EVALUATING PUBLIC URBAN GREEN SPACES: A COMPOSITE GREEN SPACE INDEX FOR MEASURING ACCESSIBILITY AND SPATIAL QUALITY

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ABSTRACT:

Greenspaces (GSs) available to the public for recreational, environmental, and aesthetic purposes are termed Public Urban Green Spaces (PUGS). Accessibility to PUGS is one of the main pre-requisite for their frequent use. With rising urbanization and inequitable distribution of GSs, a significant portion of the population remains inaccessible to the benefits provided by PUGS. Therefore, it is essential to have tools to evaluate these GSs. This study evaluates the accessibility and spatial quality of various hierarchies of PUGS using GIS-based analysis in Dehradun, India. Accessibility is assessed using network analysis, aesthetics is determined by the presence of bird population and waterbody, the surface index is determined based on NDVI thresholding, and affordability, and spaciousness are computed based on survey and GIS data. The indices are combined to form a composite green space index (CGSI) using analytical hierarchy process. CGSI shows that most of the PUGS in Dehradun have relatively poor accessibility and quality. As per World Health Organization (WHO) guidelines for providing a minimum of $9m^2$ of GS for each person, Dehradun lies way behind, providing $2.02m^2$/person. The lower hierarchy PUGS, notably totlots, which are crucial for young children's physical, mental, and cognitive development, is quite limited. On the contrary, city parks are well distributed with moderate to good accessibility and quality. CGSI is a comprehensive index encompassing different characteristics of GSs and serves as a valuable tool for setting goals, prioritizing investments, identifying areas in need of improvement, and potential locations for future GS development.

1. INTRODUCTION

Public Urban Green Spaces (PUGS) are a fundamental component of urban ecosystems that are available to the general public for recreational, environmental, and aesthetic purposes. They play a vital function in presenting a wide range of ecological and socio-economic functions to city dwellers, such as mitigating climate change and the urban heat island effect, protecting, restoring, and enhancing biodiversity, and reducing air and noise pollution. Greenspaces (GS) in residential areas maintain good social relations and mutual respect among citizens. It also helps in maintaining the mental and physical health, and well-being of the citizens. Economically, green spaces in the vicinity tend to increase property values and promote tourism and generate revenue (Ugolini et al., 2022). PUGS is a long-term asset for cities and has been acknowledged as one of the most important components of sustainable urban development. In this study, we defined PUGS as public parks and playgrounds which are open to the public for use, and the GSs associated with institutional (government, educational institutes, etc.) and military spaces are considered inaccessible GSs.

By 2030, the United Nation predicts that roughly 40.76% of the nation's population would live in urban areas, and by 2050, 68 Indian cities will have a population of more than a million (Lahoti et al., 2019). This fast urbanization is one of the key elements that transform the land surface from natural cover to impermeable surfaces and significantly alters the geographical distribution of urban land use (Patra et al., 2018). This causes a decrease in green infrastructure which can lead to higher temperatures, reduced air quality, and the loss of ecosystem services provided by GSs, such as carbon sequestration and stormwater management. It is becoming evident that to ameliorate urban environmental challenges and build our cities more efficiently for sustainable urban development, we must develop GSs. The Sustainable Development 2030 guidelines emphasize enhancing and providing access to GSs, as doing so will improve people's quality of life and will assist in mitigating climate change (Lorenzo-Sáez et al., 2021). The Indian government has also focused on preserving the existing greenery by adopting several missions and guidelines, such as the Green India Mission (GIM), Atal Mission for Rejuvenation and Urban Development (AMRUT), Smart City mission, Urban Development Plans Formulation and Implementation (URDPFI), and urban greening guidelines, which emphasize the need for a green India. Despite several programs and guidelines, there is limited research on how cities value GSs and how PUGS are being incorporated into urban development (Byomkesh et al., 2012). Thus, PUGS becomes an essential criterion to judge the sustainability of a city.

Unless PUGS are accessible by citizens, their mere availability will not serve the purpose. With rising urbanization and inequitable distribution of PUGS, a significant portion of the population remains inaccessible to the various benefits provided by PUGS, which has also raised as environmental justice issue (Wolch et al., 2014). Based on Coeterier (2000) implementation of Herzberg's two-factor theory, Van Herzele & Wiedemann (2003) describe how people perceive and interact with urban surroundings. They discovered that some circumstances, or 'preconditions' affect whether people visit a particular GS. The distance to the GS is the most crucial criterion. When these prerequisites are satisfied, how long people stay depends on the quality of GSs, including its aesthetics, naturalness, landscaping, variety of amenities, and features catering to the diverse needs of the community, such as walking paths, seating areas, sports facilities, and cultural spaces. Cities can create healthier and more livable environments by prioritizing and investing in the quality of GSs (Fan et al., 2017; Stessens et al., 2017; Van Herzele & Wiedemann, 2003).

