, moderate, high and very high green quality (see Table 1) on the scale of 0.25–1 where less than 25% of green in a cell has been categorized as low quality green hence, given a value of 0.25. In the same manner 0.5 (moderate green quality), 0.75 (high green quality) and 1 (very high green quality) value had been given to cells where percentage of green is 25–50%, 50–75% and more than 75%, respectively. The categorization of all values in four equal intervals/classes was done for the sake of simplicity as this index provides the relative value for comparative evaluation between different neighborhoods rather than any absolute value.

5.3. Derivation of height of structures map

Approximate height of buildings was determined with the help of shadow method (Evans & Stingelin, 1983) using Cartosat-2 data. The suns' altitude angle ($\tan\theta = h/s$) was calculated using shadow length (s) of a reference object whose height (h) is known or can be easily determined. The derived mathematical factor ($\tan\theta$) then

Table 1
Various parameters and their scaling to measure quality of green.

S.no.	Parameter	Percentage	Value (p_j)	Quality classes
1.	Percentage of green in each cell	0–25	0.25	Low green quality
		25–50	0.5	Moderate green quality
		50–75	0.75	High green quality
		75–100	1.00	Very high green quality
2.	Proximity to green	>50% of area of cell in Buffer around Dense Vegetation	1.00	Very high green quality
		<50% and > 20% of area of cell in Buffer around Dense Vegetation	0.75	High green quality
		Buffer around Low/Grass vegetation	0.5	Moderate green quality
		Buffer around open spaces	0.25	Low green quality
		Other Area	0.25	Low green quality
3.	Density of built-up	0–25	1.00	Very high green quality
		25–50	0.75	High green quality
		50–75	0.5	Moderate green quality
		75–100	0.25	Low green quality
4.	Height of structures	0–25	1.00	Very high green quality
		25–50	0.75	High green quality
		50–75	0.5	Moderate green quality
		75–100	0.25	Low green quality

had been multiplied by shadow length to determine the height of the object casting the shadow. The Google Earth and Eicher Map of Delhi (2008) were used as reference for understanding the pattern of development. To semi-automate the procedure, the study area was divided in low rise buildings and high rise buildings area. This layer was again overlaid with 20 m × 20 m grid cell and percentage of high-rise buildings in each cell was calculated. Based on the percentage of high-rise buildings in each cell, it is further classified in four green quality classes. High-rise buildings in each cell less than 25%, between 25 and 50%, between 50 and 75% and more than 75% had been termed as very high green quality (1), high green quality (0.75), moderate green quality (0.5) and low green quality (0.25) respectively (Table 1).

5.4. Generation of proximity to green and built-up density map

To derive the proximity to green map, the type of green map was produced from classification of IRS P6 LISS IV image. For classification, a parametric classification algorithm, maximum likelihood classifier was used (Jensen, 1986). The various steps involved in classification are as following:

5.4.1. Classification system

The basic type of urban green classes' i.e., dense vegetation, grass or low vegetation, open spaces without vegetation and built-up areas were identified as target classes. Dense vegetated areas have natural vegetation; tree foliages and of high density. It appears with dark red tone on the false color composite (FCC) of the image with irregular shape and moderately coarse texture. Low/grass vegetation areas consist of either grass or shrubs with small heights and appear dull red to pink tone on FCC, with regular/irregular shapes and smooth texture. Open spaces without vegetation areas mainly consist of open lands, playgrounds or areas devoid of vegetation. On FCC, they appear bright white to dull whitish tone with smooth texture. Built-up areas are covered by structures, having block like appearance and can be identified on FCC as areas of cyan color with very coarse texture.

5.4.2. Training data sets

Based on the image characteristics, the training data sets have been identified. As a thumb rule, the training sample should be 30*n* (Mather, 1999), where *n* is the number of spectral bands of remote sensing images. Small size training samples were selected to keep them homogeneous but care was taken to keep them large enough for determination of various statistical parameters. Since, LISS IV has 3 spectral bands; minimum 90 pixels in each class were identified. The histogram plots of these samples found to be unimodel following a normal distribution, i.e., the training dataset is pure (Arora, 2002 cited in Sandeep, Arora, & Jain, 2010).

