ANALYSIS OF SPATIAL PATTERNS IN MULTI-FUNCTIONALITY OF URBAN GREEN SPACES IN ISLAMABAD IN THE CONTEXT OF SUSTAINABILITY TRANSITIONS

by

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Analysis of Spatial Patterns in Multi-functionality of Urban Green Spaces in Islamabad in the Context of Sustainability Transitions

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بسم الله الرحمن الرحيم

DEDICATION

To

The Holy Prophet Muhammad (PBUH)

and

My loving family

DECLARATION

I *Sayyed Kifayatullah*, PhD scholar in the Department of Environmental Science enrolled under registration No. 42-FBAS/PHDES/F17, hereby declare that the knowledge contributed by analyses of data collected and results derived to draw conclusion presented in this thesis titled "*Analysis of Spatial Patterns in Multi-functionality of Urban Green Spaces in Islamabad in the Context of Sustainability Transitions*" is my own original work and has not been submitted as research work or thesis in any form in any other university or institute in Pakistan or abroad for the award of any degree. However, one out of four research papers from this thesis titled " Equitable Urban Green Space Planning for Sustainable Cities: A GIS-Based Analysis of Spatial Disparities and Functional Strategies in Islamabad, Pakistan" has been published in volume 15:22686 of *Scientific Reports Nature Portfolio* of Springer with impact factor 4:00. DOI: https://doi.org/10.1038/s41598-025-07578-2

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Deponent
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FORWARDING SHEET BY RESEARCH SUPERVISORS

The thesis entitled "Analysis of Spatial Patterns in Multi-functionality of Urban Green Spaces in Islamabad in the Context of Sustainability Transitions" submitted by Sayyed Kifayatullah in partial fulfillment of PhD degree in Environmental Science has been completed under my guidance and supervision. I am satisfied with the quality of student's research work and allow him to submit this thesis for further process of graduation with PhD Degree from Department of Environmental Science, as per IIU rules & regulations.

Date: 07-07-2024

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LIST OF ABBREVIATIONS

BTM	Benefit Transfer Mechanism
CART	Classification and Regression Tree
CBD	Central Business District
CES	Cultural Ecosystem Service
CNN	Convolutional Neural Networks
CS	Coefficient of Sensitivity
CZM	Concentric Zone Model
df	Degree of freedom
ED	Ecosystem Disservices
EROS	Earth Resources Observation and Science
ES	Ecosystem Services
ETM	Enhanced Thematic Mapper
GCC	Green Canopy Cover technique
GEE	Google Earth Engine
GFT	Google Fusion Tables
GIS	Geographic Information System
GPS	Global Positioning System
inVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
KW	Kruskal Wallis
LC	Land Cover
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LIC	Linear Iterative Clustering
LST	Land Surface Temperature
LU	Land Use
LULC	Land Use Land Cover
MDG	Millenium Development Goals
MEA	Millennium Ecosystem Assessment
MODIS	Moderate Resolution Imaging Spectroradiometer
nDSM	Normalized Digital Surface Model
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
Pak.Rs	Pakistani rupee
PES	Provisioning Ecosystem Services
RS	Remote Sensing
SAR	Synthetic-aperture radar
SPOT	Satellite Pour l'Observation de la Terre
TM	Thematic Mapper
TOA	Top Of Atmosphere
UES	Urban Ecosystem Services
UNDP	United Nations Development Programme
US	United States
USGS	United States Geological Survey
WRST	Willcoxin Rank Sum Test

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Sayyed Kifayatullah

ABSTRACT

This study investigates the spatial patterns and multifunctionality of the Urban Green Spaces (UGS) of Islamabad, Pakistan, as a means of promoting urban sustainability transitions. As cities grow fast, particularly in the developing world, the provision of UGS is paramount for creating healthy, sustainable cities and better quality of life. Urban green spaces are essential to the sustainability of fast-growing cities. Since they provide all kinds of ecosystem services, they are necessary for environmental and social development. This thesis evaluates the spatial patterns of UGS (urban green spaces) and proposes recommendations to enhance the role of UGS in urban sustainability transition in Islamabad, Pakistan. This study is distinctive in the sense that it combines Geographic Information Systems (GIS) technology and satellite remote sensing information to estimate the distribution of UGS. It further assesses the multiple benefits and public perception of UGS along with their use. It provides a complete picture of the present state of UGS and their ability to contribute to sustainable development in urban areas. The research begins with an extensive spatial analysis to evaluate the distribution of UGS in Islamabad. This means using good satellite pictures and GIS methods to get information about the already green and their features. According to the findings, UGS availability is less in poor communities while affluent areas have relatively more and better quality UGS available to them. Inequalities in the distribution of urban green spaces across areas need to be addressed by proper planning. After mapping, the thesis assesses the ecosystem services of these green space areas that include air quality improvement, temperature regulation, flood alleviation and biodiversity conservation. The economic value of these services is estimated with quantitative methods and the Benefit Transfer Method (BTM). UGS strongly and positively contributes to urban economy and health. Surveys assessing public perception and community engagement with UGS reveal a high appreciation for UGS benefits. However, there is considerable dissatisfaction with accessibility and maintenance of UGS. According to the study, the functionality of green spaces is strongly correlated to public satisfaction which is important for successful sustainability transitions. This thesis presents a framework for urban planning based on the spatial-economic-perceptual analysis that favors the extension and distribution of UGS. This research will enhance the body of knowledge on UGSs in urban settings, as well as offer relevant solutions to urban planners and policy makers. It highlights the need to consider UGS as part of the urban structure and not only as decorations. UGS must be seen as a critical element of urban infrastructure for ecological resilience and social equity. The strategies put forward intend to enable the sustainability transitions for Islamabad and serve as a guidebook for other cities facing similar issues in the Global South. The study lays the foundation to make it possible for Islamabad to be transformed into a more resilient, sustainable, and livable city by filling the gaps in the current urban planning and advocating for a data-driven and inclusive approach to UGS management. The findings and recommendations will help in shaping the urban of UGS for the future sustainability of the fast-paced urbanizing areas.

Chapter-1

INTRODUCTION

1.1. Background

Urban Green Spaces (UGS) are important for environmental sustainability and quality of urban life in rapidly urbanizing areas. They can provide numerous benefits and importantly services. As the globe is getting urbanized, there is a growing need for cities to include green areas in the urban landscape to alleviate challenges like pollution, the heat island effect and biodiversity loss (Kabisch et al., 2015; McPhearson et al., 2014). The urban growth rate in Pakistan is the highest in South Asia. It is projected that nearly half the population will reside in cities by 2025 (*Urbanisation in Pakistan | United Nations Development Programme*, n.d.). With swift urbanization, environmental degradation, inequality, and reduction of green space have all occurred which show the need for effective urban planning and sustainable management of UGS (McPhearson et al., 2014).

1.2. Significance of Urban Green Spaces

Urban green spaces offer various ecosystem services that support urban resilience. They include things like purifying the air, quietening things down, keeping temperatures good (and more) plus intangible benefits that merit mental well-being and social cohesion. Urban green spaces provide many benefits to society, like enhancing the quality of urban life and providing recreation. Studies show that UGS serve multiple functions when maintained properly. Moreover, larger UGS offer environmental benefits while enhancing the social and cultural situations of urban areas (Andersson et al., 2014; Kabisch, 2015). The purpose of the study is to investigate the spatial patterns and multifunctionality of UGS in Islamabad. Using GIS and remote sensing techniques, the study will assess the UGS distribution, typology and functionality, thereby leveraging them for urban sustainability.

1.3. Urbanization and the Need for Nature-Based Solutions

With the increasing level of urbanization by the world, cities face greater environmental pressures, from pollution to habitat loss. Urban green spaces (UGS) have become indispensable nature-based solutions to these crises, offering a form of natural infrastructure that can help deliver on environmental, social and economic objective simultaneously (Frantzeskaki et al., 2017; *Nature-based solutions - European Commission*, n.d.). In Pakistan, there was no sustainable planning for urbanization. As a result, urban sprawl reduced green cover and increased pollution (*Urbanisation in Pakistan | United Nations Development Programme*, n.d.). Islamabad is better planned than other cities of Pakistan. Recently, urban population in Islamabad has grown rapidly which has added pressure on green areas.

