Review

The Trajectories, Trends, and Opportunities for Assessing Urban Ecosystem Services: A Systematic Review of Geospatial Methods

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Abstract: Urban ecosystem services (UES) are indispensable for life. Stakeholders are improvising strategies for a more sustainable provisioning of UES. For this purpose and for identifying orientations towards geospatial data in UES studies, the “bibliometric analysis” technique was deployed. The inclinations facilitate assessments pertaining to spatio-temporal oscillations in the supply–demand equilibrium. The propensities are gaining recognition due to time and cost effectiveness. Besides this, Remote Sensing (RS) in conjunction with Geographic Information System (GIS), enables the conduct of synoptic and robust periodic evaluations. The study analyzes inclinations towards RS in contemporary research (2010–2020) focusing, particularly, on urban ecosystem services. It specifically focuses on methodological frameworks and major sources of remotely sensed data. Therefore, a total of 261 records of research articles were identified and retrieved. Subsequently, 79 articles were selected for further processing and content analysis. It transpired that approximately 30% of the selected publications deployed remotely sensed data for assessment purposes. The majority (96%) of such studies were conducted in economically developed and industrialized countries. However, the researchers from both developed and developing countries prefer open software and free data sources. Besides this, they prefer satellite-based optical sensors over image sensors such as TIR, SAR, or light sensors for acquiring data. The findings formulate that Land Use Land Cover (LULC)-based methodologies and inclinations for assessing regulating services are more frequently pursued. The findings revealed that enhanced research collaborations, access to data, and assessment gadgets are obligatory for capacity building in developing regions. Knowledge sharing and cost-effective access to RS and GIS based platforms are incumbent for ensuring urban environmental sustainability in developing economies.

Keywords: urban ecosystem services; urbanization; environmental resilience; remote sensing

1. Introduction

Ecosystem Services (ES) are the sum total of the functions, processes, and benefits that stem from ecological resources [1–3]. The reimbursements of natural capital (blue-green surfaces) are indispensable for the biosphere [4] and are classified into four distinct groups and various categories [5]. The provisioning of ES is symptomatically determined by the nature of biophysical infrastructure, its associated processes, and accompanying changes. Thus, they have spatio-temporal connotations, implications, and dimensions which have persistent bearings on the ecosystems and the services rendered by them [6]. Therefore, human beings are endeavoring to decipher the linkages between society and their environment from various perspectives [7]. The publication of Millennium Ecosystem Assessment (MEA) in 2005 proved to be a catalyst for launching an invigorative quest for monitoring the resilience of ecological resources [4].

Urban Ecosystem Services (UES) is an observational term used for assessing, evaluating, and portraying ecological infrastructure and its products in the urban areas. The information is collected for detecting spatio-temporal oscillations in the supply–demand budget of UES [8]. These estimations/information assist to determine whether the observed changes are the products of human interventions or nature-triggered modifications.

The reported demographic pressures [9], such as uncontrolled urbanization [10], access to technological gadgetry [11], and socio-economic changes [12] are embossing their indelible imprints on urban environment. Contrary to that, the required focus and actions are, still, far from the desired benchmarks in developing regions [13–16]. It entails informed assessments, coordinated efforts, and tangible measures for protecting urban ecological resources [17]. However, resource constraints thwart such proclivities which are vitally required for a resilient urban social life.

The evaluation of UES is carried out by deploying monetary and non-monetary based mechanisms. Bokhari et al. [8] opined that monetary-based tools and techniques are more suitable measures for documented economies. Whereas, non-monetary parameters seem to be a pragmatic option for transforming/developing economies, which are struggling with issues pertaining to undocumented financial transactions [4,13]. Recent advances in the domain of Remote Sensing (RS) offer time and cost-effective possibilities for assessing ES and their services [15,18]. The embedded features of Geographic Information System (GIS) and RS enable the conduct of synoptic, spatially connected, and periodic measurements in a synchronized manner. The information is utilized for interpreting man–environment interactions in a given urban setting [19].

Albeit, RS-based assessments are gaining recognition as a reliable option for modeling, mapping, and assessing ecosystems and their products [20–22]. Remotely sensed data is deployed for analyzing urban Land Use Land Cover (LULC) transformations [23–25], assessing urban heat island effect [26,27], and studying urban green species [28,29]. The data source is useful for detecting transitions in urban vegetative cover [30], water quality [31], and biomass estimation with the help of ALOS-2, PALSAR-2, and Sentinel-2A images [32]. The initiatives are obligatory for ensuring sustainable cities and societies as envisaged in (SDG 11) [33,34].

