# A SYSTEMATIC REVIEW ON URBAN GREEN SPACES

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***Abstract**: The appropriate knowledge about the component of urban green spaces (UGSs) such as their distribution and species composition, abundance has achieve priority in the pasture such as environmental observe, urban planning, urban geography, and public health. Remote sensing technologies have made an extreme improvement in the analysis of UGSs. However, an entire and detailed review of the present status, challenges and ability in this area is flawed behind. In this review paper, we scrutinize major trends in remote sensing approaches for characterizing UGSs. The studies focusing on mapping UGSs and classifying species within UGSs have increased rapidly over recent decades. However, there are fewer examples of non-tree species mapping, change detection, biomass and carbon mapping, vegetation, health assessment within UGSs. Most studies have dedicated on UGSs (mainly green spaces) which cover large areal extents, with fewer studies of smaller areas such as green spaces, urban gardens, recreational spaces and public parks, even though collectively such patches can cover substantial areas. Hence, we suggest future investigations to focus on a wider variety of different UGSs, particularly small-scale UGSs. We also mention that research focuses on developing more active image time series analysis techniques, procedures to capture the density of UGSs and the use of SAR in studies of UGSs. At the same time, further research is required to fully achievement remote sensing data within thematic applications such as monitoring changes in UGSs over time, quantifying biomass, carbon mapping and assessing vegetation health.*

***Keywords:** GIS, Public urban green space, urban planning, thematic map, landscape typologies.*

## 1. INTRODUCTION

Inhabitants in urban areas are increasing day by day and are expected to reach 70 % of the world population by 2050 (Chang et al., 2015) which will ultimately result in increased environmental problems in cities such as pollution which further results in Global warming and climatic change. In reaction, there is an increasing recognition that urban green spaces (UGSs) have a role in mitigating such environmental pressures and promote multiple effects such as health, wellbeing, and aesthetic benefits to urban dwellers (Ossola and Hopton, 2018). To maintain these positive effects, there is a need for protecting and improving existing UGSs, and at the same time developing new urban green infrastructure. Therefore, data on UGSs are important to various issues in urban science such as planning, management, and public health. Traditionally, numerous methods have been employed to accumulate information about UGSs. But they are costlier, time-consuming, and require more human power. Nowadays remote sensing technologies have occupied an important place in the study of UGSs as it can produce recurrent and broad treatment at changed spatial scales and for altered seasons (Pu and Landry, 2012). Based on current improvements such as high spatial determination imagery and free data access procedures, remote sensing is provided that a respected set of tools that are bright to minimize the need for field study, even in highly heterogeneous and multifaceted urban settings. For example, remote sensing has been established to be actual for mapping street trees (Parmehr et al., 2016), identifying class within UGSs (Shojanoori et al., 2018), planning martial shrubs in UGSs (Chance et al., 2016), and measuring plants strength within UGSs (Nasi et al., 2018). Also, present remote sensing plans such as Copernicus (Harris and Baumann, 2015) and Landsat (Zhu et al., 2019) not only afford ancient time-series data but also simplify access to newly developed data. Remaining to these profits, many scholars and managers have applied remote sensing to study UGSs (Shojanoori and Shafri, 2016).

This study will provide detailed knowledge which will enable better utilization of remotely sensed data and inspire wider attention in investigators for analyzing dealings among such data and studies of UGSs. The review begins by establishing key research questions related to the remote sensing of UGSs, with a particular interest in trends, and potential applications.