NBS in city planning is especially important in high density and rapidly urbanizing regions like Pakistan where cities have little or no green infrastructures. UGS are flexible and context-specific features that can enhance urban livability through ecological resilience and human well-being (Frantzeskaki et al., 2016). Establishing NBS through UGS are effective strategies for urban development and ecological protection in search of the sustainable urban transition.

The new approaches of Sustainability Transitions characterize Urban Green Spaces (UGS) as important elements of urban sustainability. Grin et al. provide definition where ‘transitions’ refer to radical transformations of socio-technical systems to deal with intractable societal problems. In cities, it focuses on using adaptive systems based on ecosystem services rather than infrastructure-intensive ones (Markard et al., 2016). Urban Green Spaces (UGS) are very important for transforming the cities and they act as the niches in which innovative urban practices can take place. These urban practices include urban agriculture, biodiversity enhancement, and community-led green infrastructures projects, among others (Frantzeskaki, 2019).

Cities such as Islamabad that have adequate UGS offer a chance to integrate these principles into planning. By participatory governance and data-driven mapping, Sustainability Transitions can help create strategies to integrate UGS into wider ecological and social contexts. Frantzeskaki, (2019) suggests that co-designed green infrastructure in cities in Europe has helped accelerate transitions to urban sustainability.

1.3. Research Context and Rationale

The study concerns Islamabad which is a planned city with vegetation more than other cities in Pakistan. As cities grow quickly than before, it has become quite essential to preserve, manage, and develop green spaces. Due to the lack of data on UGS in Islamabad, the decision-making of the policymakers has become ineffective. Using GIS and RS tools, this study proposes a spatially explicit quantification of UGS along with their ecosystem services and determination of multifunctional role of UGS for improving urban resilience.

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Incorporating Sustainability Transitions into urban planning can provide practical solutions to Islamabad's ecological and social dilemmas. Sustainability Transitions focuses on long-term, system-wide change that is consistent with global sustainability goals but adapted to local context (Artmann et al., 2019; Köhler et al., 2019). Mapping and quantifying the multi-functional UGS of Islamabad in this study will not only reduce the existing knowledge gaps but will also be a way forward towards transitions in a range of socio-technical regimes i.e. food through organic urban farming and healthcare through enhanced physical activity. Findings from this study could help support pathways towards sustainable urbanization in similar contexts of the Global South.

Islamabad is an ideal case because, as the federal capital, it offers a unique mix of natural and built environments. By studying UGS of Islamabad, one can provide solutions to sustainable planning of urban spaces in cities facing similar challenges of urbanization in Pakistan (Kabisch, 2015). Mapping the provision of ecosystem services by UGS in Islamabad can inform urban policy and management in the future, making green spaces central to sustainable, livable, and resilient urban settlements.

1.3. Objectives of the Study

The primary purpose of this research is to analyze the distribution, multifunctionality, and potential of Urban Green Spaces (UGS) in Islamabad in the context of ecological, social and economic value. The goal of this study is to help provide data-driven insights, thereby assisting sustainable urban planning initiatives including the UGS and the specific objectives were:

i) To quantify the extent and spatial distribution of existing UGS in Islamabad, with a focus on their geo-physical and bio-ecological attributes.
ii) To assess the multifunctionality of UGS by evaluating the ecosystem services they provide, including air purification, temperature regulation, and biodiversity support.
iii) To identify challenges and opportunities for the effective management and expansion of UGS, contributing to Islamabad's sustainability transitions.
iv) To explore community perceptions of UGS and how these spaces contribute to well-being, social cohesion, and recreational opportunities in urban settings.

The aims of the project align with integration of environmental and social aspects in the Planning of Islamabad termed as a Dynamic City. There is need for Data-driven Decision making in Urban Green Space Management Planning.

1.3. Problem statement

Pakistan is undergoing rapid urbanization, which is causing urban green space to deteriorate and be underutilized because of bad planning. Even though the capital city of Pakistan is a result of a planned development, yet the green areas of Islamabad are under immense pressure owing to population increase and infrastructure expansion (*Urbanisation in Pakistan | United Nations Development Programme*, n.d.). The city will not be resilient because of it not only the ecological aspect but also limits the social and health benefits that UGS can provide to a city. Absence of spatial data on UGS in Islamabad hampers protection and optimization of UGS.

This research study emphasizes the spatial patterns, functionality as well as perceived value of UGS in Islamabad. By identifying and measuring these spaces, researchers will assist policy planners in devising strategies to protect the UGS and to strengthen their use within the overall sustainability framework of Islamabad.

1.3. Significance of the Study

The research has tremendous implications for sustainable urban planning in Pakistan; not just for Islamabad but also for other rapidly urbanized cities. The study provides policymakers the evidence-based foundation to allocate resources for the preservation and development of UGS through spatial analysis. Acknowledging the economic, ecological and social benefits of UGS can help to guide more sustainable urban development and create healthier urban environments. Also, this study adds to the literature on Nature-Based Solutions (NBS) by showing the role of UGS in improving resilience and quality of life in the city. This research proposes to make UGS an essential component of urban sustainability agenda, which is aligned with the global sustainable development strategies to create greener city and urban resilience (Frantzeskaki et al., 2017; McPhearson et al., 2014).

1.3. Theoretical Framework

This study uses Nature-Based Solutions (NBS) and sustainability transitions as frameworks to investigate how Urban Green Spaces (UGS) can contribute to urban resilience. NBS uses natural infrastructures to respond to environmental and social challenges, which offers a conceptual view on multifunctional UGS (Frantzeskaki et al., 2017; Hölscher et al., 2021). In cities, NBS promotes green infrastructure in city planning to support a sustainable and livable future. This way of thinking speaks to Sustainability Transitions theory. That theory is about profound changes in socio-technical systems. This type of theory can fix long-term societal problems. For example, climate change and environmental degradation (Grin et al., 2010).

These theoretical bases are very much applicable to Islamabad to make its urbanization sustainable to tackle the impacts of rapid urbanization. Through these lenses, UGS is examined to show how green spaces can serve as leverage points for broader urban sustainability. The theory that green infrastructure is something more than a pretty addition to the ecology of urban places but rather it contributes to creating resilient urban systems that offer ecological, social and economic stability (Kabisch et al., 2016; Haase et al., 2017).

1.3. Justification of the Research

The rationale for conducting this research is the dire need to examine the urbanization practices in Pakistan. Environmental degradation and increased urbanization have made it paramount. Green spaces are globally acclaimed as assets tantamount to sustainable cities, however, Pakistan has not utilized this potential yet. This study is a timely assessment of the UGS in Islamabad to develop a model for integrating the green infrastructure in urban planning of the country. The findings will allow future researchers and practitioners to make green infrastructure plans that are in line with the aspirations of the country (McPhearson et al., 2014). The findings of this study can provide a reference for the local governments of Pakistan to consider green spaces as essential part of the urban infrastructure. This study also adds to the growing knowledge on the ecosystem services of cities and the value of UGS for health, biodiversity, and climate adaptation. This shows urban green spaces have an important role in the health and resilience of urban communities. It is the need of the hour advance approach.

Chapter-2

REVIEW OF LITERATURE

2.1. Introduction

The increasing concentration of human populations in urban areas presents a complex array of environmental, social, and economic challenges (Allam et al., 2022; Gu, 2019). This phenomenon, known as urbanization, necessitates the development and implementation of innovative solutions to create more resilient, livable, and environmentally sustainable cities (Martos et al., 2016; Shahidehpour et al., 2018). Urban Green Spaces (UGS), encompassing a variety of elements such as parks, gardens, green roofs, green walls, and other nature-based solutions (NBS), are increasingly recognized for their capacity to effectively address these challenges (Lehmann, 2023; Pinto et al., 2023). Urban green infrastructure (UGI) is a strategically planned network that incorporates natural and semi-natural areas and is designed and managed to provide various ecosystem services (Firehock et al., 2015). Nature-based solutions are defined as "living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social, and environmental benefits"(Langergraber et al., 2020).