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Past few decades, remote sensing, and geographic information system (GIS) technologies have been critical for the evaluation of PUGS. It has been used to determine the spatial distribution of GSs quickly and reliably throughout the city (Nurdin & Wijayanto, 2020). GS accessibility is evaluated using buffer and network analysis and many accessibility indices have been developed (Gupta et al., 2016; Kun et al., 2012; Wolff, 2021). Along with accessibility, PUGS quality is a crucial factor in determining how frequently people visit GSs. To categorize and quantify the GS vegetation, several greenness indices have been established (Czekajlo et al., 2020). Nazmfar et al. (2020) analyze the spatial distribution of crime in urban public spaces. To evaluate the quality of GSs, several landscape measures have been developed (Badach & Raszeja, 2019).

A number of studies evaluating PUGS have been conducted in developed nations (Czekajlo et al., 2020; Fan et al., 2017; Herzele & Wiedemann, 2003), however, there is a gap in the assessment of PUGS in developing nations (Gupta et al., 2016). Most of the research in India focuses on mapping and quantifying GSs distribution and per capita. The ever-increasing urbanization in developing regions possesses high pressure on the already sparse resources, and as Dehradun city in India witnessed an unparallel growth in size from 1999 onwards (Gupta, 2013), the effect of this urbanization on the PUGSs needs to be quantified. Smart City and AMRUT mission programs by Government of India emphasizes the need to develop more amount of green cover, however, assessment mechanism adopted focuses only on amount of GSs to be provided rather than ensuring its distribution, accessibility and quality. Hence, this study proposes a Composite Green Space Index (CGSI) as a tool/method for evaluation of PUGSs as well as to identify the GSs for potential improvement, and develop new strategies. The objective of the study is to evaluate the accessibility and spatial quality of different hierarchical levels of PUGS using GIS-based analysis and develop a composite index for the characterization of PUGS.

2. STUDY AREA

The study area selected is Dehradun planning area located between 30º15'N to 30º25'N and 77º55'E to 78º10'E, in the southern part of Dehradun district in Uttarakhand, India (Figure 1). It is dominated by a humid subtropical climate and characterized by tropical moist and dry deciduous forests. The Dehradun planning area comprises many urban centers which are developed around institutions and national highways as clusters. The number of cities in the adjoining areas of the Dehradun district increased four times, between 1901 and 1981, and after becoming the state capital in 2000, Dehradun witnessed unprecedented growth in size from 1987 to 2008. Though the growth of Uttarakhand state was 18.8% from 2001 to 2011, the total population growth of the Dehradun planning area is about 37.2%. According to census 2011, the total population of the Dehradun planning area is 714,223 (Gupta, 2013).

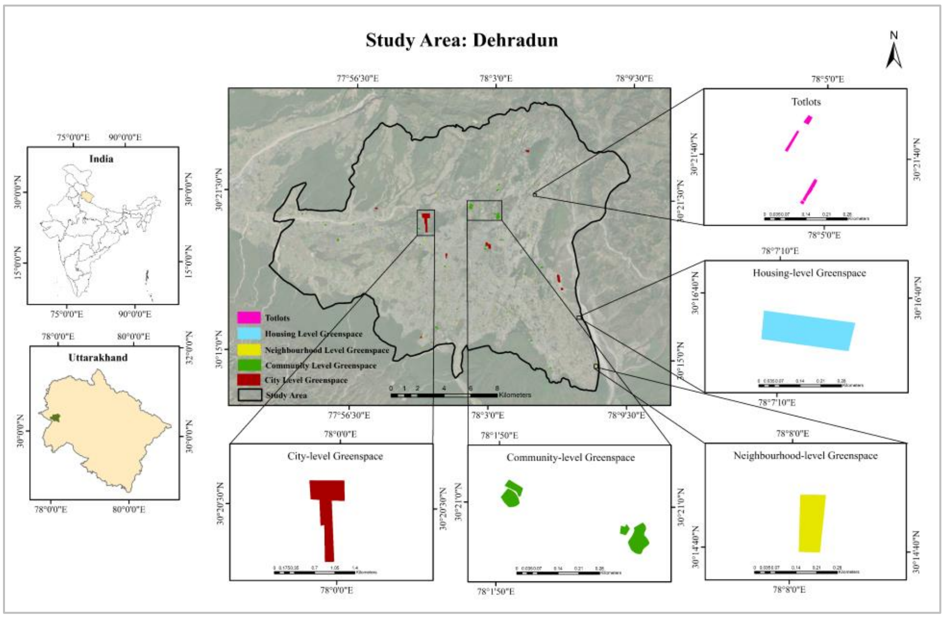

Figure 1. Study area map of Dehradun

3. MATERIAL AND METHOD

3.1 Dataset used

In this study, the optical data from Dove-R at 3m resolution acquired from Planet Labs PBC is used to digitize and classify PUGS (Planet Labs PBC). The road network dataset acquired from the open street map is used for network analysis and the bird population data is acquired from the eBird citizen science database (eBird, 2022) (Table 1).