The scenario entails for assessing the potentials of RS for ensuring urban ecological integrity. Therefore, the present study is designed in order to demonstrate the role and potentialities of remote sensing for assessing UES. It analyzes inclinations towards RS in contemporary research (2010–2020) focusing on urban ecosystem services. For this purpose, a systematic review of literature was carried out. Hence, the present study focuses on the following dimensions: (i) to evaluate how researchers utilize RS data for assessing UES; (ii) to identify the dominant orientations regarding remotely sensed data sources; and (iii) to categorize the methodological constructs relied upon for evaluations.

2. Methodology

The methodological framework of the present study is based on the systematic review of literature. For this purpose, those research publications which utilized RS for assessing

UES were identified through the Web of Science (WOS) (www.webofknowledge.com, accessed on 22 December 2020). The authors retrieved a total of 261 records of research articles against the search term “urban ecosystem services” published from January 2010 to December 2020. In retrospect and on a first perusal, it would appear that the reliance on the keyword “UES” has compromised the validity of findings by excluding studies of a similar nature but with different terminologies. However, the identification of publication through one keyword based on an “umbrella term” curtails subjectivity [35,36], prevents digressions [13], and minimizes the impacts of irrelevant (false-positive) results [37]. For this purpose, Atif et al. [4] has successfully deployed this very technique regarding their investigations pertaining to UES. However, the current investigation is inherently different as it exclusively assesses the reliance on remotely sensed data in contemporary UES studies.

It is pertinent to mention that only those records were selected which were published or accepted for publication in the English language. However, review papers were excluded from the count for ensuring objectivity. The information was processed by deploying a two-tier cascading arrangement. Firstly, those publications were identified which had the term “Urban Ecosystem Services” in the title, abstract, or keywords. Subsequently, in the second phase only those articles were selected which rely on remotely sensed data (Figure 1). Based on that mechanism, 79 records qualified for further processing and content analysis (Table A1).

Figure 1. Flow chart for review of literature.

The significant findings pertaining to: (i) the type of ES being focused; (ii) the nature of RS dataset(s)/the purpose of assessment; and (iii) methodology(s) deployed for investigation identified and portrayed through Dendrogram (Figure 11). The scheme is preferred for spotting similarities and differences among/between strategies employed for assessments by Booth et al. [38].

3. Results

3.1. The RS and UES Research

The findings transpire that 29.89% of the total retrieved records ($n = 261$) relied on RS data for assessing UES. Significant inter and intra-continental differences were observed regarding the use of RS (Figures 2 and 3). The findings formulate that remotely sensed data-based research contributions from the European context (58.97%) are the highest. It transpired that the proportionate shares from the remaining continents were negligible as compared to their volume of urbanization (Figure 3). The majority of reviewed publications (96.15%) were planned in industrialized and developed regions, whereas the share from the developing hemisphere turned out to be quite miniscule (3.85%). It reflects the prevalent schism between the global “North and South” in this domain as well. The findings corroborate the notions rendered by Atif et al. [4] and Akhtar et al. [13], that such differences are linked to economic, scientific, and technological advancements.

Figure 2. The spatial distribution of reviewed studies.

Figure 3. Continent-wise apportionment of reviewed studies.

3.2. Temporal Fluctuations in Tendencies

For assessing temporal fluctuations, the data (79 publications) were assessed. The available data were compartmentalized into two arbitrarily selected time intervals, i.e., 2010–2015 and 2016–2020. The largest number of publications appeared in the year 2016 ($n = 14$). The findings (Figure 4) depict that during the early phases of the first selected time interval (2010–2015), there was a growing tendency for RS. However, during the later phase (2016–2020), observable oscillations are evident in the proportionate share of different years, such as 2017 (15.19%), 2018 (16.46%), 2019 (8.86%), to 2020 (13.92%). Atif et al. [4] also reported such tendencies based upon their investigation.

Figure 4. Temporal distribution of reviewed publications (2010–2020).