## 2. Literature Survey

In an urban conversion state, land-use change collective with a lack of UGS stewardship results in minor, fragmented, and degraded UGS [Dallimer, M., Davies-2015]. One of the biggest challenges in this situation is the lack of capacity to plan and implement change [Town & Country2014], due to the unavailability of data or records of the current situation of UGS [Troy, A., & Wilson-2006]. This lack of a complete dataset coupled with rapid administrative boundary expansion and unauthorized land conversion in the urban conversion process makes the monitoring and management of UGS a more complex process. The local authorities fail to understand the associated trade-off of land allocation and its implications on the overall urban environment of a city. The local authorities refer to the cadastral maps for planning, observing, and management of UGS, however, these maps fail to characterize the complete landscape character, the various set of functions achieved by UGS, their distribution, and other associated attributes. This lack of base data in understanding the multifaceted and active landscapes prevalent in cities becomes one of the major hindrances in the decision-making process. Thus, the need for more detailed maps (spatial data) with spatial heterogeneity of the quantity and quality of services provisioned to guide a more integrated understanding of UGS arises [Meyer, B. C., & Grabaum, R.-2008] The spatial dataset augmented with detailed landscape layers facilitates the effective communication and evaluation of service supply or the demand side of UGS [De Groot, R. S., Alkemade-2010], for which geographic information system (GIS) is very operative and widely recognized as an “automated systems for the capture, storage, retrieval, analysis, and display of spatial data” [Clarke, K. C.-1995]. GIS allows overlaying different information in an integrated manner that is perceptive and communicable to different stakeholders [Muyphy, E.; King, E.E.-2013]. Hence, GIS efficiently integrates, symbolizes, and connects data to guide the preparation process of UGS. These remotely-sensed data are widely used for Land Use Land Cover Change (LUCC) studies. The coarse spatial scale (30 m resolution) identifies green spaces consistently across larger geographical units generated during the classification process of imagery, in the form of random polygons with distinctive land cover, however, the data may not be expressive to planners in terms of units recognizable on the ground [Yusof, M., & Johari, M-2013]. The classification of remotely-sensed data is based on the reflectance of ground cover, which is converted into polygons with distinct land cover, though, the unit size and the classes of green spaces measured are broad and lack functional classification and ownership details (e.g., isolated or public green spaces), which are essential for accomplished landscapes. Thus, the need to produce spatial data that consider other characteristics of human-dominated landscapes in addition to numerical green space cover arises to allow more sophisticated methods for analyzing green spaces for urban planning purposes [Dennis, M., Barlow-2014]. Hence, the maps generated by analyzing the remote sensing data referred to as thematic maps [Gupta, K.; Sharma-2015], which association "spatial and non-spatial data" were explored as a significant tool for dataset preparation in this study. Few studies platform the growing use of GIS in development, such as in Vietnam, a dataset of urban trees and green space of two cities was ready by mapping in GIS [Gopal, S., & Woodcock-1994]. Some more authors have used it to map urban green infrastructure and understating land cover change [Sreetheran, M-2007]. In India, as well mapping of secure green spaces (national parks and forest), urbanization and changing land use land cover trends, green space quality, and quantity study at the neighborhood scale are evident in recent publications [Kafafy, N. A.-2010], however spatial data with finer details are mostly unavailable. Though this is dynamic for planning and decision making, at present spatial and digitized data for UGS is not presented for most Indian cities, thus poorly affecting the planning process. A recent study by Angularity and Narayanan also highlighted the need for green space mapping to provision land distributions during master plan preparation for emerging urban centers [Tan, P. Y., Wang, and J- 2013]. Thus, to protect, achieve and successfully plan the threatened and stressed UGS in a combined manner, it is important to record what is prevalent in the city.

With this context, the study endeavors to develop a mapping methodology to create a thematic map of public UGS for the Aurangabad city as a case.

## 3. Methodology

**Table 1: The Different Methodology And Various Database**

| Sr. No | Method | Year | Database | Result |
|---|---|---|---|---|
| 1. | Thematic Map, Kappa Coefficient, Mapping Methodology Systematic Random Sampling Method, Error Matrix, ArcGIS 10.5.1, Google Earth, GIS | 2019 | Spatial And Non-Spatial Data, Holistic Dataset, Integrated Dataset With Added Information And Status Of Different Typologies Of Green Spaces, Lakes, Drainage, River, Urban Forests, Institutional Green Spaces, Parks, Playgrounds And Gardens | 95% |
| 2. | Quantum GIS Spatial Analysis | 2015. | CORINE And Global Land Cover, Urban Atlas | 90% |
| 3. | Automatic Classification Maximum Likelihood Classifier ESA SNAP 3.0 And ESRI ArcGIS Desktop 10 Software | 2016 | S2A Data | 86% |
| 4. | Maximum Likelihood Algorithm Global Positioning System (GPS), Histogram Equalization Remote Sensing Data, GIS Technology | 2013 | Topographic Map And Remote Sensing Data | 70% |
| 5 | Arc GIS 10.3 And ERDAS Imagine 2013 Software's For Analysis | 2017 | Numerous Spatial And Non-Spatial Datasets | 75% |
| 6. | Laying Test Plots ArcGIS 10.3. | 2020 | Landsat-8 And MODIS Data | 70% |

| | | | | |
|---|---|---|---|---|
| 7 | GIS-Based Multi-Criteria Analysis (MCA), ArcGIS 10.2 And ERDAS Imagine 2010 | 2021 | Spatial And Non-Spatial Data | The GIS-Based Multi-Criteria Analysis Performed In This Study Found That, In The Current Situation, The Larger Land Mass (47 %) Of The Town Is Suitable For Developing Urban Green Spaces. The Town, Therefore, Has Great Potential To Develop Adequate Urban Green Spaces. |
| 8 | Cellular Automata<br>Genetic Algorithm (GA)<br>Spatial-Explicit Model<br>Markovian Process | 2011 | IRS P-6 Data And Topographic Sheet In GIS | There Is A Significant Entropy Change (46.41%) In The Last 35 Years. The Increase Of Entropy Values Indicates That There Is An Increase In Urban Sprawl And The Urban Growth Tends To Be More Dispersed Over A Period Of Time. |
| 9 | Geographical Information Systems (GIS) And Remote Sensing Technology<br>ArcGIS Software And Spatial Analyst Tools, Global Positioning System (GPS)<br>Maximum Likelihood Algorithm | 2014 | Topographic Map 57 O/6, Remote Sensing Data Of LISS III And PAN Of IRS ID Of 2014 | The Results Clearly Show That LU/LC Changes Were Significant During The Period From 1990 To 2014. This Study Clearly Indicates The Significant Impact Of Population And Its Development Activities On LU/LC Change. |