5.4.3. Image classification

The IRS P6 LISS IV image was classified with the help of identified training data sets in four basic types of urban green classes as described earlier. Hence, the final type of green map shows all the four classes classified.

5.4.4. Accuracy assessment

The stratified random samples were collected in order to determine the accuracy of classification, which were compared with the reference data. The overall accuracy for the classified image was found to be 91.2%, which is more than the minimum accuracy criteria of 85% (Anderson, Hardy Ernest, Roach, & Witmer, 1976)

5.4.5. Generation of buffer and proximity to green map

A buffer zone of 20 m keeping in mind the 20 m grid cell size was generated around the vegetated areas excluding built-up area. The buffer zone around dense vegetation, grass/low vegetation and open spaces without vegetation were categorized as high quality, moderate quality and low quality green area, respectively. The grid of 20 m × 20 m was overlaid on this buffer image and then a proximity to green map was generated. The criteria for defining the green quality classes in proximity to green map are given in Table 1. The cell which has area in buffer around dense vegetation more than 50% was termed as very high quality (1) and less than 50% and more than 20% was termed as high green quality (0.75). Buffer around low/grass vegetation and buffer around open spaces and built-up was termed as moderate green quality (0.5) and low green quality (0.25), respectively.

5.4.6. Generation of built-up density map

The classified built-up area was used to calculate the built-up density in the study area. This layer is not a mirror image of GI layer as it did not take into account the open spaces without vegetation as built up area. In the same manner, 20 m × 20 m grid was overlaid on this layer to calculate percentage of built-up in each cell. Less than 25% of built up in a cell has been awarded maximum value of 1, i.e., very high green quality. Similarly, Cells having percentage of