3.3. Remote Sensing Data Sources and UES

Research orientations regarding types of ES and Ecosystem Disservices (ED) were assessed (Figure 5). For the purpose of deciphering the linkages/interconnectedness between different ES services, the pair-based assessment technique was employed (Figure 6). The majority of the studies ($n = 55$) were adjudged to be cumulative assessments of four designated types of ES services. However, inclinations were observed to be more skewed towards regulating services as compared to cultural, provisioning, and supporting services.

Figure 5. Types of UES and reviewed publications during 2010–2020.

Figure 7 portrays the frequency of data sources relied upon for data acquisition and Figure 8 illustrates their year-wise contribution. It transpired that most studies relied on no-cost/open data sources, such as Landsat family, MODIS, SPOT, etc., for assessing UES. Satellite-based optical sensors were preferred over image sensors, such as TIR, SAR, or light sensors for acquiring data. Open and free data resources, such as aerial ortho-photos and Google Earth imagery are mainly consulted for land use classification and data validation. The information was integrated with socio-economic and demographic data repositories for holistic appraisals. Subsequently, the evaluations were integrated with ecological inventories and portrayed in the form of urban atlas.

Figure 6. Pair based interconnectedness among UES.

Figure 7. The frequency of data sources relied upon for assessments.

Figure 8. The year-wise contribution of data sources.

3.4. Methodological Frameworks and RS

UES are assessed by deploying multiple conceptual paradigms and approaches. The assessments (Figure 8) transpired that LULC-based technique was the preferred choice (59%) for assessing UES. It is followed by the Normalized Difference Vegetation Index (NDVI) amounting to 23%; Mapping Urban Tree (15%); Land Surface Temperature (LST) method (11%); the Green Canopy Cover technique (GCC) (6.3%); and Normalized Difference Water Index (NDWI)-based parameters (3.8%). Besides these methods, inVEST and mixed model-based approaches are gaining recognition as well. A growing propensity for innovative measures, such as Linear Iterative Clustering (LIC); Normalized Digital Surface Model (nDSM); Convolutional Neural Networks (CNN) etc., was also noticed (Figures 9 and 10).

Figure 9. The frequency of methodological frameworks deployed for assessments.

Figure 10. The year-wise contribution of methodological frameworks deployed for assessments.

For the purpose, similarities, and dissimilarities in data sources, methods and types of UES relied upon for assessments were adjudged. Figure 11 reflects the similarities/dissimilarities in orientations towards UES, based on the cluster analysis technique. It portrays a cascading hierarchy of clusters (Figure 11). The Dendrogram construes the presence of two notable sets of clusters (A and B) having 0% similarity between them. The difference is attributable to the type of urban ecosystem services selected/relied upon for assessments in the selected publications. The intra group variations were observed more noticeably in group A as compared to group B. It formulates that the publications in group A were designed from divergent perspectives, scales, and scopes for assessments. However, the reliance on LULC technique for assessing UES was recognized as a common feature in both the observed groupings.

Figure 11. The similarities and differences among methodologies (Group A and Group B) and Cluster analysis technique.

4. Discussion

The growing quantum of global urban population [39,40], the unprecedented expansions in urban areas [41], and associated ecological footprints are stressing people and their environment [13,42]. Stakeholders are improvising strategies for social, economic, and ecological resilience of urban life and infrastructure. For this purpose, the reliance on remotely sensed data for assessing, monitoring, and managing urban ecosystems and their services is gaining recognition [8,43]. The quantitative findings based on this investigation affirm that the reliance on RS and GIS is gaining recognition as tools for informed decision making. However, a significant decline in publications focusing on UES was noticed (Figure 4). The decline authenticates the reported observations that the propensities towards assessing UES are waning. Thus, the review of contemporary literature will serve as a barometer for assessing the causations and promoting scientific investigation regarding UES. The orientations are obligatory for realizing the objective of sustainability of urban environments.

The scrutiny of literature construed a delicate interplay between economic development and propensities towards environmental conservation. Whereas, whilst economic development encourages consumer culture, it simultaneously provides fiscal and technological support for ensuring environmental resilience. The findings (Figure 2.) surmise that the developed economies offer as more conducive playground for relying on RS in UES research. The spatial distribution of selected publications (Figures 2 and 3) authenticates the notions about economic development and proclivities towards UES research [8,13,44]. The gap in publications (Figure 3) between “the developed North” and “the developing south” supports the dictum that an empty stomach does not afford the luxury of a choice.