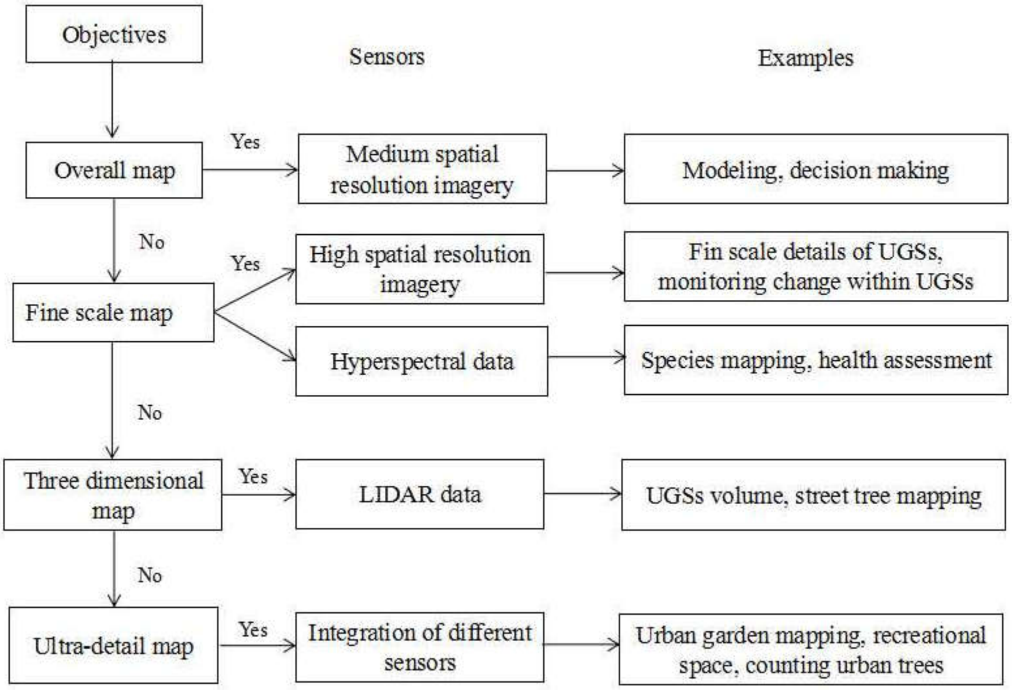


**Fig. 1: A Possible Nested Architecture for Remote Sensing Of UGSs.**

We studied various research papers while doing this research hence we did some questionaries' answering regarding the future of UGSs research work.

**3.1 While using remote sensing in various studies of UGSs, it takes diverse time as well as space.**

Between 1982 and 2000, most studies were dedicated to representing the green status of UGSs and used data from graphical clarification of aerial photos (Nowak et al., 1996) and arena operations (Shojanoori and Shafri, 2016). This could be large because of the lack of appropriate remote sensing technology for detecting and mapping UGSs, immature digital image processing, and pattern recognition algorithms, limited computing power, and lack of open access to remotely-sensed data (Jensen and Cowen, 1999; Shojanoori and Shafri, 2016). Likewise, it is value observing that while some high spatial resolve satellite sensors (e. g., IKONOS) were launched prior to 2001, the lack of appropriate image processing techniques could have hindered progress towards applications of these data in UGSs (Blaschke, 2010). At the opening of the 21st century, the use of remote sensing to train UGSs improved quickly. Although many remote sensing milestones have occurred during 2001–2019, we selected four major developments which have promoted the remote sensing of UGSs.

1. The increased availability of high spatial resolution remote sensing technology (e.g., QUICKBIRD (launched in 2001), Orb View (launched in 2003)) has made fine scale monitoring of UGSs possible, which is important in most UGS investigations.
2. Great spatial purpose imagery has become accessible at a worldwide scale complete Google Earth, in the form of different products such as aerial photographs, satellite imagery, and street views. Secondly, there has been an increasingly widespread deployment of two data sources either stand-alone or collective collected: Light Finding and Extending (LiDAR) and hyper spectral remote sensing machinery. LiDAR sensors are able to produce accurate evidence on the perpendicular assembly of vegetation within UGSs by using discrete returns and waveform data. Hyper spectral sensors simplify the documentation of vegetation classes within UGSs via spectroscopic investigation (Jensen et al., 2009). Stand-alone or combined use of LiDAR and hyper spectral sensing have become important in many practical studies of UGSs.
3. Prior to 2008, the cost of admission to Landsat images (medium spatial resolution) had controlled our capability to screen UGSs. Since 2009, however, all archived Landsat scenes have become available to all users at no charge via several websites. This has revolutionized the use of the Landsat archives in establishing new science, algorithms, and data products in urban geography.
4. The European Space Agency has implemented the Copernicus program with a free and open access policy for imagery from the Sentinel satellites since 2015 (medium spatial resolution optical and radar data) which has been helpful in many revisions of UGSs (Dennis et al., 2018).