The concept of UGS as NBS has gained significant traction in recent years due to its potential for addressing critical urban challenges, including climate change, biodiversity loss, and the degradation of human well-being (Dorst et al., 2019; Kabisch, Korn, et al., 2017; Snep et al., 2020). UGS contributes to sustainability transitions by providing a wide spectrum of ecosystem services (Fang et al., 2023), including flood mitigation, urban heat island reduction, air purification, noise reduction, and support for biodiversity. They offer recreational opportunities, enhance aesthetic value, and contribute to the cognitive development of urban residents. The integration of UGS into urban planning and design is essential for promoting sustainable urban development and improving the quality of life for urban populations. However, effectively harnessing the potential of UGS as NBS requires a comprehensive understanding of their multifaceted roles in urban environments. It is crucial to consider the multifunctionality of UGS, recognizing their capacity to deliver multiple benefits simultaneously.

Previous research has explored the potential benefits of GI in urban areas, particularly highlighting their role in regulating water flow and temperature, improving water quality, and enhancing the overall quality of life for urban dwellers (Aronson et al., 2017; R. Huang et al., 2022; Y. Wang et al., 2014; Yao et al., 2020). Additionally, some studies emphasize the importance of incorporating social justice considerations into UGS planning and research, recognizing the equitable distribution of these spaces (Hunter et al., 2019). This systematic literature review aims to build upon this existing knowledge by conducting a thematic review that specifically focuses on UGS as NBS for sustainability transitions, going beyond the analysis of individual benefits to examine how UGS can contribute to systemic change towards more sustainable urban systems.

2.1. Methodology

In a rapidly expanding urban landscape, the need for sustainable development becomes increasingly evident. Three concepts stand out: Urban Green Spaces, Sustainability Transition, and Nature-Based Solutions. This review explores the key themes and provides a snapshot of what current research has to say about these critical issues by exploring how these concepts come together. In this study, the existing literature was examined through a systematic approach, following the PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Harms et al., 2024; Jato-Espino et al., 2023). The focus is on the intersection of Urban Green Spaces, Sustainability Transition, and Nature-Based Solutions. In order to conduct a comprehensive search across two major academic databases, Web of Science and Scopus, we carefully selected keywords relevant to the focus areas of our research. It was found that 270 articles were found in Web of Science and Scopus, 120 of which were from Web of Science between the year 2006 and 2020 (Figure 2.1). To reduce the number of unique articles to 200, we first eliminated duplicate records in the dataset. To determine if these articles aligned with the themes of our study, we examined their titles and abstracts carefully in order to assess whether they were relevant to our research. As a result of this process, we were able to drastically narrow down our selection, eliminating 120 articles from our list and leaving us with 80 that we thought were worth digging deeper. The 80 full-text articles were then thoroughly reviewed, making sure that they both focused on the UGS, ST, and NBS topics and that they had been published in English as a second step. As a result of this phase of our research, 50 articles were eliminated that were either not aligned with or failed to meet the necessary standards. This phase required careful consideration, and ultimately resulted in the exclusion of 50 articles. The literature review we conducted was based on 30 articles that we selected as the basis for discussing the key trends and insights in UGS, ST, and NBS research that were uncovered in our literature review.

In order to ensure that the 30 selected studies were thoroughly reviewed (Table 2.1), we collected all the necessary details in a comprehensive manner. Among the items collected were the authors' names, year of publication, title, journal, and DOI of the study. As part of our analysis, we carefully examined each study's research goals, questions or hypotheses, and data collection, analysis, and design methods.

However, we were not focused just on the technical details, but also tried to understand how each research contributed to the broader field, emphasizing the relevance of these studies to urban planning and sustainability. Thematic analysis allowed us to identify recurring patterns, such as the importance of Urban Green Spaces (UGS) in driving sustainability transition, how Nature-Based Solutions (NBS) are being integrated into urban planning, and the overall benefits of combining UGS and NBS for urban sustainability. Further, we evaluated the different geographical locations where these studies were conducted, as well as how they utilized quantitative or qualitative approaches.

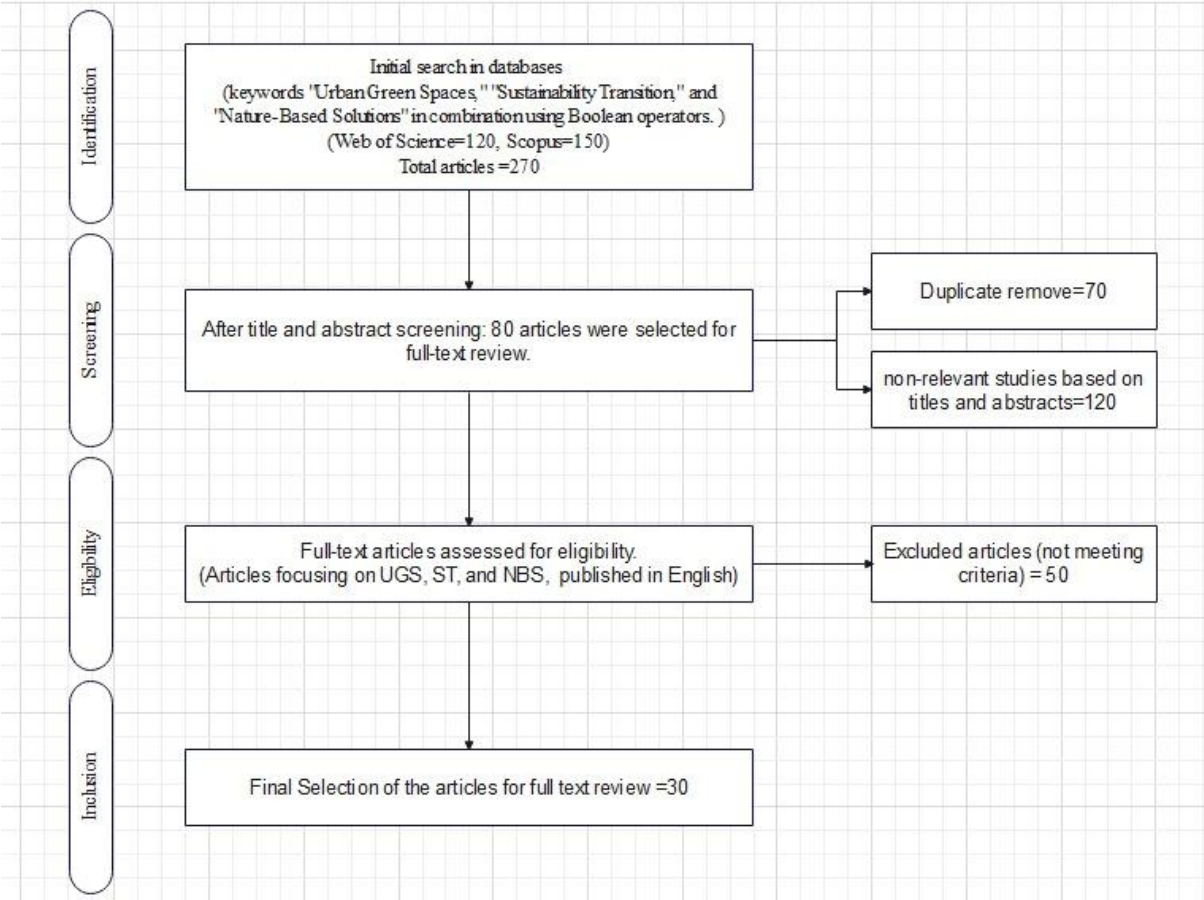

Figure 2. 1. PRISMA framework-based approach for systematic literature review.