An increasing proportion of Asian scientists was observed focusing on UES in their published studies. The study also affirms that the share of Asia is more in published UES research as compared to the contributions from North America during the selected time interval (2000–2020). The observations are contrary to the assessments rendered by [43,45], but authenticate the robustness of conclusions of de Araujo Barbosa et al. [43]. The plausible explanation is rooted in the paradigm of “economic growth” and its trickle-down effects. The reported and projected estimates about urban demography and concomitant urban-centric economic developments in Asia [14,16] are pushing for urban ecological sustainability. Consequently, researchers are focusing on and improvising measures for ensuring socio-economic and environmental integrity of urban areas. However, Europe was observed in the leading role according to the assessment criteria of this study. The early exposure to urban environmental degradation, access to advanced technologies, and urban-based economic development spurred “environmentalism” in Europe [46,47]. The European exposure to early industrialization and its aftermaths helped to acknowledge the significance of nature and its contribution [48]. These stimulators encouraged urban environmental sustainability. These concomitant dividends are pouring out in the form of scholastic initiatives and publications.

Critical findings (Figures 7 and 8) transpired that the majority of studies relied on no-cost “open data sources”. Landsat, MODIS, and SPOT families were most frequently consulted for data acquisition. For this purpose, the majority of studies relied on the open and free data repositories, such as aerial ortho-photos and Google Earth imageries. The information was subsequently processed, analyzed, and portrayed through GIS environment. It is pertinent to mention here that the majority of these selected studies were carried out in economically and technologically developed regions (Figures 2 and 3). On the contrary, the lack of resources for capacity building in developing regions retard the exposure, experience, and expertise of researchers; therefore, they rely less on these gadgets, i.e., RS and GIS. It surmises the hardships being faced by the academia and research fraternities in the less developed parts of the globe. Moreover, the restrictions to access/consult scholarly contributions due to “financial/monetary” constraints discourage their utilization in the fragile and resource-parched economies.

The assessments rendered that reliance on secondary data sources in the studies focusing on UES is a preferred choice among researchers. The observation corroborated the notion rendered by Tavares et al. [49], that RS facilitates data acquisitions for ecological studies. Reliance over RS ensures time and cost effectiveness. For this purpose, Landsat and Sentinel satellite families are frequently consulted (Figures 9 and 10). This predisposition is an outcome of accessibility, availability, and cost factors [49,50]. Moreover, the data aggregation of Landsat and Sentinel families is possible and required for deciphering long-term oscillations in the natural environment [51], whereas high-resolution images, such as SPOT-5 [52,53], aerial and digital orthophotos [54–56], Worldview-2 [57,58], RapidEye imagery [59], GeoEye [60], IKONOS [60,61], and Quickbird [61–63] are considered as more reliable options for evaluating UES. However, the utilization of these repositories depends on the accessibility and availability of financial resources.

The findings formulate that regulating services are more focused on research, as compared to other categories of UES, while the content analysis revealed that the LULC evaluation based on RS data is a widely deployed mechanism for assessing UES [64–67]. The tendencies are gaining recognition due to objective, accurate, and user-friendly orientations of this mechanism. Recent advances in associated techniques (such as NDVI, LAI, LST, NDWI, and TCA) are providing more objectivity to LULC assessments [62,65,68–70]. The cluster analysis (Figure 11) corroborates the reported assertions of [8,49,71] that LULC assessments deftly infer about the fluctuations in UES. Growing exposure, experiences, and expertise are popularizing and giving impetus to the use of remotely sensed data in ecological studies [72,73]. However, growing restrictions on data acquisition [49] are posing newfound challenges for developing economies. The scenario entails for constructive support from developed to developing regions for global environmental security.

The observations underline the need for an out-of-the-box solution for this dichotomous situation. While the mechanics of the market economy operate on the premises of profit, the ecological health of the planet earth calls for cost-effective holistic interventions. It requires a sustainable solution with the support of developed economies and donors in the light of climate and justice debate. The cost-free dissemination of knowledge and sharing of experiences will symptomatically contribute towards capacity building. This stimulator will encourage the intended orientations towards urban green infrastructure in developing regions. Intellectual collaboration and funding are vitally required for informed assessments/decision making regarding urban ecological resources. A paradigm shift based on the principle of knowledge sharing will serve as a catalyst for transforming perceptions regarding the environment in such contextual settings.