The collective properties of these four key signs of progress in remote sensing can be seen via the growing number of journals that have oppressed these technical abilities to study UGSs. An additional motive for the surge in remote sensing-based training of UGSs has been the calls by global establishments for more wide-ranging inquiries of UGSs in recent years. For example, the World Health Organization (WHO) has dedicated a distinct report to UGSs which validates their multiple assistances for public health (WHO, 2016).

### 3.2. These are the main technical point while using remote sensing to study of UGSs.

#### 3.2.1. Importance of technical considerations in UGSs classes and thematic areas.

UGSs classes and thematic areas have an important impact on remote sensing-based investigation. UGSs can be generally separated into two modules (Wang et al., 2018; Haase et al., 2019):

(a) Average to large-scale UGSs such as garden and urban green spaces, Trees.

(b) Small-scale UGSs such as parks or courtyard green of isolated households and spread squares of trees.

It stands important that though small-scale UGSs each inhabit an incomplete area when careful in their entirety, they can represent an important quantity of urban space. Furthermore, thematic presentation parts of remote sensing UGSs can be classified as general UGSs mapping, classes mapping, record and valuation, change detection, and ecosystem accommodations. While many investigation activities have been concerned with the remote sensing of UGSs, the connection among technical reflections of remote sensing, thematic areas, and UGSs classes is unspecified. The inspiration for remote sensing ascends from the likely to excerpt material about UGSs indeed (e.g., detecting the location of UGSs, identifying UGSs' vegetation cover species, and estimating the fraction of UGSs), quickly and at minimum cost. However, the demands on remote sensing may vary according to the UGSs classes and thematic application areas and it is solid to outline universal values or optimum features for remote sensing of UGSs. In specific, the cost-effectiveness of using remote sensing may be needy on the balance among data and treating costs and the assistance provided to a certain application. For example, urban tree type's material might be needed for exactness management of UGSs, while land cover mapping (e.g. vegetation and invulnerable sides) at the landscape ruler may be sufficient for the administration of UGSs crosswise a complete city. In this background, mapping of urban tree species can be accepted out using hyper spectral and LiDAR data which is likely to incur significant costs (Jensen et al., 2009) though Landsat or Sentinel images can be recycled for large-scale UGSs mapping at a minimal cost (Rosina and Kopecka, 2016). Hence, there is a sequence of mechanical subjects which need to be measured when decisive the most suitable remote sensing methods in pieces of training of UGSs, and indication is drawn from the works to highlight these topics in the balance of this component.

**3.2.2. Spatial resolution**

Nowadays has grown very fast and is very complex and has heterogeneous landscapes where vegetation is frequently existing as very small covers or even dispersed trees (Mitchell et al., 2018). Also, a helping of UGSs may be on isolated belongings, which may be tough to access in the field and comparatively small in size, but numerous in quantity. Thus, the investigation of UGSs often difficulties high spatial resolution remotely sensed imagery, as demonstrated in many studies (Li et al., 2015b; Tigges and Lakes, 2017; Mitchell et al., 2018; Sun et al., 2019).