S.No.	Dataset	Source
1	Dove-R (3m)	Planet Labs PBC
2	Road Network	Open Street Map
3	Bird population	eBird

Table 1. Detail of datasets used in the study

3.2 Methodology

3.2.1 Preparation of Road network: The road network data extracted from the open street map (OSM) is updated and modified keeping Google Earth as a basemap. The updated road network data unknowingly have errors like overlaps or gaps and the network is not well connected, which will affect the network analysis process. Thus, these errors are corrected by creating a topology dataset in ArcGIS. The road pattern of the city is radial with five main transportation corridors originating from the center of the city. These radial roads serve the inter-city and intra-city traffic. Thus, the road network is classified as highway, major, minor, and local road (Gupta et al., 2016) based on the general information on the road type and knowledge of the study area.

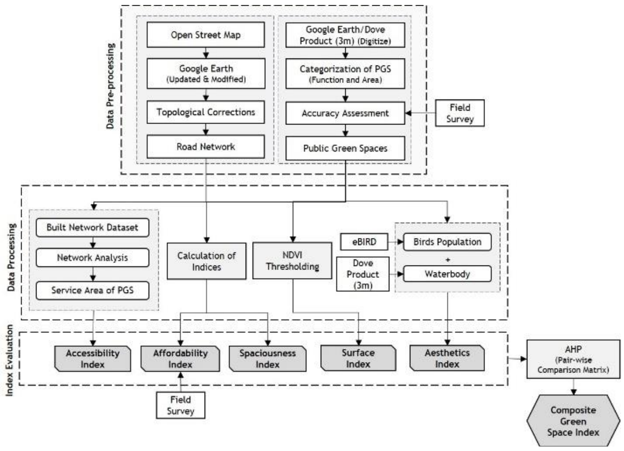

Figure 2. Methodology flowchart for the study

3.2.2 Preparation of PUGS: The green spaces are digitized keeping Google Earth and Dove-R data as base map in the GIS environment. The digitized PUGS are classified as totlot, housing, neighbourhood, community, and city-level GSs based on the population and area categorization of the Master Plan of Delhi-2021 (MPD-2021) (Anon, 2010) and general knowledge of the area. A totlot is defined as the smallest unit of UGS at the doorstep, to cater to the needs of early-stage children and provide them a safe environment to play. Similarly, a housing-level park and playground are located near the vicinity of a residential area, so that it is regularly used by children (Gupta et al., 2016). A neighbourhood and community-level park provide a green area to spend quality time with friends and family, and a city-level park provides a weekend leisure activity for the entire circle of relatives (Herzele & Wiedemann, 2003). For example, Gandhi Park has an area of 43,654 m^2, which must be classified as community-level GS, but according to its function, it is a city-level GS. Similarly, many PUGS are classified based on their function rather than strictly adhering to the area-based classification of MPD-2021.

3.2.3 Calculation of Indices: In this study, indices for assessing the accessibility and spatial quality of PUGS, namely, accessibility index, aesthetics index, affordability index, spaciousness index, and surface index are calculated.

(a) Accessibility Index (*AI*): The concept of accessibility was first proposed by Hansen (1959) as a potential tool for urban planning. PUGS accessibility is associated with the ability to access the GS, both physically, i.e., without any barriers, and psychologically, which is specific to certain citizens with disabilities (Biernacka & Kronenberg, 2018). There are many methods to assess accessibility, such as axial distance, buffer analysis, network analysis, cost-weighted distance, and minimum distance. In the past few decades, network analysis which originates from graph theory and topology holds a prominent place in GIS to model network conditions. It is used to understand the interrelation between the network elements, based on different impedances, turn restrictions, traffic, and speed limits (Kun et al., 2012).