Table 2. 1. List of publications included in the systemic literature review

SN	Author(s)	Year of Publication	Title of the Study	Journal / Publisher	DOI
1	(Andersson et al., 2014)	2014	Reconnecting cities to the biosphere: Stewardship of green infrastructure and urban ecosystem services	Ambio	10.1007/s13280-014-0506-y
2	(N. Barton et al., 2012)	2012	Valuation of ecosystem services from Nordic Watersheds: From awareness raising to policy support?	Ecological Economics	10.6027/TN2012-506
3	(Connop et al., 2016)	2016	Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure	Environmental Science & Policy	10.1016/j.envsci.2016.01.013
4	(Thomas Elmqvist et al., 2013)	2013	Urbanization, biodiversity and ecosystem services: Challenges and opportunities: A global assessment	Springer	10.1007/978-94-007-7088-1
5	(Hansen et al., 2015)	2015	The uptake of the ecosystem services concept in planning discourses of European and American cities	Ecosystem Services	10.1016/j.ecoser.2014.11.013

6	(Kabisch et al., 2014)	2014	Green justice or just green? Provision of urban green spaces in Berlin, Germany	Landscape and Urban Planning	10.1016/j.landurbplan.2013.11.016
7	(Keesstra et al., 2018)	2018	The way forward: Can connectivity be useful to design better NBS towards achieving SDG's?	Science of The Total Environment	10.1016/j.scitotenv.2018.06.342
8	(Thomas Elmqvist et al., 2013)	2013	Urbanization, climate change, and ecosystem services	Springer	10.1007/978-94-007-7088-1
9	(Raymond et al., 2017)	2017	An impact evaluation framework to support planning and evaluation of nature-based solutions projects	Science of The Total Environment	10.1016/j.scitotenv.2016.11.173
10	(Saarikoski et al., 2016)	2016	Multi-criteria decision analysis and cost-benefit analysis: Comparing alternative frameworks for integrated valuation of ecosystem services	Ecosystem Services	10.1016/j.ecoser.2016.10.014
11	(Tzoulas et al., 2007)	2007	Promoting ecosystem and human health in urban areas using green infrastructure: A literature review	Landscape and Urban Planning	10.1016/j.landurbplan.2007.02.001
12	(J. Wang et al., 2018)	2018	Towards a better understanding of Green Infrastructure: A critical review	Ecological Indicators	10.1016/j.ecolind.2017.09.018
13	(Zhou et al., 2011)	2011	Spatial–temporal dynamics of urban green space in response to rapid urbanization and greening policies	Landscape and Urban Planning	10.1016/j.landurbplan.2010.12.013
14	(Ahern, 2011)	2011	From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world	Landscape and Urban Planning	10.1016/j.landurbplan.2011.02.021
15	(Haase, Larondelle, et al., 2014)	2014	A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation	Ambio	10.1007/s13280-014-0504-8
16	(Gómez-Baggethun et al., 2013)	2013	Classifying and valuing ecosystem services for urban planning	Ecological Economics	10.1016/j.ecolecon.2012.08.019
17	(Davies et al., 2017)	2017	Urban green infrastructure in Europe: Is greenspace planning and policy compliant?	Land Use Policy	10.1016/j.landusepol.2017.08.018
18	(Frantzeskaki et al., 2017)	2017	Nature-based solutions accelerating urban sustainability transitions in cities: Lessons from Dresden, Genk and Stockholm cities	Springer	10.1007/978-3-319-56091-5_5
19	(Matthews et al., 2015)	2015	Reconceptualizing green infrastructure for climate change adaptation: Barriers to adoption and drivers for uptake by spatial planners	Landscape and Urban Planning	10.1016/j.landurbplan.2015.02.010
20	(Nesshöver et al., 2017)	2017	The science, policy and practice of nature-based solutions: An interdisciplinary perspective	Science of The Total Environment	10.1016/j.scitotenv.2016.11.106

21	(Anguelovski et al., 2018)	2018	From landscapes of utopia to the margins of the green urban life: For whom is the new green city?	City	10.1080/13604813.2018.1473126
22	(Wolch et al., 2014)	2014	Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'	Landscape and Urban Planning	10.1016/j.landurbplan.2014.01.017
23	(Lovell et al., 2013)	2013	Supplying urban ecosystem services through multifunctional green infrastructure in the United States	Landscape Ecology	10.1007/s10980-013-9912-y
24	(Coutts et al., 2015)	2015	Green infrastructure, ecosystem services, and human health	International Journal of Environmental Research and Public Health	10.3390/ijerph120809768
25	(Alves et al., 2019)	2019	Assessing the Co-Benefits of green-blue-grey infrastructure for sustainable urban flood risk management	Journal of Environmental Management	10.1016/j.jenvman.2019.03.036
26	(Kabisch & van den Bosch, 2017)	2017	Urban green spaces and the potential for health improvement and environmental justice in a changing climate	Springer	10.1007/978-3-319-56091-5_12
27	(Demuzere et al., 2014)	2014	Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure	Journal of Environmental Management	10.1016/j.jenvman.2014.07.025
28	(Naumann et al., 2011)	2011	Design, implementation and cost elements of green infrastructure projects. Final report to the European Commission, DG Environment	Ecologic Institute and GHK Consulting	N/A
29	(Kim et al., 2016)	2018	The Value of Green Infrastructure on Vacant and Residential Land in Roanoke, Virginia	Sustainability	10.3390/su8040296
30	(Kabisch et al., 2015)	2015	Human-environment interactions in urban green spaces—A systematic review of contemporary issues and prospects for future research	Environmental Impact Assessment Review	10.1016/j.eiar.2014.08.007

2.3. Results

2.3.1. Trend in research and publications of UGS as NBS for ST

Over the period 2006-2020, Figure 2.2 reveals how the number of publications has changed. Although the number of studies published each year has fluctuated, the overall trend shows an upward trend. This is highlighted by the dotted line. During 2014 and 2018, publication activity spiked, suggesting that this research area was particularly active at that time. The research output fluctuated over time, with some dips, especially between 2012 and 2020.

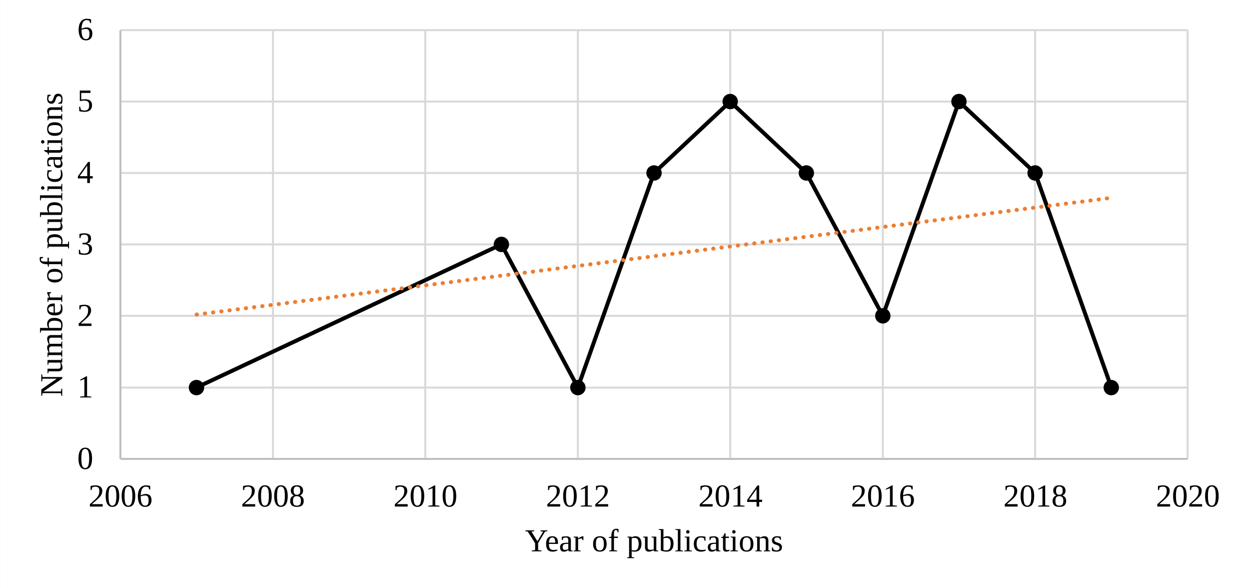

Figure 2. 2. Publications related to urban green spaces, sustainability transition, and nature-based solutions over the period 2006-2020.

Figure 2.3 summarizes most of the research on Urban Green Spaces, Sustainability Transition, and Nature-Based Solutions. With *Landscape and Urban Planning* (n=6), and *Science of the Total Environment* (n=3) are being the most frequently published journals, and Springer (n=4) were among the most frequently published. In promoting these important issues, these journals have played a significant role during the period between 2006 and 2020.