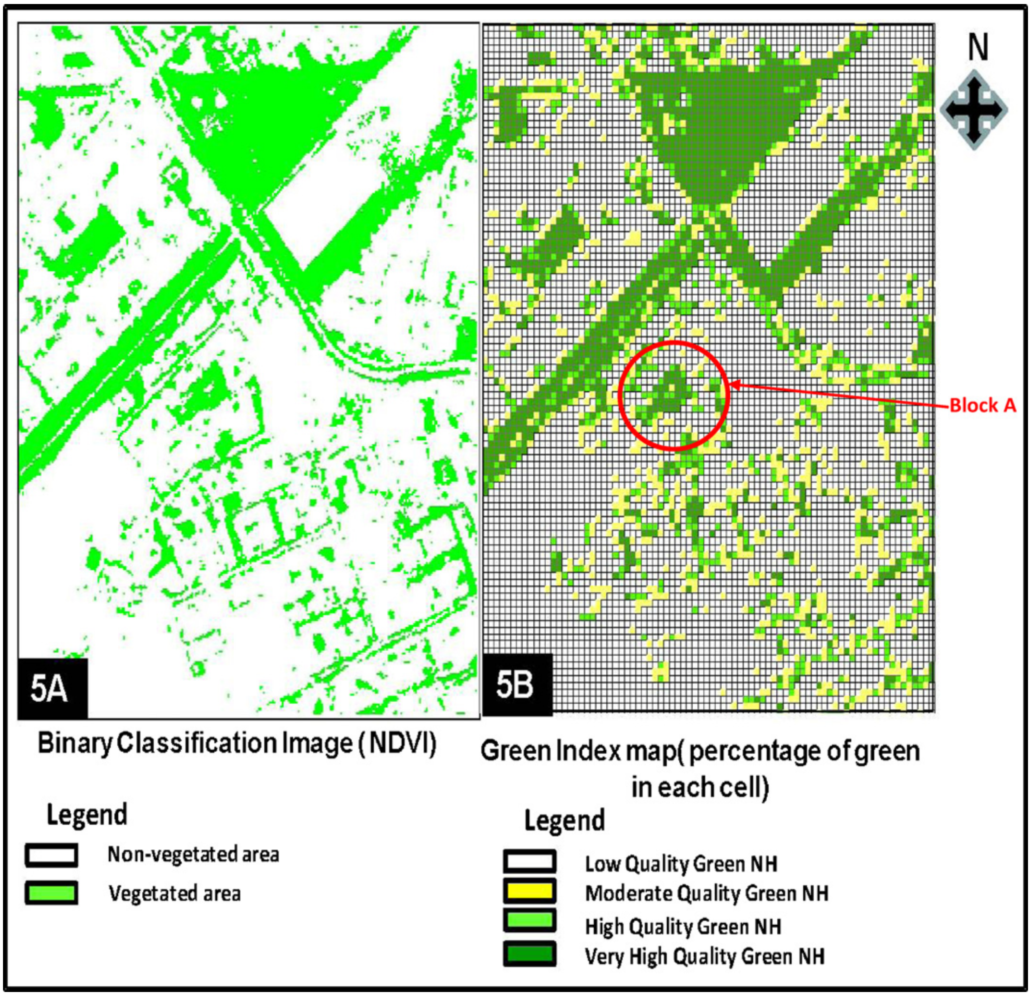

Fig. 5. Binary classification image and Green Index Map.

built-up as 25–50%, 50–75% and more than 75% have been classified as high green quality (0.75), moderate green quality (0.5) and low green quality (0.25), respectively.

5.5. Derivation of weights

The pair wise comparison method developed by Saaty (Malczewski, 1999) in the context of Analytic Hierarchy Process (AHP) has been used for determining the weights of individual parameter. It takes as an input the pair wise comparison of each parameter with another parameter on the scale of 1–9 for the development of pairwise comparison matrix. The relative preference of one parameter above another is defined by Delphi method (Hsu & Sandford, 2007) i.e., urban planners; educationist and researchers working in the field of urban planning have been asked to rank relative preference of one parameter above another. These relative rankings were discussed in group and their relative importance on the scale of 1–9 had been defined. After the computation of weights using Saaty's pair wise comparison method, the Consistency Ratio (CR) (should be <0.10 for consistent weights) was computed to test the consistency of weights. Again, groups of weights which has CR < 0.10 were identified and then consulted with urban planners; educationist and researchers working in urban planning field to zero down on one group of relative weights as final.

5.6. Generation of Urban Neighborhood Green Index map and comparative evaluation

The finalized weights were then used to derive the UNGI by combining them to the derived layers. The UNGI value for each cell was computed as given below:

$$\mathrm{UNGI}_i = \sum_{j=1\text{ to }4}^{i=1\text{ to }n} w_j \times p_{ij} \qquad (1)$$

where UNGI_i is the Urban Neighborhood Green Index of ith cell, where $i = 1$ to n; w_j is the relative weight of jth parameter, where $j = 1$ to 4; p_{ij} is the value of jth parameter in ith cell, where $i = 1$ to n.

For comparative evaluation of neighborhoods, the neighborhood type map had been generated using Cartosat-2 data by employing visual interpretation technique. Based upon their characteristics such as density of built-up, type of development and height of structures, the study area has been divided in four major categories of neighborhoods, i.e., railway corridor (no residential area), low rise low density Neighborhood, low rise high density neighborhood and high rise low density neighborhood (Fig. 2). After computing the mean and standard deviation of GI and UNGI values the, comparative analysis of greenness in different neighborhoods has been carried out.