PUGS Hierarchy	Time Impedance (min)	Radial Distance* (m)
Totlot	1	50
Housing	5	150
Neighbourhood	10	400
Community	15	800
City	60	3200

*****radial distances are based on Herzele & Wiedemann (2003) classification

Table 2. Time impedance and radial distance for accessibility analysis of PUGS

As discussed above, the MDP-2021 classifies GSs in different hierarchical levels based on population and area parameters, but it does not define any distance standards. A study carried out by Gupta et al. (2016) in Delhi, defined different linear distances for GSs based on Van Herzele & Wiedemann (2003) approach. Also, according to a survey conducted by Luthra & Gupta (2012) in Delhi, it has been found that there is an inclination towards longer walking time for a higher level of GS. Since, this study at the national level well elaborates on-ground scenario in India, a similar criterion for network analysis has been followed in Dehradun too.

In this study, PUGS accessibility is assessed using network analysis, which involves creating a network dataset and generating service area polygons for each PUGS based on the time impedance specified in Table 2, where totlots, housing, neighbourhood, and community-level GSs are at a walking distance of 1, 5, 10 and 15 minutes respectively, and city level GSs are accessed by vehicles with a travel distance of about one hour (Gupta et al., 2016). The time impedance is based on the average speed of travel. According to Gupta et al. (2016), the average walking speed for local and minor roads is 0.75 m/s, and for highway and major roads is 1.00 m/s. According to Thakur et al. (2021), the average speed of motorized traffic on pedestrian-free roads, i.e., highways and major roads, fluctuates from 26 to 39 km/h, and in the presence of pedestrians, speed lowers down to 10 to 17 km/h. Thus, the average speed of 3.75 m/s for local and minor roads and 9.03 m/s for highway and major roads are considered in this study (Table 3).

Type of Road	Speed (m/s)	
	Walk	Vehicle
Local	0.75	3.75
Minor	0.75	3.75
Major	1.00	9.03
Highway	1.00	9.03

Table 3. Average speed of travelling

The accessibility index is defined as the ratio of the service area generated through network analysis, and the maximum service area (Equation 1) calculated using radial distances, as given in Table 4.

$$AI_i = \frac{SA_i}{Max\ (SA)} \quad (1)$$

Where AI_i is the accessibility index of i^{th} PUGS, SA_i is the service area of i^{th} PUGS and $Max\ (SA)$ is the maximum service area around the PUGS. The maximum service area is a circular area of a specified radius, i.e., the linear distances used to define the service area for buffer analysis in many studies (Gupta et al., 2016; Van Herzele & Wiedemann, 2003).

(b) Aesthetics Index (*AE*): A GS aesthetics relates to its perceptual attributes to the physical features of GSs and its surrounding that make them beautiful and attractive (Coles & Grayson, 2004; Fan et al., 2017). To improve user experience and foster peace and enjoyment inside the GS, aesthetics is crucial. Although, it is arbitrary and subject to change, in this study the bird population in and around the GS and the presence of waterbodies have been considered to determine the aesthetics of PUGS using the given Equation 2.

$$AE_i = (B_{ini}) + B_{bi}) + W_i \quad (2)$$

Where AE_i is the aesthetics index of i^{th} PUGS, B_{ini} is the number of birds inside i^{th} PUGS, B_{bi} is the number of birds around a 500m buffer of i^{th} PUGS, and W_i is the area of waterbody present in i^{th} PUGS. The bird count is acquired from eBird (eBird, 2022), which is a citizen science database and waterbody is digitized from Dove-R data. The data have been normalized to calculate the aesthetics index.

(c) Affordability Index (*AF*): As an entrance fee is a barrier for people wanting to visit a GS, affordability is a crucial aspect to consider when evaluating a GS. Although most of the PUGS in Dehradun are free to the general public, there are a few PUGS like Forest Research Institute, Dehradun Zoo, etc., which charge entrance fee. It is calculated using the given Equation 3, where the entrance fee for each GS is divided by the maximum entrance fee in the study area, and is further subtracted by 1 (Fan et al., 2017).

$$AF_i = 1 - \frac{P_i}{Max\,(P)} \quad (3)$$

Where AF_i is the affordability index of i^{th} PUGS, P_i is the entrance fee for i^{th} PUGS and *Max(P)* is the highest entrance fee (i.e., Rs. 750 at Joyland, Sahastradhara).

(d) Spaciousness Index (*SI*): The visitor's perception of the GS's size, shape, and associated level of comfort is referred to as spaciousness. According to (Grahn, 1994), people enjoy themselves more when there are more GSs nearby. It is calculated using the given Equation 4 (Fan et al., 2017).

$$SI_i = \sqrt{\frac{A_{pi}}{A_{ci}}} \quad (4)$$

Where SI_i is the spaciousness index of i^{th} PUGS, A_{pi} is the actual area of i^{th} PUGS, and A_{ci} is the area of a circle with the same perimeter as i^{th} PUGS. A higher value of SI indicates a higher quality of spaciousness.