5. Conclusions

Urbanization and modifications in urban areas are stressing the urban environment. Holistic appraisals of concomitant impacts on UES are imperative for informed decision making to ensure the resilience of urban life. The critical findings of this investigation authenticate the assertions that accessibility, availability, and cost of data and analysis are the crucial factors considered by the researchers. The findings of this review contemplate that the focus of contemporary studies regarding urban areas is drifting from interpretation to knowledge acquisition for informed decision making. For this purpose, reliance on RS and GIS is gaining recognition. The inclinations were observed more directed towards assessing regulating services, when compared to other categories of ES. Besides this, the LULC-based assessment technique is commonly deployed for evaluating UES. The assessments affirm that an overwhelmingly larger share of UES research comes from the developed world. Researchers from developed and developing countries prefer a no-cost or open data sources for investigating UES. Meanwhile, difficulties in data accessibility, the lack of availability of RS and GIS-based software, and the absence of capacity building measures in developing countries is impeding all research momentum. Consequently, the reliance on remotely sensed data is waning. It entails for “out of the box” measures for stimulating RS-based UES research in the transforming economies. Availability of

open-ware tools, such as Google Earth Engine and cost-free access to databases, allied with other capacity building measures, are vitally required.

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Appendix A

Table A1. List of the articles used for systematic literature review.

Sr. No.	Title	Journal	Year	Vol	Page(s)	Issue	DOI
1	Scale-Crossing Brokers and Network Governance of Urban Ecosystem Services: The Case of Stockholm	Ecology and Society	2010	15	25	4	
2	Emergy-based evaluation of peri-urban ecosystem services	Ecological Complexity	2011	8	38–50	1	10.1016/j.ecocom.2010.12.002
3	The urban environmental indicator “Biotope Area Ratio”—An enhanced approach to assess and manage the urban ecosystem services using high resolution remote-sensing	Ecological Indicators	2012	13	93–103	1	10.1016/j.ecolind.2011.05.016
4	Urban ecosystem services: tree diversity and stability of tropospheric ozone removal	Ecol Appl	2012	22	349–360	1	10.1890/11-0561.1
5	A social-ecological assessment of vacant lots in New York City	Landscape and Urban Planning	2013	120	218–233		10.1016/j.landurbplan.2013.05.003
6	Urban ecosystem services assessment along a rural-urban gradient: A cross-analysis of European cities	Ecological Indicators	2013	29	179–190		10.1016/j.ecolind.2012.12.022
7	Urban vegetation classification: Benefits of multitemporal RapidEye satellite data	Remote Sensing of Environment	2013	136	66–75		10.1016/j.rse.2013.05.001
8	Contribution of Ecosystem Services to Air Quality and Climate Change Mitigation Policies: The Case of Urban Forests in Barcelona, Spain	Ambio	2014	43	466–479	4	10.1007/s13280-014-0507-x
9	Measuring urban ecosystem functions through ‘Technomass’—A novel indicator to assess urban metabolism	Ecological Indicators	2014	42	10–19		10.1016/j.ecolind.2014.02.035
10	Mapping the diversity of regulating ecosystem services in European cities	Global Environmental Change	2014	26	119–129		10.1016/j.gloenvcha.2014.04.008
11	Urban vegetation structure types as a methodological approach for identifying ecosystem services—Application to the analysis of micro-climatic effects	Ecological Indicators	2014	42	58–72		10.1016/j.ecolind.2014.02.036
12	Development of a concept for non-monetary assessment of urban ecosystem services at the site level	Ambio	2014	43	454–465	4	10.1007/s13280-014-0502-2

Table A1. Cont.