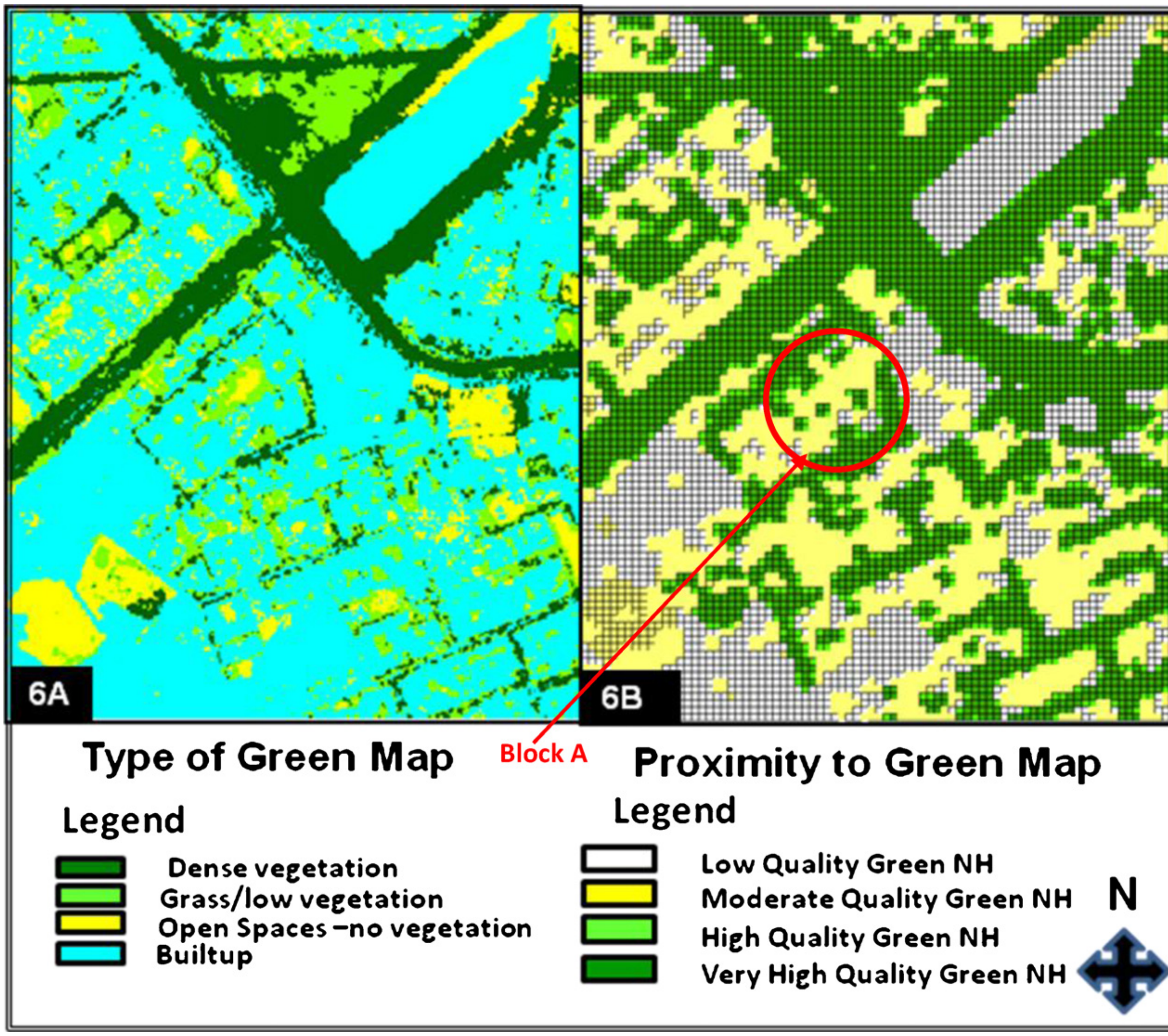

Fig. 6. Type of green map, proximity to green map.

6. Results

The binary classification (vegetated and non-vegetated area) (Fig. 5A) and subsequent GI map (Fig. 5B) were generated based on the parameters given in Table 1. From the GI map, it is clearly visible that 70% of study area comes under moderate to low quality green and most of the high and very high quality green is clustered in 4 patches.

The type of green map (Fig. 6A) was used for generating proximity to green map (Fig. 6B) and Built-up density map (Fig. 7A). Analysis of GI map and proximity to green map asserts the effect of type of vegetation and its proximity. For example, a park (Block A) consisting grass vegetation and dense vegetation along boundary is under high green quality in GI map but under moderate green quality in proximity to green map. Besides, there is a significant increase in moderate quality green area as the map depicts the effect of vegetation on its surroundings as well.