(e) Surface Index (*SF*): The type of surface in and around PUGS has a significant impact on their quality and user experience. The surface also has environmental implications, where a pervious surface with vegetation and permeable pavement or gravel improves the ecology by allowing better water infiltration, reducing stormwater runoff, and promoting groundwater recharge. On the contrary, an impervious surface has a negative impact on its ecology (Coles & Grayson, 2004). In this study supervise classification and NDVI thresholding was performed, and four types of surfaces were categorized as dense vegetation, sparse vegetation, waterbody, and impervious surface. Weights were assigned to them and the surface index was calculated using the given Equations 5 and 6.

$$S_i = (V_{di} \times 1) + (V_{si} \times 0.5) + (W_i \times 0.2) + (I_i \times 0) \quad (5)$$

$$SF = (S_{ini} \times 1) + (S_{bi} \times 0.5) \quad (6)$$

Where S_i is the surface value of i^{th} PUGS, V_{di} is the area of dense vegetation present in i^{th} PUGS, V_{si} is the area of sparse vegetation present in i^{th} PUGS, W_i is the area of waterbody present in i^{th} PUGS, I is the area of impervious surface present in i^{th} PUGS, S_{ini} is the surface value inside the i^{th} PUGS, and S_{bi} is the surface value around a 500m buffer of i^{th} PUGS. The surface index is the sum of the surface value in and around the PUGS.

3.2.4 Development of Composite Green Space Index (CGSI): The CGSI assess the accessibility and spatial quality of GSs and quantifies them for promoting environmental sustainability, social equity, informed urban planning, public health, and realizing the economic benefits associated with green infrastructure. CGSI ranges from 0 – 1, where a higher value indicates GSs with very good accessibility and quality, whereas a lower value indicates poor accessibility and quality. The indices calculated so far are combined using an analytic hierarchy process by computing a pairwise matrix and assigning weights to each index. The resultant CGSI is calculated using the given Equation 7.

$$CGSI_i = (AI_i \times 0.32) + (AE_i \times 0.29) + (SF_i \times 0.17) + (SI_i \times 0.16) + (AF_i \times 0.07) \quad (7)$$

Where $CGSI_i$ is the composite green space index of i^{th} PUGS, AI_i is the accessibility index of i^{th} PUGS; AE_i is the aesthetics index of i^{th} PUGS; SF_i is the surface Index of i^{th} PUGS; SI_i is the spaciousness index of i^{th} PUGS; AF_i is the affordability index of i^{th} PUGS.

4. RESULTS AND DISCUSSION

4.1 Spatial distribution of PUGS

The study area map (Figure 1) shows the spatial distribution of different hierarchical levels of PUGS in the Dehradun master plan area. The neighbourhood-level GSs are high in number, i.e., 174, followed by housing and community-level GSs. Totlots are very few, only 34. Although the number of city-level GSs is low, only 11, the percentage of area occupied by them is the maximum (~38.56%), followed by the community (~31.08%), neighbourhood (~20.66%), and housing (~9.19%). Totlots cover the least percentage of the area (~0.52%) (Figure 3).

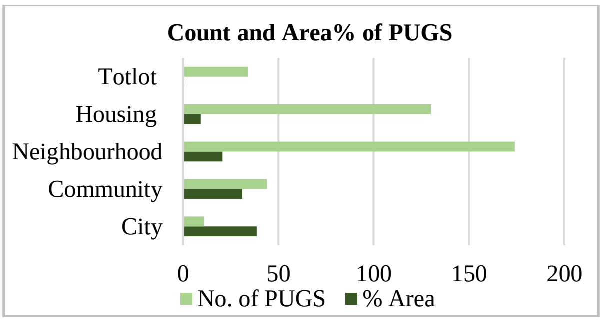

Figure 3. Count and percentage of area covered by PUGS

The spatial distribution of PUGS hierarchies revealed that there is an overall deficiency in the lower hierarchy of PUGS, especially the totlots. Totlots are very important for the physical, mental, and cognitive development of early-age children by providing them a safe accessible space to play (Goldstein, 2012). There are very few totlots clustered together in apartments. Housing-level GSs located near the vicinity of the residential area are poorly dispersed; the majority are concentrated in the city centre and are absent to the west. Neighbourhood-level GSs being the highest in number are widely spread in the city core but rapidly reduce towards the west. Community-level GSs exhibit slightly different patterns, as they are present in the west direction. Although that there are just 11 city-level GSs, they are well distributed and span nearly the whole study region. The absence of PUGS in the west direction can be attributed to the growth pattern of Dehradun city during 1987-2008, as most urban growth was observed in the south, southeast, and southwest directions (Gupta, 2013).