Sr. No.	Title	Journal	Year	Vol	Page(s)	Issue	DOI
13	Quantification and monetary valuation of urban ecosystem services in Munich, Germany	Zeitschrift Fur Wirtschaftsgeographie	2015	59	188–200	3	
14	REVIEW: Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands	Journal of Applied Ecology	2015	52	1020–1032	4	10.1111/1365-2664.12469
15	The role of urban green infrastructure in mitigating land surface temperature in Bobo-Dioulasso, Burkina Faso	Environment, Development and Sustainability	2015	18	373–392	2	10.1007/s10668-015-9653-y
16	Socio-ecological dynamics and inequality in Bogotá, Colombia's public urban forests and their ecosystem services	Urban Forestry & Urban Greening	2015	14	1040–1053	4	10.1016/j.ufug.2015.09.011
17	Intensity and spatial pattern of urban land changes in the megacities of Southeast Asia	Land Use Policy	2015	48	213–222		10.1016/j.landusepol.2015.05.017
18	Understanding spatial patterns in the production of multiple urban ecosystem services	Ecosystem Services	2015	16	33–46		10.1016/j.ecoser.2015.08.007
19	Contrasting values of cultural ecosystem services in urban areas: The case of park Montjuïc in Barcelona	Ecosystem Services	2015	12	178–186		10.1016/j.ecoser.2014.11.016
20	A comparison of the economic benefits of urban green spaces estimated with NDVI and with high-resolution land cover data	Landscape and Urban Planning	2015	133	105–117		10.1016/j.landurbplan.2014.09.013
21	Land sparing is crucial for urban ecosystem services	Frontiers in Ecology and the Environment	2015	13	387–393	7	10.1890/140286
22	High-Resolution Mapping of Urban Surface Water Using ZY-3 Multi-Spectral Imagery	Remote Sensing	2015	7	12,336–12,355	9	10.3390/rs70912336
23	A framework towards a composite indicator for urban ecosystem services	Ecological Indicators	2016	60	38–44		10.1016/j.ecolind.2015.05.035
24	Appraisal of social-ecological innovation as an adaptive response by stakeholders to local conditions: Mapping stakeholder involvement in horticulture orientated green space management	Urban Forestry & Urban Greening	2016	18	86–94		10.1016/j.ufug.2016.05.010
25	Estimating stormwater runoff for community gardens in New York City	Urban Ecosystems	2016	20	129–139	1	10.1007/s11252-016-0575-8

Table A1. Cont.

Sr. No.	Title	Journal	Year	Vol	Page(s)	Issue	DOI
26	The impact of land use/land cover scale on modelling urban ecosystem services	Landscape Ecology	2016	31	1509–1522	7	10.1007/s10980-015-0337-7
27	Exploring local consequences of two land-use alternatives for the supply of urban ecosystem services in Stockholm year 2050	Ecological Indicators	2016	70	615–629		10.1016/j.ecolind.2016.02.062
28	The value of urban ecosystem services in New York City: A spatially explicit multicriteria analysis of landscape scale valuation scenarios	Environmental Science & Policy	2016	62	57–68		10.1016/j.envsci.2016.04.012
29	Carbon sequestration through urban ecosystem services: A case study from Finland	Sci Total Environ	2016	563–564	623–632		10.1016/j.scitotenv.2016.03.168
30	Mapping transition potential with stakeholder- and policy-driven scenarios in Rotterdam City	Ecological Indicators	2016	70	630–643		10.1016/j.ecolind.2016.02.028
31	Balancing demand and supply of multiple urban ecosystem services on different spatial scales	Ecosystem Services	2016	22	18–31		10.1016/j.ecoser.2016.09.008
32	Sustainable drainage system site assessment method using urban ecosystem services	Urban Ecosystems	2016	20	293–307	2	10.1007/s11252-016-0593-6
33	Green Roof Cost-Benefit Analysis: Special Emphasis on Scenic Benefits	Journal of Benefit-Cost Analysis	2016	7	488–522	3	10.1017/bca.2016.18
34	Deriving and Evaluating City-Wide Vegetation Heights from a TanDEM-X DEM	Remote Sensing	2016	8	940	11	10.3390/rs8110940
35	Modeling above-ground carbon storage: a remote sensing approach to derive individual tree species information in urban settings	Urban Ecosystems	2016	20	97–111	1	10.1007/s11252-016-0585-6
36	Spatially explicit urban green indicators for characterizing vegetation cover and public green space proximity: a case study on Brussels, Belgium	International Journal of Digital Earth	2016	10	798–813	8	10.1080/17538947.2016.1252434
37	Analysing scale, quality and diversity of green infrastructure and the provision of Urban Ecosystem Services: A case from Mexico City	Ecosystem Services	2017	23	127–137		10.1016/j.ecoser.2016.12.004
38	Improving models of urban greenspace: from vegetation surface cover to volumetric survey, using waveform laser scanning	Methods in Ecology and Evolution	2017	8	1443–1452	11	10.1111/2041-210x.12794

Table A1. Cont.