**3.2.3. Spectral resolution**

The spectral reply of UGSs is produced by radiation cooperating with a combination of vegetation and urban resources, together which can be very heterogeneous. Thus, in order to separate UGSs from other urban topographies and describe the vegetation within UGSs, remotely-sensed data of enough spectral determination is required. The spectral perseverance of remote sensing tools can usually be separated into two collections: multispectral and hyper spectral. Multispectral sensors typically include 4–8 bands that span the visible, near-infrared, short wave infrared spectral, and thermal infrared areas although hyper spectral sensors naturally have many hundreds of bands that cover these spectral areas. Equally types of tools can provide valuable material for describing UGSs. Multispectral organizations tend to be talented at discerning vegetation within urban areas and plotting of UGSs, while hyper spectral sensors are usually required for identifying vegetation species within UGSs (Voss and Sugumaran, 2008; Alonzo et al., 2014). Yet, cultivating the spectral resolve of the multispectral system can have an important effect, for example, it has been shown that the adding of four new bands to World View 2 improves the capabilities for species discrimination compared to IKONOS (Pu and Landry, 2012). The first study has shown a judgment amongst the use of hyper spectral data at high spatial perseverance and multispectral data with like resolution when reading UGSs (Pu and Landry, 2012). A full review of the properties of spectral resolution on detecting urban vegetation can be found in Fassnacht et al. (2016). Some researchers using hyper spectral systems have identified important wavelength regions for classifying urban forests and trees, particularly the green edge, green peak, yellow edge, red, and near-infrared (Xiao et al., 2004; Alonzo et al., 2013; Liu et al., 2017). Moreover, it has been claimed that urban tree classes can be classified using the blue area due to their comparatively lower photosynthetic action in this region (Pu and Liu, 2011). Despite the potential value of hyper spectral sensors, some studies have used these sensors in investigations of UGSs, while some rely on multispectral remote sensing mainly at the medium spatial resolution. This is likely due to the incomplete availability of hyper spectral data which are collected from airborne stages and few satellite sensors that have restricted spatial attention and pretty high acquisition costs. It is significant to note that while EO-Hyperion data can make an influence in analyzing UGS due to their hype spectral sensing capability and free access (Lv and Liu, 2009), their medium spatial resolution (30 m), partial spatial exposure, and coarse temporal resolve have hampered frequent use of this satellite sensor in such studies.

**3.2.4. Timing of image acquisition**

Timing of image acquisition is a very important consideration in remote sensing of UGSs because of vegetation phonological cycles which cause changes in leaf biochemistry and cover the structure of vegetation (Voss and Sugumaran, 2008; Tigges et al., 2013; Li et al., 2015a; Pu et al., 2018). Such phonological cycles lead to temporal variations in the remotely-sensed response of vegetation. In general, fall and spring have been created to be the most suitable times for mapping UGSs and classifying vegetation species (Voss and Sugumaran, 2008; Jensen et al., 2012; Zhang and Qiu, 2012; Duarte et al., 2018). However, there are a variety of findings on this issue. For example, Liu et al. (2017) reported that for a species diverse area, the presence of a mixture of trees with leaf-on and leaf-off circumstances could reduce sorting accuracy when mapping urban tree brands. Another study indicated an improvement in the accuracy of tree class mapping in late spring (April) (Pu et al., 2018). Voss and Sugumaran (2008) testified no development in overall accurateness when smearing hyper spectral data from fall as compared to a summer dataset, yet the fall dataset provides more consistent results for all tree classes while the summer dataset had a few higher individual class precisions. It is likely that the variability in results connected to the control of acquisition may be explained by variations in species composition of the study sites used across different studies and the varying physiological responses of species to the different climatic contexts of the study sites. To reduce such conflict, a substitute way is to use multi-date imagery rather than single data for studies of UGSs (Tigges et al., 2013; Li et al., 2015a; Pu et al., 2018; Yan et al., 2018). For example, using remotely sensed imagery developed in summer and winter terms can simplify the judgment of deciduous and evergreen trees (Xiao et al., 2004).

**3.2.5. LiDAR**

Light recognition and ranging (LiDAR) systems offer one of the most correct methods for describing vegetation covers from local to regional scales (Liu et al., 2017). The main mechanism of LiDAR is that laser pulses are emitted at the measured object and backscattered returns are recorded and analyzed in order to characterize the 3-dimensional (3-D) properties of the vegetation surface and canopy structure (Tanhuanpaa et al., 2014). Therefore, LiDAR can reduce the influence of shadow, measure structural attributes and biophysical limitations, and deliver three-dimensional evidence (Voss and Sugumaran, 2008; Jiang et al., 2017; Liu et al., 2017). Numerous studies have established the assistances of combining LiDAR with hyper spectral data and high spatial resolution imagery (Zhang and Qiu, 2012; Alonzo et al., 2013; Dian et al., 2016).

**3.2.6. Synthetic Aperture Radar (SAR)**

SAR sensors actively send microwave signals to the Earth's surface and detect the backscattered energy. Therefore, SAR sensors perceive Earth's external day or night and under all-weather situations. Spread microwave signals can also enter vegetation canopies and soil external layers which may be of value in some assessments of UGSs. However, despite these advantages of SAR sensors, the literature pays scant attention to the use of SAR data in studies of UGSs. Our study shows that many studies have demonstrated a potential role for SAR, mainly through fusion with optical sensor data, in the arrangement of broad urban land cover types i.e. without specific attention on UGSs (e.g., Ban et al., 2010; Niu and Ban, 2013; Werner et al., 2014; Zhang et al., 2018; Zhang and Xu, 2018) as well as through the acknowledged contributions of SAR data in forestry (Fassnacht et al., 2016). Therefore, the use of SAR data in trainings of UGSs performs to be a valuable area for future inquiries.