4.1.1 Accuracy Assessment: The accuracy of PUGS classification is estimated by conducting ground survey based on stratified random sampling and preparing a confusion matrix. An overall accuracy of 93.06% and a kappa of 0.90 was obtained.

4.2 Accessibility and Spatial Quality Indices

The indices calculated for each PUGS are classified into five classes, namely, very poor (0.00–0.19), poor (0.20–0.39), moderate (0.40–0.59), good (0.60–0.79), and very good (>0.80).

4.2.1 Accessibility Index (*AI*): Accessibility is a fundamental element in determining the usage of PUGS by local residents (Van Herzele & Wiedemann, 2003). To compare the accessibility of various hierarchies of PUGS, an accessibility index is constructed which ranks the GSs based on the accessible road network around it. The percentage of various hierarchy of PUGS falling in different AI ranges is calculated. About ~26% of totlot falls under the poor accessibility range, and the remaining ~74% falls under the moderate accessibility range. The major portion of housing level GSs falls under the moderate (~37%) to poor (~28%) class. Almost half (~53%) of the neighbourhood-level GSs have poor accessibility, and every community-level GSs have very poor to poor accessibility. On the brighter side, the city-level GS has very good accessibility (Figure 4). There are very few studies conducted to assess the accessibility to PUGS at the national level. One such study conducted by Gupta et al. (2016) is significant and provides a good insight into the accessibility of different hierarchical levels of GSs, but was conducted at a local level. At this pace of development and urbanization, there is a requirement for assessing the GSs at the city level.

4.2.2 Aesthetics Index (*AE*): Aesthetics play a crucial role in creating attractive and enjoyable GSs that improve the well-being and contentment of those who visit PUGS. Most of the totlots, housing, and neighbourhood-level GSs in Dehradun have poor aesthetics. Very few community-level GSs have good aesthetics (~4%), and only ~9% of city-level PUGS have very good aesthetics (Figure 4). Forest Research Institute in Dehradun is a city-level PUGS known for its exceptional aesthetics which can be attributed to a combination of its architectural beauty, lush green surroundings, well-maintained gardens, and historical significance. On the other hand, the unappealing appearance of other PUGS in Dehradun reflects the lack of planning, design, and lack of maintenance of greenery, which in turn provides limited habitat and biodiversity.