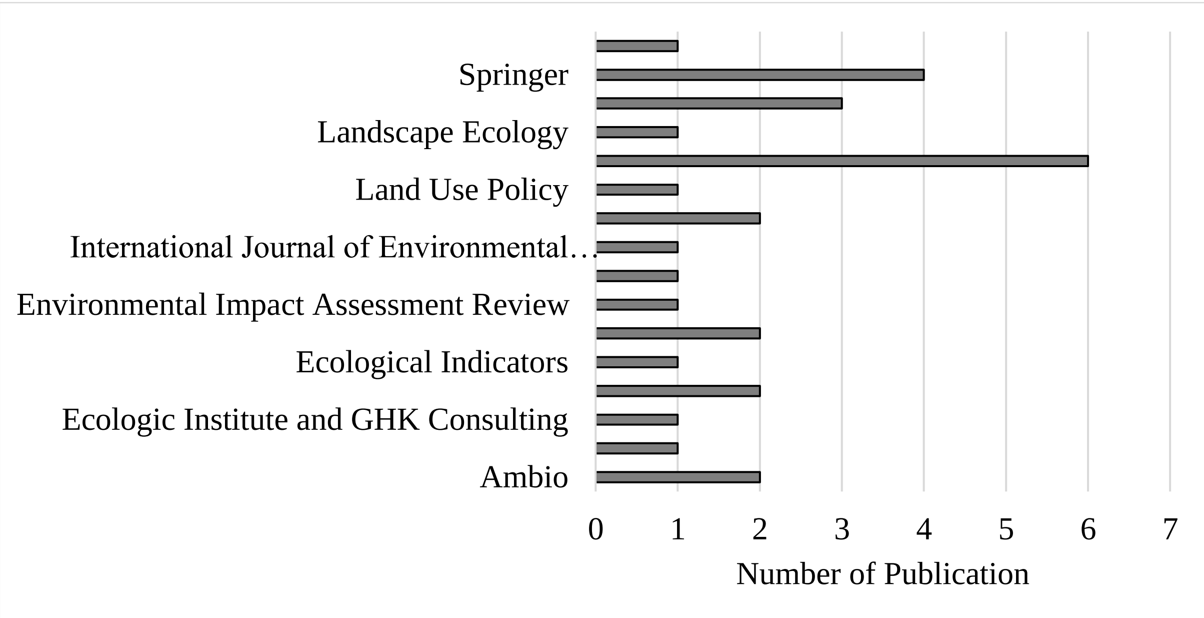

Figure 2. 3. Distribution of publications across journals and publishers.

2.3.2. Word cloud analysis of the research objectives

The key themes from the research objectives of the selected studies (n=30) were visualized using a word cloud analysis. Figure 2.4. provided an immediate and clear indication of which themes were predominant across the studies. According to the analysis, urban" and "green" were the most prominent words, highlighting the strong focus on urban green spaces in the study. The importance of ecosystem services and sustainable infrastructure was also highlighted by other key terms such as "ecosystem," "infrastructure," and "services." However, terms such as "sustainability," "equity," "resilience," and "biodiversity" still played a significant role, indicating how diverse and interdisciplinary the research was. With this word cloud, researchers were able to grasp the main focus areas of their research in a straightforward and intuitive way, demonstrating the wide-ranging approach they took to urban development and sustainability challenges. As a result, there was a better understanding of the most important themes.

Figure 2. 4. Research objectives based word cloud analysis in the selected (n=30) studies.

2.3.3. Categorization of research questions and hypothesis

Furthermore, we categorized the research questions and hypotheses into groups based on the main focus areas of the selected studies (Table 2.2). A strict categorization and inclusion criteria had already been applied, indicating the importance and further categorization of "Green Infrastructure," "Ecosystem Services," and "Urban Planning.". There were also prominent categories in the research questions and hypotheses related to "Health and Well-being," "Policy and Governance," "Sustainability," "Climate Change," and "Social Equity." The broad range of topics highlights the research's broad scope.

Table 2. 2. Frequency count of categorization of the research questions and hypothesis of the selected studies.

Category	Count
Green Infrastructure	10
Ecosystem Services	5
Urban Planning	5
Sustainability	2
Climate Change	2
Health and Well-being	3
Policy and Governance	3
Social Equity	1

2.3.4. Similarities and differences in research methodological approach

Analysis of the methodological similarities and differences among the 30 reviewed studies was performed by using a hierarchical clustering dendrogram (Figure 2.5). The selected studies were grouped according to their "*research designs*", "*data collection methods*", and "*data analysis techniques*". At one end of the dendrogram, studies such as Study 25 and Study 13 demonstrated a high degree of methodological consistency, utilizing comprehensive approaches such as case studies, surveys, and GIS analysis. In contrast, studies at the other end, such as Study 3 and Study 30, showed greater methodological diversity, including case studies, systematic reviews, and conceptual analyses, as well as qualitative and thematic approaches. Using this clustering, we were able to identify common research practices within the field while also highlighting methodological diversity.

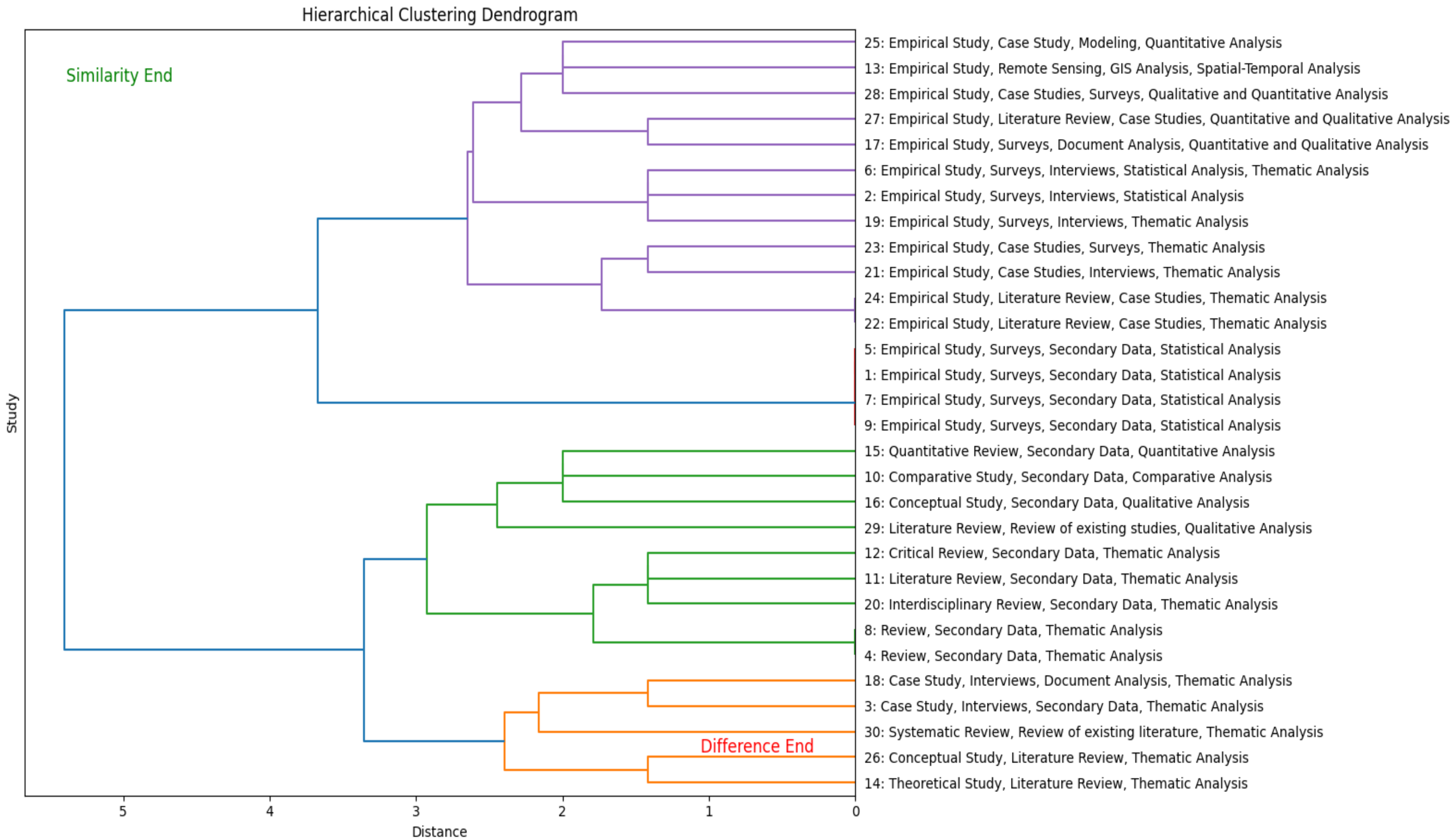

Figure 2. 5. Hierarchical clustering dendrogram based on the research designs, data collection methods, and data analysis techniques

2.3.5. Thematic analysis of the selected studies

The co-occurrence matrix of themes in all selected studies was used to analyze themes. Figure 2.6. provides a clear and insightful picture of how different topics are related to one another in the literature reviewed. In the matrix, cells depict the frequency with which two themes occur together in the same study, while the intensity of the color shows how often these co-occurrences occur. This matrix shows which themes tend to be explored together and which are less frequently explored together.