**3.2.7. Google Earth**

Satellite sensors images may not deliver information on the visual effects of UGSs on citizens (Yang et al., 2009; Jiang et al., 2017; Li et al., 2018). To reward this problem, a variety of studies (3.5 %) have used Google Earth products, including Google Street View. For instance, Yang et al. (2009) developed the Green View Guide which is based on measuring vertical profiles from Google Street View imagery to analyze urban forest structures. Likewise, Li et al. (2018) planned the Sky View Issue using Google Street View imagery to amount the quantity of sky that is filled by structures and tree coverings. Jiang et al. (2017) pointed out that Google Earth imagery and the software i-Tree street can be used to objectively calculate tree cover density at little or no cost to the user. Richards and Edwards (2017) verified that hemispherical canopy photos taken from Google Street View could be used to assess the shading of diffuse and direct radiation by the canopy at a certain location. Hence, there is upward evidence that Google Earth products can have a role to play in understanding UGSs.

**3.2.8. Google Earth Engine (GEE)**

Google Earth Engine (GEE), a cloud-based geospatial processing computing platform, offers satellite data processing and geographic information system(GIS) analysis from local to global scale (Gorelick et al., 2017). GEE employs medium spatial resolution satellite sensors such as Landsat and Sentinel for monitoring land use and land cover in an efficient way. The range of studies has highlighted a potential role for GEE in UGSs (Huang et al., 2017, 2018b; Zhang et al., 2019). For example, Huang et al. (2018b) assessed the influence of urban form on the structure of UGSs in 262 cities in China based on the GEE. Huang et al. (2017) quantified the change in health benefits generated by urban green spaces in 28 megacities worldwide between 2005 and 2015 by using GEE. Zhang et al. (2019) estimated the spatial accessibility of urban forests based on the GEE. Thus, although the spatial resolution of remotely sensed data in GEE may not be sufficient for capturing details of UGSs, there is growing evidence that GEE can play a central role in analyzing UGSs at regional and global scales.

**3.2.9. Pre-processing-atmospheric correction**

Earth's atmosphere influences surface-reflected radiation recorded by satellite sensors; this can be detrimental to the remote sensing of surface characteristics and the effect can be amplified over urban regions because of the polluted atmosphere. Consequently, the quality of satellite images usually needs to be improved by using atmospheric correction algorithms (Pu and Landary, 2012).

**3.2.10. User demands and cost-efficiency**

The main rationale behind using remotely sensed imagery in studies of UGSs is to reduce the costs associated with field data collection campaigns. To the best of our knowledge, detailed evaluations of the financial benefits or detriments of using remotely sensed data in measurements of UGSs have not been presented. As the cost of remotely sensed imagery could be an obstacle for detailed, large scale and repetitive measurement of UGSs, it is contended that such costs are outweighed by the value derived from such work in improving UGSs and delivering multiple benefits and services (Jensen et al., 2009; Chen et al., 2017b).

**3.3. The following techniques have been used in the remote sensing of UGSs**

Remote sensing-assisted mapping of UGSs can play an important role in characterizing the spatial distribution of vegetation cover within urban regions (e.g., Puissant et al., 2014) and several analytical techniques have been suggested for mapping UGSs.

Such as hybrid methods, object-based image analysis, land cover indices, and fraction methods.

**3.4. The major thematic application areas for remote sensing of UGSs**

A variety of thematic application areas related to UGSs have been supported using remote sensing and the specific approaches within each application area that have been used. It is worth noting that providing the details of analytical methods is beyond the scope of this paper and it is suggested that readers consult the corresponding cited literature for further information on the approaches used.

**3.4.1. Inventory and Assessment**

In inventory and assessment applications, researchers have focused on measuring different aspects of UGSs. We found that studies assessing the health of vegetation in UGSs (Xiao and Mcpherson, 2005; Asmaryan et al., 2013; Nasi et al., 2018; Nouri et al., 2018) and geospatial modeling were dominant within this group. The rest of the studies concentrated on other aspects such as leaf area modeling, vegetation phenology, and economical investigations. Among this group, Nouri *et al. (*2018) quantified the impacts of salinity on UGSs while Asmaryan *et al. (*2013) monitored the effects of pollution on the urban vegetation.

**3.4.2. Biomass and Carbon Estimation**

Remotely sensed data have been used in monitoring carbon and biomass within UGSs. This research has mainly used regression modeling between carbon/biomass and remotely sensed variables.

**3.4.3. Change Detection**

An important topic for urban policymakers is the objective measurement of UGSs changes through an approach that takes into account not only major changes between land cover types (e.g., urban brownfields to green spaces) but also information on more subtle changes within UGSs (e.g., changing species composition). Various techniques for monitoring UGSs have been developed using medium and high spatial resolution imagery.