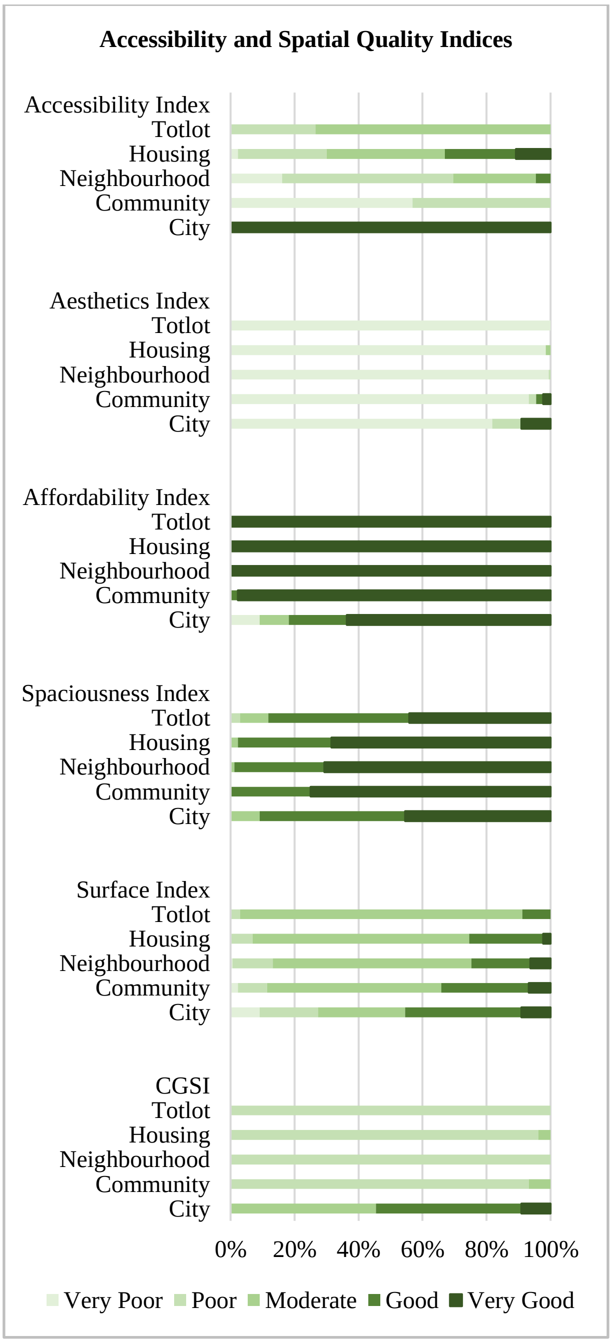

Figure 4. Accessibility and spatial quality indices of PUGS (a) accessibility index, (b) aesthetics index, (c) affordability index, (d) spaciousness index, (e) surface index, (f) composite green space index

Additionally, raising awareness and involving the community in conservation initiatives can contribute to the restoration of bird habitats and the overall aesthetics of UGS.

4.2.3 Affordability Index (*AF*): Since most of the PUGS in Dehradun do not have any entrance fee, they are very affordable. Only one community-level GS, i.e., MDDA Park in Rajpur, charge a small amount of entrance fee. About ~38% of city-level GSs charge entrance fees, ranging from Rs. 20 to Rs. 750, for Forest Research Institute and Fun and Food Kingdom respectively (Figure 4).

4.2.4 Spaciousness Index (*SI*): About 88% of totlots are spacious, and only ~12% of totlots fall under poor to moderate spaciousness index. Similarly, housing, neighbourhood, and community-level GSs have moderate to very good spaciousness index values. About ~90% of the city-level GSs have high spaciousness value, and only ~10%, including, Forest Research Institute have moderate spaciousness index value (Figure 4). This is because of the restrictions in accessing a few parts of the green areas, which have been reserved for the FRIDU students, IGNFA, and CASFOS trainees. Spaciousness has a positive impact on the quality of GSs by enhancing comfort, air circulation, visual appeal, and overall well-being.

4.2.5 Surface Index (*SF*): About ~91% and ~75% of totlots and housing level GSs have poor to moderate surface index. Also, ~75% of neighbourhood-level GSs have very poor to moderate surface index. About ~34% and ~45% of community and city-level GSs have well surface index values (Figure 4). The type of surface in PUGS can have various effects on their functionality and quality. The suitability of PUGS for various activities may vary depending on the surface type. For instance, impervious surfaces like concrete or pavement are good for activities like walking, jogging, or cycling, grassy areas are suitable for picnics, sports, or relaxing. The functionality and enjoyment of the urban green spaces (UGS) are improved by selecting the right surface type for the intended purpose (Coles & Grayson, 2004). The surface influences the maintenance requirement of PUGS. To maintain grass or natural soil, regular mowing, watering, or reseeding may be necessary. Others, like paved surfaces, could need routine maintenance like cleaning or repairs. Pervious surfaces also play a role in drainage and water management, enhance biodiversity, support ecological processes, and build more resilient and sustainable habitats (Ramaiah & Avtar, 2019).

4.3 Composite Green Space Index (CGSI): The CGSI constructed to compare the accessibility and spatial quality of various hierarchies of PUGS in Dehradun city reveals that most of the PUGS have poor CGSI, despite being in a good number. Every totlot and neighbourhood-level GSs have poor CGSI value. The major portion of housing level GSs falls under the poor (~96%) and moderate (~4%) CGSI range. Similarly, ~93% and ~7% of community-level GSs have poor and moderate CGSI values. For city-level GSs, most of them (~91%) have moderate to good CGSI value, and about ~9% have very good value for CGSI (Figure 4). Figure 5 shows the spatial distribution of various hierarchies of PUGS classified as per the range of CGSI values. Most of the housing, neighbourhood, and community-level GSs in Dehradun are entrusted to the government for their maintenance. Unfortunately, there appears to be a significant lapse in fulfilling this responsibility due to the limited financial resources allocated for the development and maintenance of GSs, resulting in a lack of facilities, poor infrastructure, and insufficient maintenance. As the city-levels GSs cater to a larger population, they receive significantly more attention compared to other hierarchies of PUGS. City level GSs such as Forest Research Institute, Buddha Temple, and Malsi Dear Park also serve as attractions for tourists and boost the local economy. While city-level GSs attract more attention, it is vital to remember that efforts should be made to enhance other hierarchies of PUGS in other locations and guarantee an equitable distribution of high-quality GSs among various communities and neighbourhoods.