The study area had been classified in two height classes' i.e., low-rise buildings and high-rise buildings. Buildings with approximate height of 2–3 storeys were classified as low-rise buildings and buildings with height of more than 2–3 storeys and up to 7–8 storeys were classified as high-rise buildings. Further, based on the percentage of height of structure in each cell, height of structure map had been generated. The derived height of structure map is presented in Fig. 7B. The classification divides the study area in two distinct patches and approximately 65% of the study area is covered under low rise structures.

Weights for all the parameters had been determined using Saaty's pair wise comparison method. A pairwise comparison matrix was developed based on expert's opinion and used to compute the weights of parameters as 0.27, 0.25, 0.30 and 0.18 for percentage of green, proximity to green, density of built-up and height of structures, respectively.

UNGI value was calculated for each cell by using arithmetic weighted overlay approach (Eq. (1)). The calculated values further classified in four green quality classes for the ease of visualization and comparative evaluation. The generated UNGI map is presented in Fig. 8.

GI concentrates only on percentage of green in urban area but UNGI addresses the spatial distribution of UGS and their interlinking with urban built-up, vertical dimension of urban built-up and their impact on UGS. The mean and standard deviation of GI and UNGI were compared to bring out the difference between the GI and UNGI approach. The mean and standard deviation values for comparative evaluation of identified neighborhoods have been presented in Table 2.

The railway corridor area is characterized by the dense vegetation area consisting of railway line and green buffer area around,