**3.4.4. Ecosystem Services**

In this thematic application area, we found three major groups of studies: modeling, policy investigation, and morphological spatial pattern analysis (MSPA) ple, Jensen et al. (2004) built a neural network model to estimate urban leaf area using the field. A range of models has been constructed to evaluate different aspects of UGSs. For exam measurements and satellite remote sensing data for studying the urban quality of life and urban forest amenities. Some studies have employed a hedonic model for UGSs evaluations (Franco and Macdonald, 2018; Mei et al., 2018). The hedonic method is an indirect approach to valuing public goods and has been widely used in environmental economics studies (Franco and Macdonald, 2018; Mei et al., 2018). This is the best known and most widely accepted method for valuing urban forest amenities. A number of studies have focused on policy and planning evaluations, mainly using GIS or Google Street View analysis. For instance, Richards and Edwards (2017) analyzed hemispherical photographs extracted from Google Street View to quantify the proportion of green canopy coverage and the proportion of annual radiation that is blocked from reaching ground level by the canopy along with Singapore's road network. They showed that there was significant variation between different urban land-use types, with trees providing more shade in parks and low-density low-rise areas than in industrial and higher-density residential areas. Mapping the provision of street tree ecosystem services could help to prioritize areas for new planting by identifying streets or street sections with low shading. Moreover, MSPA was also employed in two studies with the aim of quantifying urban sustainability in the context of the planning and management of UGSs.

**3.4.5. Overall UGSs Mapping**

Our review showed that previous studies have examined a wide range of aspects of overall UGSs mapping. Studies have concentrated upon urban vegetation mapping (all types of vegetation covers) and urban tree mapping. This is consistent with previous research showing the importance of establishing a database on the spatial distribution and abundance of UGSs which could play a significant role in supporting existing sustainable urban regulations and may emerge as an indicator of the degree of urban quality (Van de Voorde et al., 2008). Beyond mapping, characterizing biophysical parameters and types of UGSs are of central importance in the smart management of UGSs (Jensen et al., 2009). However, there are only a small number of studies making use of remote sensing technology for such purposes. For example, Ren et al. (2015) estimated canopy density, basal area, and leaf area index using remotely sensed vegetation indices. Despite gardens being important urban ecosystems, there were only two studies that focused specifically on this type of UGS (Baker et al., 2018; Haase et al., 2019). This may imply that there are difficulties in extracting detailed information on the precise land use characteristics of UGSs from remotely sensed imagery.

### 3.4.6. Species Mapping

Managers of urban areas are interested to know about vegetation species to maintain UGSs appropriately and more importantly to protect UGSs from invasive species. Previously, species mapping in UGSs species was challenging and costly because it was based on field surveys. However, urban managers and scientific communities are now able to identify vegetation species within urban regions in an accurate and timely way through remote sensing technology.

### 3.4.7. Three-Dimensional Modeling

This group of studies covers the analysis of the vertical characteristics of UGSs and uses such information to establish three-dimensional models. Such studies are based on LiDAR data and a combination of LiDAR and high spatial resolution imagery. For example, Caynes et al. (2016) quantified the relative density of vegetation within different vertical strata using LiDAR data. They also calculated the foliage height diversity for each raster cell to characterize the vertical complexity of vegetation in UGSs. Moreover, several models using vertical information derived from remote sensing were developed to estimate the volume of UGSs. For instance, Hecht et al., 2008Hecht et al. (2008) developed a model based on fuzzy logic techniques and LiDAR point clouds to estimate UGS volume.

## 4. Discussion

### 4.1. Future Technical Requirements

The findings of this review showed that the amount of scientific literature relevant to remote sensing-assisted analysis of UGSs has been increasing rapidly since 2000. This trend demonstrated the significant contribution of the science of remote sensing to the monitoring, planning, and management of UGSs. The review revealed that the analysis of fine-scale remotely sensed data lies at the core of much work on UGSs. Fine-scale remotely sensed data offer a wealth of detailed information that may be used to answer a wide range of critical questions related to UGSs. In addition, LiDAR data, ultra-high spatial resolution imagery, hyper spectral data, and Google Earth Products provide a spectrum of useful information which can be used stand-alone or in combination. Although the remote sensing of UGSs has matured considerably, there is scope for significant further development. The key concerns that have been identified based on the review are presented below.