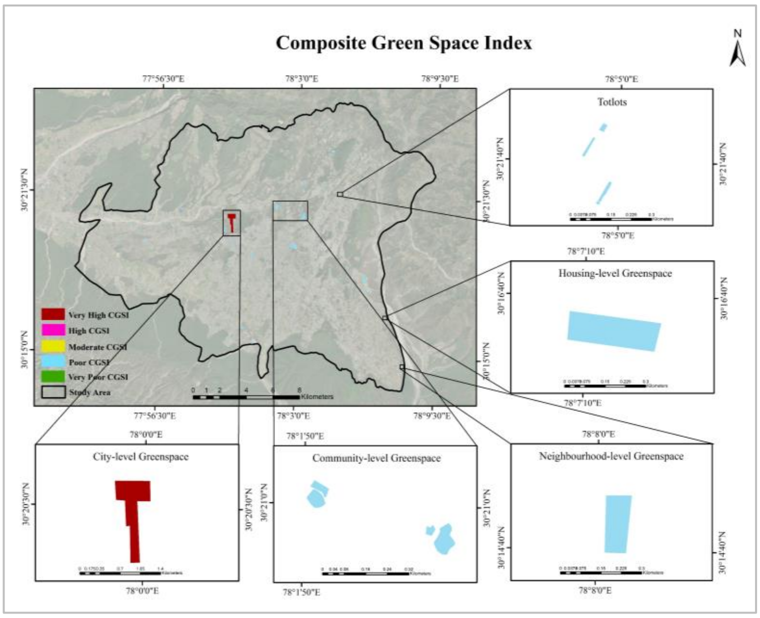

Figure 5. Spatial distribution of different hierarchy of PUGS based on composite green space index (CGSI)

As cities become more and more populated due to growing urbanization, there are several urban environmental issues, including air and water pollution, urban heating, and urban floods, which have a detrimental effect on both the ecosystem and human health. UGS are frequently defined as green lungs that aerate the city matrix, enhance a city's appearance, and are vital for urban health and the environment. A well-distributed and interconnected UGS has the potential to improve society's overall sustainability and energy efficiency (Ugolini et al., 2022). Hence, it is essential to have methods and tools for evaluating GSs, identifying the areas with potential for improvement, and developing new strategies. Moreover, the national missions of "green India" and "enhanced energy efficiency" highlighted in the National Action Plan on Climate Change (NAPCC), emphasize the need for green India (Imam & Banerjee, 2017). The Smart City mission also emphasizes providing a sustainable environment as one of its key objectives, with the goal of green city by 2030, preserving and developing open spaces, and restoration of parks (Prasad & Alizadeh, 2020). AMRUT also aims at increasing the amenity value of cities by enhancing greenery & well-maintained open spaces (Smith & Pathak, 2018). Dehradun being under the Smart City & AMRUT mission aims at increasing the PUGS and thus this study has been conducted to develop a tool that will help to quantify the GS.

Using remotely sensed data, the developed CGSI will evaluate the key elements of PUGS and comprehend the intricacy of various components related to it. It provides a valuable tool for setting goals, prioritizing investments, identifying areas in need of improvement and potential locations for future green space development, and ensuring equitable assess to GSs for all residents. This index can play a crucial role in urban planning by providing valuable information and insights that inform decision-making and guide the development of sustainable, livable cities.

Through the adoption of numerous policies and guidelines, the government has shown a dedicated approach to preserving the existing greenery. They have developed plans and regulations to protect and sustain GSs. The index developed in this study will be shared with the central, state, and municipal bodies involved, including organizations such as Town and Country Planning Organization (TCPO) to promote sustainable development and raise urban dwellers' quality of life.

5. CONCLUSION

PUGS are vital components of sustainable and livable cities, providing opportunities for society to interact with the environment, learn about ecological processes, and protect native biodiversity in the urban area This study fills part of the significant gap in the analysis of hierarchical level of PUGS in a developing nation. The study proposes to evaluate the accessibility and spatial quality of various hierarchies of PUGS by developing a CGSI. The study revealed that most of the PUGS in Dehradun have poor CGSI. Although the city-level GSs have moderate to very good CGSI, there is an overall deficit of lower hierarchies of PUGS, especially the totlots, covering the least percentage of area, only ~0.52%. As per World Health Organization (WHO) guidelines for providing a minimum of $9m^2$ of GS for each person, Dehradun lies way behind, providing $2.02m^2$/person. This study emphasizes the need of developing a comprehensive index encompassing different characteristics of GSs. CGSI provides a valuable tool for setting goals, prioritizing investments, identifying areas in need of improvement and potential locations for future green space development, and ensuring equitable assess to GSs for all residents. In conclusion, through the development and utilization of CGSI, cities can create vibrant, resilient, and sustainable urban environments that enhance the overall quality of their communities.

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