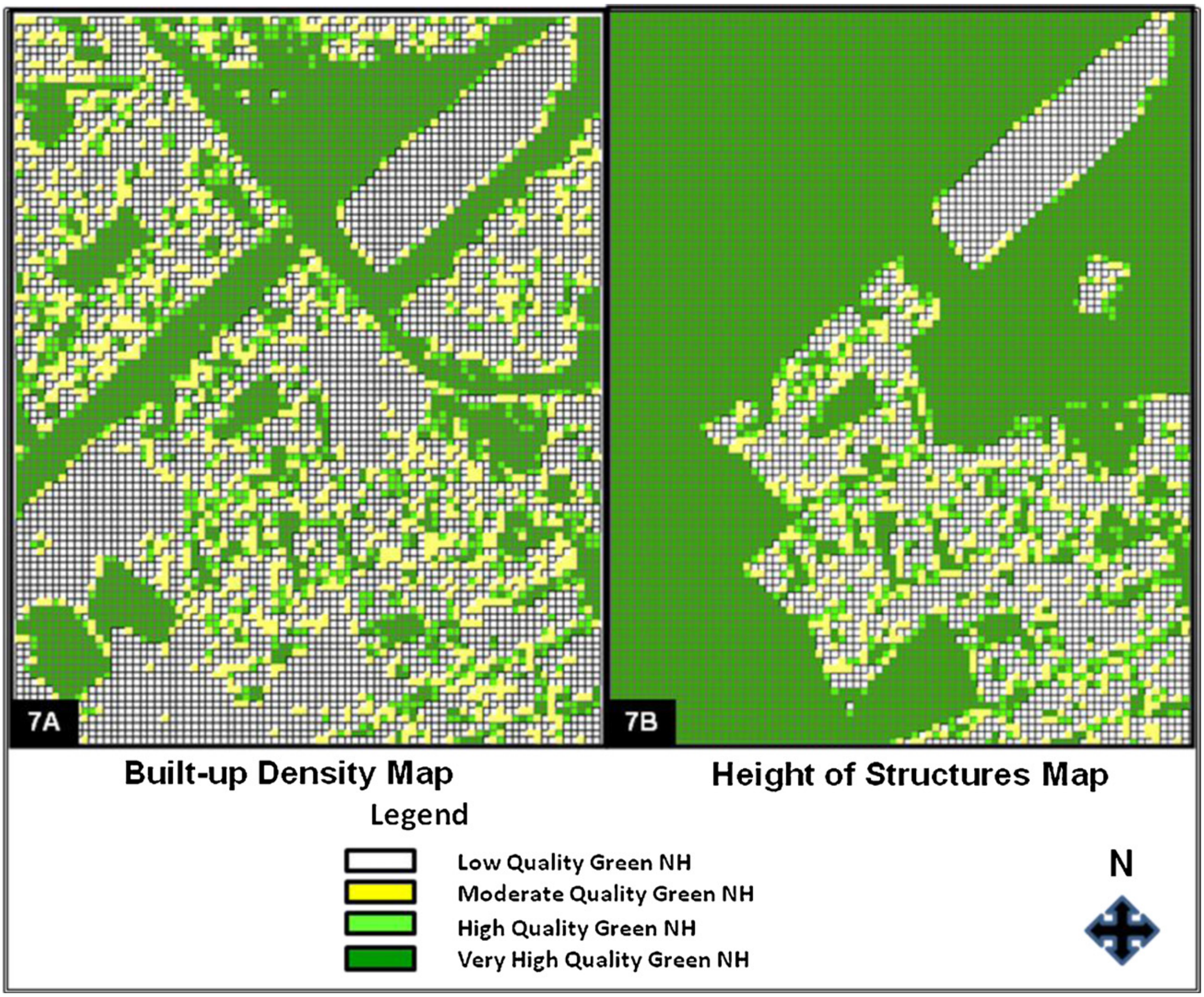

Fig. 7. Built-up density map, height of structures map.

has highest mean value of GI and UNGI. Out of the three type of residential neighborhoods, the high-rise low-density neighborhood and low-rise low-density neighborhood has the same mean GI values, i.e., 0.44 and low-rise high-density neighborhood has lowest mean GI value, i.e., 0.29. The mean values of UNGI is higher for low-rise low-density neighborhood, i.e., 0.62 as compared with high-rise low-density neighborhood, i.e., 0.54 and it is lowest for low-rise high-density neighborhood, i.e., 0.47. While closely analyzing the results, significant difference is observed in the mean values of GI and UNGI specifically in low rise low density neighborhood and high-rise low density neighborhood. Here it illustrates the benefit of using UNGI over GI. As per mean GI values, both neighborhoods are equal in terms of amount of green, i.e., if both areas are judged based on remote sensing images and GI alone, they are equal in terms of urban green quality. But when assessed using UNGI high-rise low density area has lower mean value of UNGI, i.e., 0.54 as compared with low-rise low density neighborhood, i.e., 0.62. It describes the effect of urban density and nearness to green on quality of green in urban neighborhood. In short, area with high-rise buildings requires more amounts of properly distributed good quality green spaces to have the same environmental quality than the area which has low rise buildings as density of people living in the same ground area changes with change in height of residential buildings.

The pattern of standard deviation (SD) values of GI for all four types of neighborhoods is same as mean GI. The value of SD is highest for railway corridor area, i.e., 0.34, nearly equal for low rise low density neighborhood and high-rise low density neighborhood 0.28 and 0.27 respectively and lowest for low rise high density neighborhood. SD of UNGI is lowest for low rise high density NH, i.e., 0.14, highest for railway corridor area 0.29 but the order within the low-rise low density NH and high-rise low density NH has

Table 2
Comparative evaluation of different neighborhoods.

Type of neighborhood	Green Index (GI)		Urban Neighborhood Green Index (UNGI)	
	Mean	Standard deviation	Mean	Standard deviation
Railway corridor	0.73	0.34	0.79	0.29
Low-rise low-density NH	0.44	0.28	0.62	0.21
High-rise low-density NH	0.44	0.27	0.54	0.24
Low-rise high-density NH	0.29	0.14	0.47	0.14

Table 3
Area wise distribution in various neighborhoods.