- Presence of shadow in high spatial resolution imagery can reduce the accuracy of UGSs mapping (Zhang and Qiu, 2012; Merry et al., 2014). Considerable further research is therefore needed for recovering information from areas under shadow or at least to minimize the effects of shadow.
- Compared to species detection studies on the use of hyper spectral information in UGSs such as public parks and urban gardens are currently still in an early experimental stage. Spectra of UGSs respond to a mixture of different types of vegetation species and urban materials (Jensen et al., 2012). Future research should improve the understanding of the reflectance characteristics of vegetation covers in such environments. Ultimately, this could facilitate accurate species mapping, invasive plant detection, health assessment, and above all, smart management of UGSs.
- There is a need to develop methods for extracting informative and intelligent information from Google Street View, for example, species characteristics and the quality of UGSs as might be perceived by users of the spaces.
- Existing mapping approaches may not be sufficient to capture the complexity of the UGSs such as mapping private gardens and yards. More advanced techniques such as fractional approaches (Haase et al., 2019), deep learning algorithms (e.g., DenseNet (Hartling et al., 2019)) and hybrid frameworks (Liu and Wu, 2018) could be used as alternative methods for achieving this.
- Copernicus, Landsat and Google Earth data policies guarantee continuous data acquisition and dissemination for decades. This capability is triggering a shift from single image analysis to time series processing. Novel approaches must be established to optimally analyze the temporal characteristics jointly with spatial and spectral information within these images.
- Since GEE is composed mainly of medium spatial resolution imagery, developing new approaches for quantifying small UGSs patches based on the GEE platform should be addressed in future studies.
- While this review covered the contributions of remote sensing in studies of UGSs, we did not review the detailed technical aspects. A robust evaluation of all algorithms used in the reviewed studies would require a standardized setting with

respect to targeted topics which is beyond the scope of this research. Future research should, therefore, review the analytical approaches used in the application of remote sensing in USGs studies, such as the techniques used to model leaf area in urban regions or to detect changes in UGSs.

- Although several studies have indicated that SAR imagery could be of value in the urban land cover mapping (e.g., Ban et al., 2010; Niu and Ban, 2013; Werner et al., 2014; Zhang et al., 2018; Zhang and Xu, 2018), the potential of such data specifically in studies of UGSs seems to be under-examined. Given the increasing availability of high-quality SAR data, notably Sentinel-1A data from the Copernicus programmer, there is now a timely opportunity to explore the contributions of these data in studies of UGSs.
- Although many research endeavors have been oriented towards applications of GEE in the study of UGSs, there is a great need for providing a comprehensive comparison (e.g. systematic review) among a range of techniques in GEE in terms of analyzing UGSs.
- Small-scale UGSs, when considered in their totality, can represent a significant amount of urban spaces. In this view, the result of the present review was consistent with previous research (Wang et al., 2018; Haase et al., 2019) showing that remote sensing of UGS has tended to overlook the analysis of small-scale UGS. Therefore, more research is needed to quantify small-scale UGSs.

### 4.2. A potential framework for future applications of remote sensing in the context of UGCs

The utility of remotely sensed data for investigating UGSs has been explored in this paper. It has been demonstrated that the remotely sensed data offer a valuable source of information that allows researchers and managers working with UGSs to move beyond traditional methods and tackle large-scale problems. However, for this potential to be realized it will be crucial to follow a suitable framework in order to appropriately conduct scientific or engineering projects based on remote sensing of UGSs.

## Conclusion

Studying the overall UGSs is critical for designing effective schemes to improve the environmental conditions within cities, and for the sustainable management and development of urban vegetation. This review aimed to highlight the importance of remote sensing technology in this respect, and thereby, serve as a potential guide to researchers.

The data used were found to consist of two main classes. Firstly, satellite imagery at medium spatial resolution. Here, sensors such as Landsat, and Sentinel (optical sensors) have contributed significantly to the capabilities in the overall mapping of UGSs and change detection using time series archives. Such data offer the benefits of requiring less complex image processing techniques and being free to access. However, the spatial resolution of these sensors hinders the process of detecting fine-scale characteristics of UGSs in complex urban regions. In contrast, sensors with a high and ultra-high spatial resolution (e.g., IKONOS) have offered fine-scale information monitoring subtle change within USGs in studies of USGs. A number of studies have employed LiDAR, hyper spectral, and other data sources in order to determine specific characteristics of UGSs. The review also undertook an in-depth analysis of the image processing approaches employed to derive information on UGSs. The techniques used include hybrid approaches, fraction analysis, land cover indices, per-pixel classification, point sampling, visual interpretation, analysis of pre-existing maps, and deep learning. The review suggested that researchers selected their methodologies based on the complexity of the project. For example, land cover indices may be sufficient to obtain information on the general pattern of UGSs while mapping street trees may need a hybrid approach. Thus, in this respect, project demands determine remotely sensed data types and corresponding processing requirements. A critical part of the review was to consider the different thematic applications of remote sensing in the context of UGSs. The findings showed that overall UGSs mapping and species mapping are the dominant applications while less attention has been given to other aspects. It is likely that the aforementioned applications can be handled easily, for example by being less reliant on field campaigns and having easy access to the data sources, compared to other application areas such as biomass and carbon estimation where data for calibrating and validating remote sensing techniques is more difficult to acquire, further research is needed to quantify small-scale UGSs. Standing on the edge of a paradigm shift from remote sensing science to the application level, it is important that those with expertise in UGSs bring their expertise into remote sensing science so as to introduce innovative approaches for solving UGSs problems. Moreover, we encourage efforts within the UGSs community to share data and techniques for dealing with the challenges presented by UGSs for the years to come.

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