A number of researchers are interested in understanding how green infrastructure influences ecosystem services, which is why themes such as *"Green Infrastructure"* and "*Ecosystem Services*" often appear together. As a result, understanding how green infrastructure impacts ecosystem services is a crucial area of interest in the field. The matrix also indicates that *"Urban Green Spaces"* , *"Human Health"* and *"Environmental Justice"* are often discussed at the same time. Based on this combination, studies often focus on green spaces' broader benefits to health and equity in cities.

"*Climate Change Adaptation*", *"Urban Planning"* and *"Ecosystem Services"* are also connected in the matrix. This relationship indicates an increasing interest in how urban planning can incorporate natural ecosystems to help cities adapt to climate change. In order to address climate challenges, urban development must be viewed from an environmental perspective.

It also enables us to identify research gaps that don't appear together as often. These gaps suggest areas where more study could be valuable, providing opportunities to explore new connections between themes that haven't been studied as much. Co-occurrence matrixes not only highlight the main relationships between themes in current research, but also suggest places where future studies could look deeper into less explored areas.

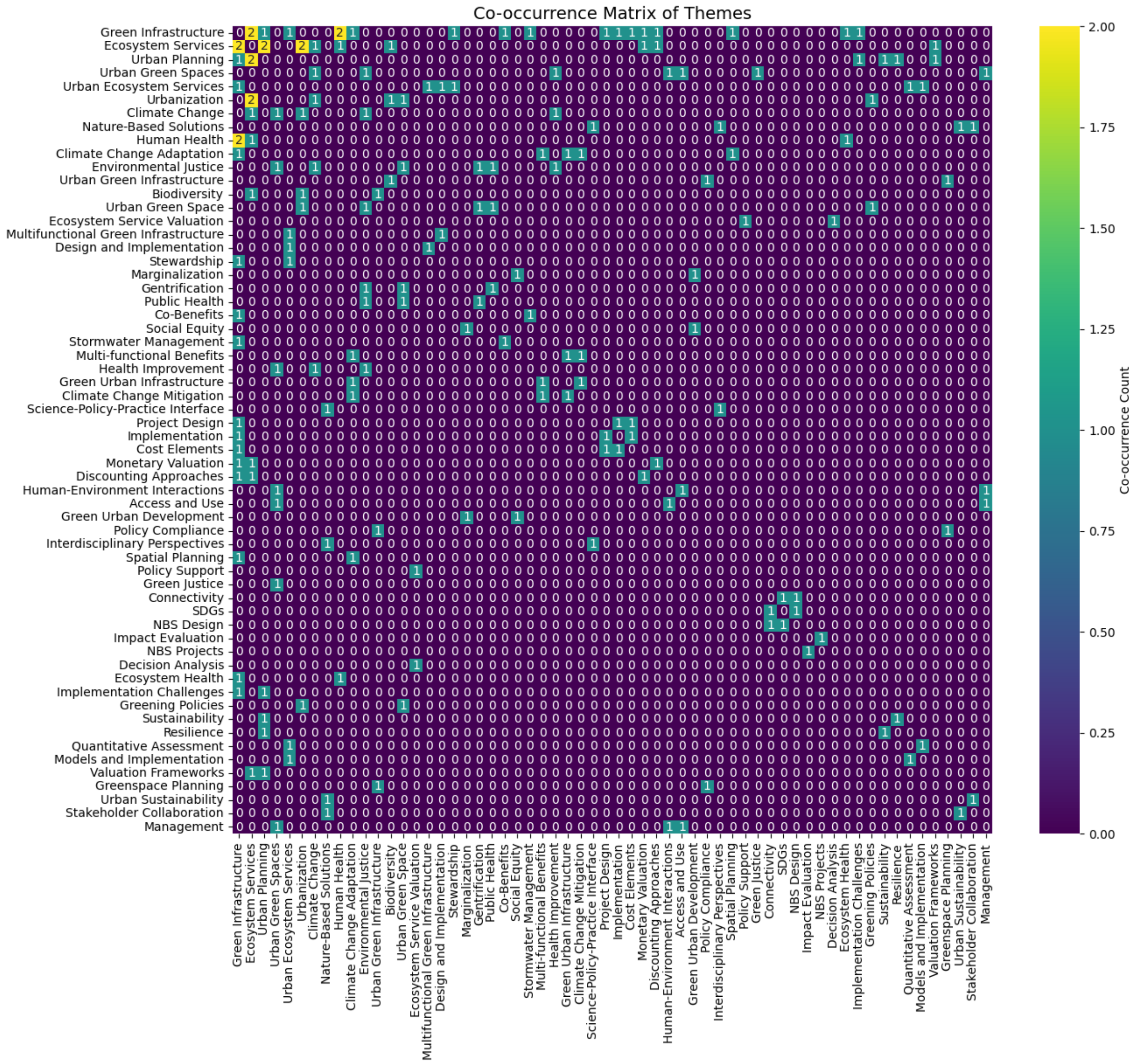

Figure 2. 6. Thematic co-occurrence matrix of the focused studies.

2.3.6. The Role of Urban Green Spaces (UGS) in Urban Sustainability Transitions

Findings of the advanced text analysis, sentiment analysis, word frequency and topic modelling uncovered deeper insights into UGS contribution and their impact on urban sustainability. These insights reveal the vital role these spaces play in creating healthier, more resilient cities. The word cloud (Figure 2.7) gives us a visual depiction of the most common themes associated with UGS. Words like "*Supports*" "*Urban*" "*Enhances*" and "*Resilience*" are prominent, showing that UGS is frequently discussed in the context of supporting urban development, enhancing community resilience, and promoting fair distribution of environmental benefits. These themes stand out as central to UGS research.

Figure 2. 7. Assessment of word frequency of UGS in urban sustainability transitions.

Sentiment analysis, illustrated in Figure 2.8, depicts how researchers perceive about UGS roles. Most sentiments are *positive*, reflecting a strong belief in UGS' benefits to cities. Whether it's improving public health, providing green spaces, or enhancing biodiversity, UGS are overwhelmingly positive. There are some *neutral* sentiments, suggesting a balanced view of certain aspects. However, *negative* opinions are non-existent, indicating UGS are widely appreciated.

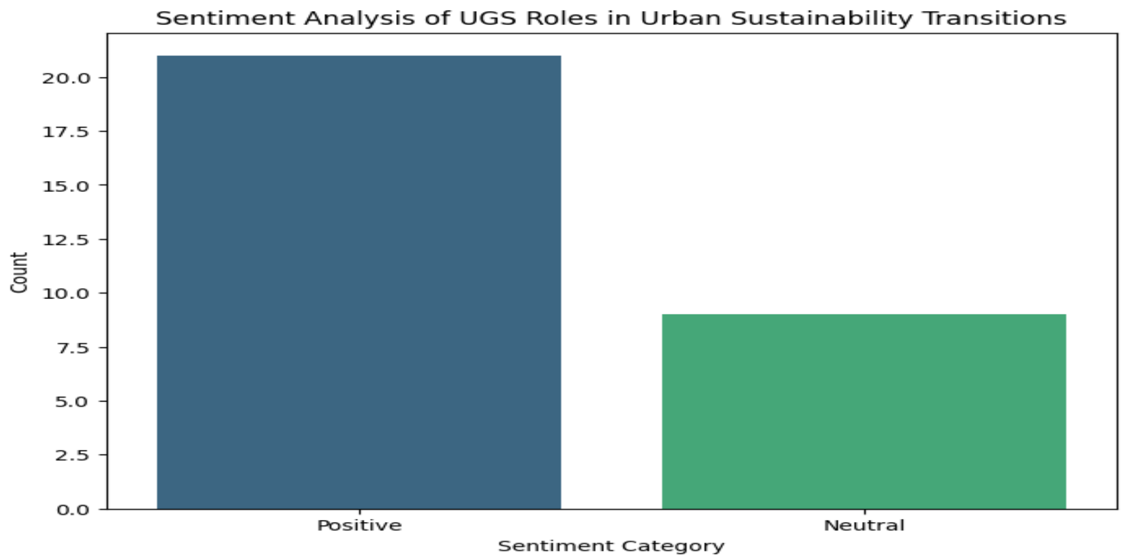

Figure 2. 8. Sentiment analysis of UGS roles in urban sustainability transitions.