Area of green quality	Railway corridor (n^* = 2036)		Low-rise low-density NH (n^* = 2252)		High-rise low-density NH (n^* = 2818)		Low-rise high-density NH (n^* = 1491)	
	GI	UNGI	GI	UNGI	GI	UNGI	GI	UNGI
Area of low quality	28.39%	20.55%	68.26%	19.46%	59.55%	50.62%	92.83%	60.11%
Area of moderate quality	3.88%	6.16%	10.66%	45.58%	15.61%	23.87%	3.41%	27.59%
Area of high quality	5.20%	10.78%	7.78%	19.37%	12.42%	20.63%	1.91%	9.80%
Area of very high quality	62.52%	62.50%	13.30%	15.59%	12.42%	4.88%	1.86%	2.50%
Total	100%	100%	100%	100%	100%	100%	100%	100%

n^* indicates the total number of cells in each neighborhood type (sample size).

changed as compared with SD of GI, i.e., 0.21 and 0.24 respectively. From the SD values, it is apparent that low rise low density NH has more homogeneous urban green as compared with high rise low density development. It is true that high rise development is preferred now days to contain the land requirements with accelerated urban growths but the need of good quality green areas in high-rise neighborhoods are much more prominent.

The index and neighborhood wise area distribution of green is given in Table 3 for each neighborhood. The values of GI and UNGI both had been categorized in four equal intervals for the sake of simplicity and ease of interpretation. In low-rise low-density neighborhood, the area distribution within different quality classes is varying significantly with respect to GI and UNGI. Here area under low green quality reduces quite significantly from 68.26% to 19.46%. In UNGI, due to consideration of characteristics of built-up area, it depicts the situation at ground in much more realistic manner.

The above discussion clearly illustrates the importance of including characteristics of built-up such as built-up density, height of buildings and distribution of green spaces while evaluating the urban green. As land resources are becoming scarce and globally urban areas are growing at fast rate, availability of land is always a question, planners has no other option than to go for high rise development. But high-rise development area needs to have more amounts of good quality green spaces.

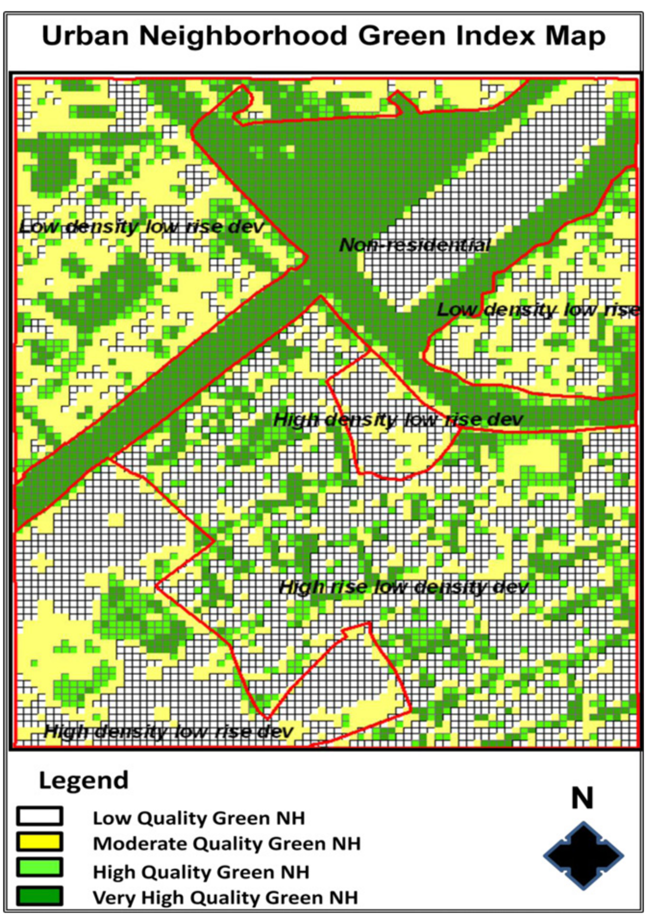

Fig. 8. Derived Urban Neighborhood Green Index Map.

7. Discussion and conclusions

Globally, urban areas are growing at an alarming pace. In fact, it is expected that by 2030 almost five billion people will live in urban areas, which would amount to 60% of the projected global population of 8.3 billion (Venugopal et al., 2010). As a direct consequence of such accelerated urban growth, there is increasing pressure on urban areas leading to the urban greens in cities being diminished even though they are the lungs of cities.