Sr. No.	Title	Journal	Year	Vol	Page(s)	Issue	DOI
39	Projecting the CO2 and Climatic Change Effects on the Net Primary Productivity of the Urban Ecosystems in Phoenix, AZ in the 21st Century under Multiple RCP (Representative Concentration Pathway) Scenarios	Sustainability	2017	9	1366	8	10.3390/su9081366
40	Capturing the value of green space in urban parks in a sustainable urban planning and design context: pros and cons of hedonic pricing	Ecology and Society	2017	22	13	2	10.5751/es-09365-220221
41	Assessing mismatches in ecosystem services proficiency across the urban fabric of Porto (Portugal): The influence of structural and socioeconomic variables	Ecosystem Services	2017	23	82–93		10.1016/j.ecoser.2016.11.015
42	A GIS-based mapping methodology of urban green roof ecosystem services applied to a Central European city	Urban Forestry & Urban Greening	2017	22	54–63		10.1016/j.ufug.2017.01.001
43	Mapping and Monitoring Urban Ecosystem Services Using Multitemporal High-Resolution Satellite Data	IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	2017	10	669–680	2	10.1109/jstars.2016.2586582
44	The potential of green infrastructure application in urban runoff control for land use planning: A preliminary evaluation from a southern Italy case study	Ecosystem Services	2017	26	345–354		10.1016/j.ecoser.2017.04.015
45	Analysing urban green space accessibility and quality: A GIS-based model as spatial decision support for urban ecosystem services in Brussels	Ecosystem Services	2017	28	328–340		10.1016/j.ecoser.2017.10.016
46	Temporal Changes in Ecosystem Services in European Cities in the Continental Biogeographical Region in the Period from 1990–2012	Sustainability	2017	9	665	4	10.3390/su9040665
47	Ecological landscape regulation approaches in Xilingol, Inner Mongolia: an urban ecosystem services perspective	International Journal of Sustainable Development and World Ecology	2017	24	401–407	5	10.1080/13504509.2016.1273263

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Sr. No.	Title	Journal	Year	Vol	Page(s)	Issue	DOI
48	Urban ecosystem services—assessment of potential at the different spatial scale: an example of poznan	Ekonomia I Srodowisko-Economics and Environment	2017	1	207–225	60	
49	A Needs-Driven, Multi-Objective Approach to Allocate Urban Ecosystem Services from 10,000 Trees	Sustainability	2018	10	15	12	10.3390/su10124488
50	A Differentiated Spatial Assessment of Urban Ecosystem Services Based on Land Use Data in Halle, Germany	Land	2018	7	101	3	10.3390/land7030101
51	Extraction of Urban Water Bodies from High-Resolution Remote-Sensing Imagery Using Deep Learning	Water	2018	10	585	5	10.3390/w10050585
52	Assessing ecosystem services of bornova’s green infrastructure, izmir (turkey)	Fresenius Environmental Bulletin	2018	27	3530–3541	5A	
53	Exploring temporal dynamics of urban ecosystem services in Latin America: The case of Bogota (Colombia) and Santiago (Chile)	Ecological Indicators	2018	85	1068–1080		10.1016/j.ecolind.2017.11.062
54	Assessing how green space types affect ecosystem services delivery in Porto, Portugal	Landscape and Urban Planning	2018	170	195–208		10.1016/j.landurbplan.2017.10.007
55	Mapping and Quantifying Variations in Ecosystem Services of Urban Green Spaces: A Test Case of Carbon Sequestration at the District Scale for Seoul, Korea (1975–2015)	International Review for Spatial Planning and Sustainable Development	2018	6	110–120	3	10.14246/irspsd.6.3_110
56	Visual structure of landscapes seen from built environment	Urban Forestry & Urban Greening	2018	32	71–80		10.1016/j.ufug.2018.03.020
57	Within-Class and Neighborhood Effects on the Relationship between Composite Urban Classes and Surface Temperature	Sustainability	2018	10	645	3	10.3390/su10030645
58	Study of the Spatiotemporal Variation Characteristics of Forest Landscape Patterns in Shanghai from 2004 to 2014 Based on Multisource Remote Sensing Data	Sustainability	2018	10	4397	12	10.3390/su10124397
59	Assessing Mismatches in the Provision of Urban Ecosystem Services to Support Spatial Planning: A Case Study on Recreation and Food Supply in Havana, Cuba	Sustainability	2018	10	2165	7	10.3390/su10072165

Table A1. Cont.