Topic modeling, as shown in Figure 2.9, breaks down the discussion into five main themes: *"Resilience and adaptation"*, *"Policy and planning"*, *"Health and Well-being"*, *"Equity and*

Justice", and *"Biodiversity and Ecosystem Services"*. Each theme is explored in the context of UGS's role in urban sustainability. For example, "Resilience and Adaptation" focuses on how UGS helps cities withstand climate change, while *"Health and Well-being"* highlights UGS' contribution to both human and environmental health.

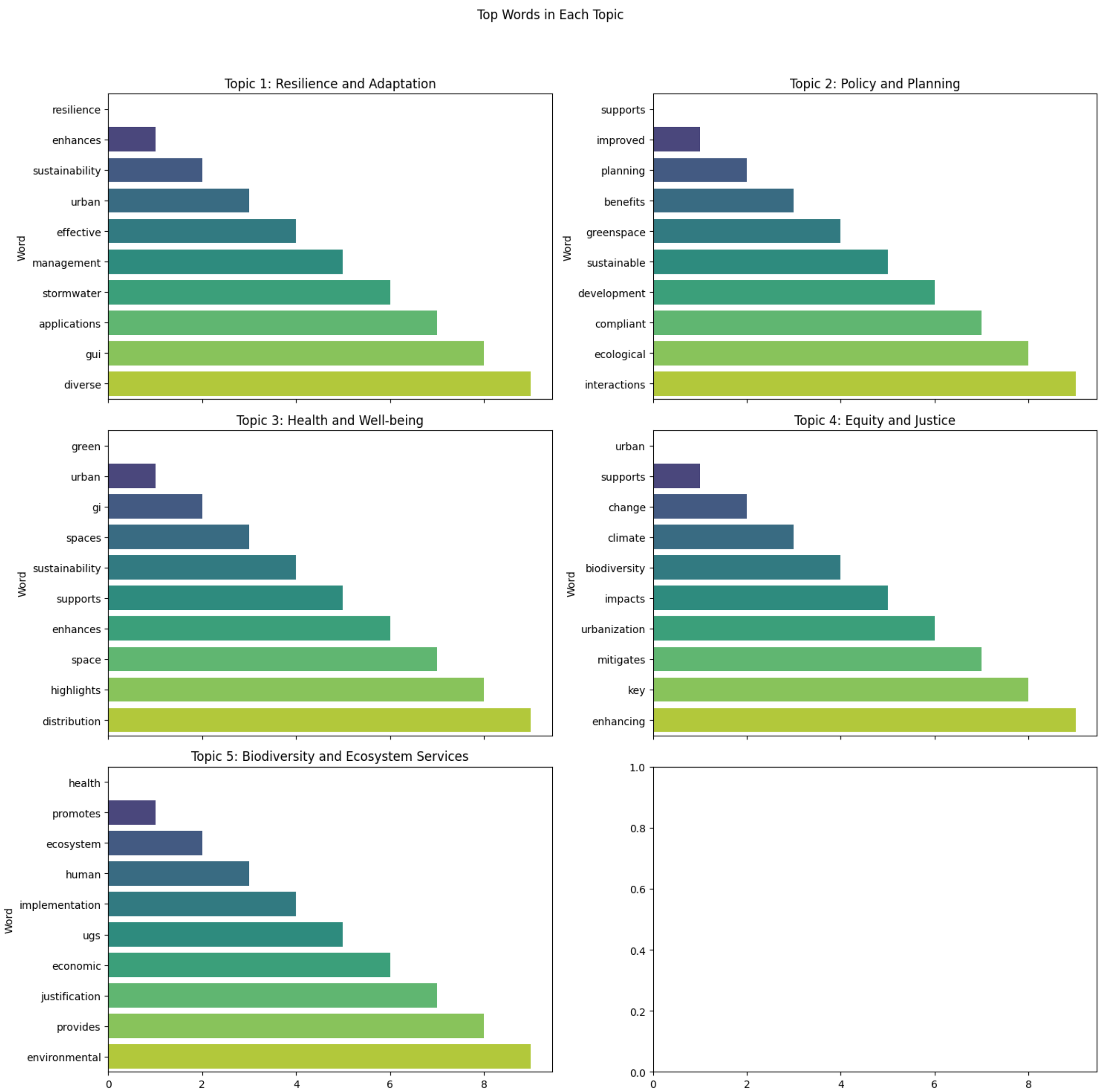

Figure 2. 9. Top words based thematic topic modeling.

Finally, Figure 2.10 shows sentiment analysis broken down by these sustainability transitions based topic categories. The topics of "Health and Well-being" and *"Policy and Planning"* are particularly notable for their strong positive sentiment, emphasizing the high value placed on UGS in these research areas.

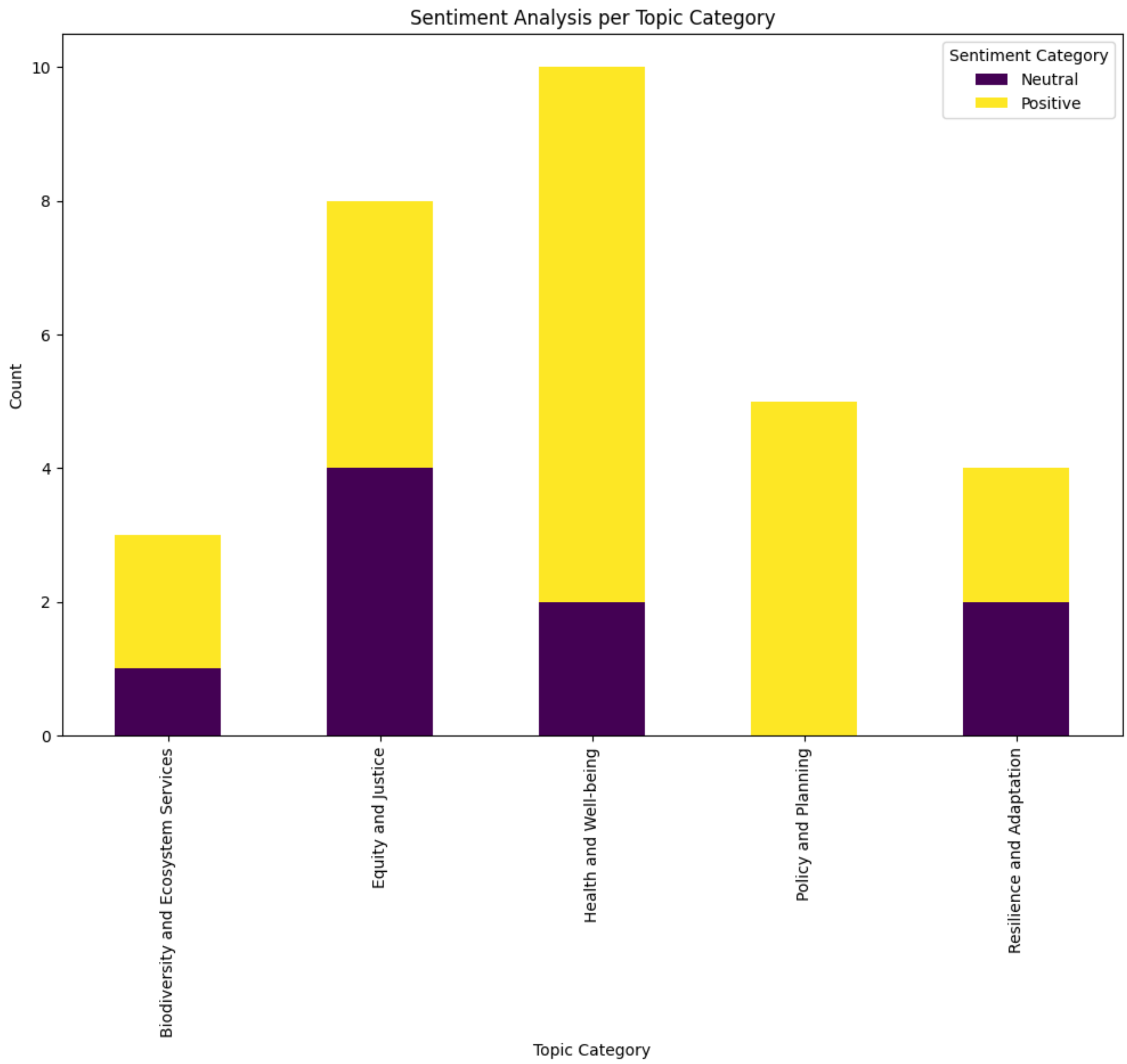

Figure 2. 10. Sentiment analysis per topic category.