There is a need for getting quantifiable information regarding green structures and their amount and distribution for sustainable planning (Lang et al., 2008). The developed index provides a decision support tool to evaluate, quantify and compare various neighborhoods in terms of amount and distribution of green structure. Rather than merely measuring the overall percentage of green, i.e., GI, the UNGI reflects the importance of distribution of green areas in specific neighborhoods and environments. It also takes into account the characteristics of urban vegetation and built up. The developed index will be an input to model and evaluate future scenarios better aligned to principles of sustainable community development. Since, neighborhood is the working level for application of greening strategies, the developed methodology can help in identifying the critical neighborhoods, which in turn can be used to identify action areas for improving the quality of green. This index can be used by the spatial planners in real estate sector as well. The application of this index can provide an opportunity to undertake a range of neighborhood greening strategies and will be a useful input for urban planning system. The developed index utilizes those parameters which can be interpreted from the remote sensing data with comparative ease and requires minimum input in terms of vigorous ground based data. Besides, the tool is simple to apply and different included parameters are easily interpretable and comprehendible by town planners and city administrators. The index was developed keeping in mind the variety of developments in urban areas and parameters were defined accordingly.

The 20 m × 20 m grid cell was taken considering the minimum mapping unit as 3 pixels by 3 pixels of IRS P6 LISS IV data, which comes to approx. 18 m × 18 m. Schöpfer and Lang (2006) used 100 m grid size after intensive consultation with town planners. The result shows that the present methodology is an improvement over 100 m grid size as 20 m grid size presents the spatial variability at finer resolution. This is just one realization of different combinations of cell sizes and methodology developed can be applied to any size of grid cell to incorporate the neighborhood systems. Bringing the results at grid level helps in simplifying the analysis and comparison between different parts of the same areas can be made. The developed index calculates the relative value rather than an absolute value. In this study more emphasis was laid on to develop the methodology. However, for determining the absolute value, model areas across the urban areas can be taken up in future and developed methodology can be applied.

The study demonstrates that remote sensing images coupled with GIS can be a valuable tool for evaluating the urban green structures. GIS can be an effective tool in preserving and monitoring green and open spaces in an urban area (Ruangrit & Sokhi, 2004). Today, there are several instances where GIS incorporated with other data sources such as remote sensing images and aerial photographs are providing innovative and alternative solutions in the management and monitoring of urban green (Faryadi & Taheri, 2009). GIS is widely accepted in urban landscape planning as it can provide better understanding on the spatial pattern and changes of land use in an area. In future, spatial arrangement of green spaces can be captured in more refined manner with the help of 3D model using stereo pair/LIDAR data, which will provide additional height information to more realistically model the influence of neighboring buildings.

In highly urbanized areas such as big towns and cities it is extremely difficult to find space to plant a new tree. The creation of new green space in already-built urban neighborhoods' provides a longer term challenge to planners. Hence, focus for greening should be shifted to individual green assets (plants on terrace, terrace garden, indoor plants, private garden/lawns, etc.). Detailed environmental policy must be formulated and implemented at neighborhood level with the help of resident welfare associations. Randall, Churchill, and Baetz (2003) suggested neighborhood greening techniques including the naturalization of existing parks and increased foliage along streets and rights of way. The naturalization approach involves less frequent cutting in grassy fields, the introduction of native species, and the cessation of pesticide and herbicide applications. Increased plantings along streets and boulevards would improve the aesthetics of neighborhoods, and may provide some relief from climatic extremes and urban heat island effects. The largest hidden potential, which may be tapped in a large scale, is the individual green assets – comprising of garden, indoor plantation and terrace plantation. This potential needs to be tapped at the household level cutting across all sections of the society. Strengthening this section along with the enhancement and protection of the visible green assets with the aid of geospatial tools, enhanced community involvement and holistic urban planning will stabilize the beneficiary role of urban green space on urban environment.

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