Sr. No.	Title	Journal	Year	Vol	Page(s)	Issue	DOI
60	Mapping the Changes in Urban Greenness Based on Localized Spatial Association Analysis under Temporal Context Using MODIS Data	ISPRS International Journal of Geo-Information	2018	7	407	10	10.3390/ijgi7100407
61	Significance of Urban Green and Blue Spaces: Identifying and Valuing Provisioning Ecosystem Services in Dhaka City	European Journal of Sustainable Development	2018	7	435–448	1	10.14207/ejsd.2018.v7n1p435
62	Analyzing temporal changes in urban forest structure and the effect on air quality improvement	Sustainable Cities and Society	2019	48	101548		10.1016/j.scs.2019.101548
63	Under one canopy? Assessing the distributional environmental justice implications of street tree benefits in Barcelona	Environmental Science & Policy	2019	102	54–64		10.1016/j.envsci.2019.08.016
64	Dynamics of Urbanization and its impact on Urban Ecosystem Services (UESs): A study of a medium size town of West Bengal, Eastern India	Journal of Urban Management	2019	8	420–434	3	10.1016/j.jum.2019.03.002
65	Urban ecosystem conditions and ecosystem services—a comparison between large urban zones and city cores in the EU	Journal of Environmental Planning and Management	2019	63	798–817	5	10.1080/09640568.2019.1613966
66	Multitemporal Geospatial Evaluation of Urban Agriculture and (Non)-Sustainable Food Self-Provisioning in Milan, Italy	Sustainability	2019	11	1846	7	10.3390/su11071846
67	Mapping the social values for ecosystem services in urban green spaces: Integrating a visitor-employed photography method into SolVES	Urban Forestry & Urban Greening	2019	38	105–113		10.1016/j.ufug.2018.11.012
68	Tree Cover for the Year 2010 of the Metropolitan Region of São Paulo, Brazil	Data	2019	4	145	4	10.3390/data4040145
69	Identifying urban vegetation stress factors based on open access remote sensing imagery and field observations	Ecological Informatics	2020	55	101,032		10.1016/j.ecoinf.2019.101032
70	Evaluating the contribution of urban ecosystem services in regulating thermal comfort	Spatial Information Research	2020		12		10.1007/s41324-020-00336-8
71	A Multidimensional Assessment Model Using RE-3DSG Sensors on Net ES and GVR for Sustainable and Smart Cities	Sensors (Basel)	2020	20	16	5	10.3390/s20051259

Table A1. *Cont.*

Sr. No.	Title	Journal	Year	Vol	Page(s)	Issue	DOI
72	Investigating the Patterns and Dynamics of Urban Green Space in China's 70 Major Cities Using Satellite Remote Sensing	Remote Sensing	2020	12	1929	12	10.3390/rs12121929
73	Children's green walk to school: An evaluation of welfare-related disparities in the visibility of greenery among children	Environmental Science & Policy	2020	110	10–13		10.1016/j.envsci.2020.05.009
74	A multi-criteria spatial approach for mapping urban ecosystem services demand	Ecological Indicators	2020	112	106,119		10.1016/j.ecolind.2020.106119
75	Towards nationally harmonized mapping and quantification of ecosystem services	Sci Total Environ	2020	703	134,973		10.1016/j.scitotenv.2019.134973
76	Ecosystem services mapping for green infrastructure planning-The case of Tehran	Sci Total Environ	2020	703	135,466		10.1016/j.scitotenv.2019.135466
77	Environmental justice and outdoor recreation opportunities: A spatially explicit assessment in Oslo metropolitan area, Norway	Environmental Science & Policy	2020	108	133–143		10.1016/j.envsci.2020.03.014
78	Mapping trade-offs and synergies among peri-urban ecosystem services to address spatial policy	Environmental Science & Policy	2020	112	79–90		10.1016/j.envsci.2020.06.002
79	Spatiotemporal dynamics of urban ecosystem services in Turkey: The case of Bornova, Izmir	Urban Forestry & Urban Greening	2020	49	126,631		10.1016/j.ufug.2020.126631

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