The findings highlighted that in the previous research, UGS were not just a nice-to-have attribute, but essential components of sustainable urban living. The prominent focus of the studies were found to revolve around how adapt to challenges, improve public health, ensure equality, and support the environment. This is all while being viewed in a positive light by those who study and implement them. These findings highlight the need to continue integrating UGS into urban planning and policy, ensuring cities can thrive both now and in the future.

2.4. Discussion

The emergence of UGS as a viable approach for addressing environmental issues in cities has gained acknowledgment. Studies confirm that urban green spaces (UGS) provide many services that help the city prepare for climate events and ecological processes. When integrated strategically as nature-based solutions, urban greening solutions reduce urban heat, manage stormwater and enhance biodiversity by providing habitats for various species (Andersson et al., 2014; Larondelle et al., 2014). According to research, suitable UGS can reduce temperature and help alleviate urban heat island effect, thereby providing a space of refuge during extreme weather events(Demuzere et al., 2014). UGS is important for climatic variations prone region due to its climate adaptation capacity. Yet, the successful use of UGS is dependent on the doing of spatial planning that upholds ecological connectivity and urban development requirements.

The number of published papers related to Urban Green Spaces (UGS), Nature-Based Solutions (NBS), and Sustainability Transitions (ST) has generally increased between 2006 and 2020 as shown in Figure 2 with the help of a dashed line. In essence, the United Nations' Sustainable Development Goals (SDGs) (UN, 2015, Carlsen et al., 2022) have influenced the growth in publications over the years 2014–2018 on urban sustainability at the global scale. At these times, urban resilience strategies and nature-based solutions are becoming more integrated within policy frameworks according to experts (Hansen et al., 2015). The gradual decline after 2018 may reflect changing funding priorities or may occur over a longer timescale. This timeline places the study in the context of broader scholarship, showing how a more focused, interdisciplinary research initiative is needed to understand the multiple roles UGS play.

Access to UGS improves physical and mental health, increases social cohesion, and enhances the quality of life. A common issue in the literature is that these advantages are not distributed evenly across different socio-economic groups. Research show that low-income areas tend to have limited access to good UGS; hence planned should equally include children and serendipitous green spaces of all social groups (Anguelovski et al., 2018; Wolch et al., 2014). This gap raises concerns about environmental justice because of the social resilience and well-being that fair access to UGS can create. Policies that prioritize making existing green infrastructures in under-served areas could help bring diversity to the people using UGS and avail themselves of their health and social benefits.

The data in Figure 3 show the publication trend of UGS, NBS and ST in leading journal. The journal Landscape and Urban Planning has published six papers and Science of the Total Environment has published three papers, both of which are dual important journals on urban greening and sustainability transitions. Their applied urban studies focus coincides with the growing stress on ecological-social-economic integration in urban planning (Matthews et al., 2015). Springer's prominence as a publisher shows how international and scientific the field is.

This helps the field to develop. Having a concentrated output in journals demonstrates the importance of targeted dissemination of knowledge for effective knowledge transfer among researchers, practitioners and policymakers. As urban areas adopt more data-led city planning frameworks, these platforms provide important resources for decision-making based on evidence.

Urban Green Spaces (UGS) refer to parks, gardens, and other nature-filled areas in cities. They are important to enhance biodiversity in a city. According to Elmqvist et al., (2013), UGS contribute towards a place for different animals to live. Studies to enhance biodiversity in cities require UGS with a variety of vegetated types (Connop et al., 2016). This variety not just improves ecosystem products but also makes cities more resilient to change (Haase, Frantzeskaki, et al., 2014).

The UGS's successful implementation strongly relies on effective governance that needs to establish regulations for the planning, funding, and maintenance of green spaces (Matthews et al., 2015). Different scholars stress the need for decentralized governance structures that include local communities in UGS management. This participatory method can result in spaces that better fulfil community needs and promote stewardship. Nonetheless, the effective use of UGS is often hampered by policy fragmentation and weak inter-agency coordination, especially in cities with complex governance (Frantzeskaki et al., 2017).

Another challenge is financing UGS aside from governance challenges. Countries with an advanced economy rely on public-private partnerships and green bonds to secure financing, while countries with an emerging economy have limited resources for the maintenance and expansion of UGS. Some community fundraising and international environmental grants can be helpful in this regard (Anguelovski et al., 2018). Despite the potential of these models, their limited utilization indicates that a more coordinated approach is essential to close the financing gap for sustainable urban greening.

Figure 6 shows the co-occurrence matrix, which indicates the links between themes. For example, "Green Infrastructure" and "Ecosystem Services," are repeated together which implies their involvement in improving the resilience and functionality of the urban ecosystem. These intersections fit into the multi-level perspective of sustainability transitions which highlights the links between the socio-technical systems and environmental governance (Markard et al., 2020).

Interestingly, the themes "Social Equity" and "Climate Change Adaptation" show room for research. Filling these gaps could lead to actionable recommendations for inclusive urban planning and development, particularly in rapidly urbanizing contexts, where risk from climate change disproportionately affects marginalized groups (Anguelovski et al., 2019). The research allows us to further investigate how UGS can achieve equity and resilience together.

Urban green spaces have been shown that they can massively affect public health, be it physical or mental health. Studies show that being able to reach green places lowers stress, bets mood, and gets people moving. All of which are requirements to fight off urban diseases like obesity, anxiety and heart disease (Kabisch et al., 2015). Researchers have shown that exposure to green areas can help children's cognitive development, while adults feel less mental fatigue. These benefits show how valuable UGS (urban green spaces) is for society overall (Dadvand et al., 2015). In addition, UGS reduces air pollution, which is important for the health of people living in highly populated urban areas. Plants in parks can trap air pollutants, which helps to clean the air or to reduce respiratory risks (Nowak et al., 2014).

The public health and environmental benefits of various forms of UGS are considerable. However, the financial sustainability of these actions in various urban areas – especially low-income urban areas – remains a key challenge. Costs for creating and maintaining UGS include land acquisition, landscaping, and maintenance costs. In higher-income cities, financing models like green bonds and corporate sponsorships have proven effective in supporting UGS development (Geneletti et al., 2016; Saarikoski et al., 2016). Many cities today use such models to allow the private sector to subsidize public costs so that open spaces, or the greening of spaces, can be more consistent and accessible.

Poor countries often lack funding to develop Urban Green Spaces. To illustrate, community-led actions where local residents undertake maintenance of UGS have been successful in ensuring sustainable maintenance and cost reductions. Programs like these diminish the financial burden on local governments, promote community ownership, and may result in the longer-lasting green spaces. Opening up more options for smart financing that includes payments for ecosystem services (PES) could provide a steady stream of income, especially if placed within the context of urban development.

In order for cities to implement NBS, UGS must be integrated into long-term, flexible plans that consider changing environmental and social needs. Studies show that UGS is not about designing green spaces, but about how spatial planning fully exploits the multifunctional benefits and connectivity of the green space (Ahern, 2013). UGS must be designed for various usages, ranging from a park to a biodiversity corridor, and be placed in a larger urban context also consisting of other natural and constructed elements (Hansen et al., 2015).

Recent studies point to the establishment of green corridors connecting isolated patches of UGS as a desirable strategy to enhance ecological resilience and facilitate the movement of species across the urban fabric (Kremer et al., 2016). These pathways also enable the easier movement of residents between the green spaces thereby improving accessibility and usage. Integrating such designs can play a role in developing a sustainable urban ecosystem that adapts with the population and the environment over time. Nonetheless, for this to happen, policies will have to be coordinated so that urban development goals and environmental conservation priorities become aligned in such a way that UGS become integral to urban infrastructure.

Chapter-3

EVALUATING UGS DISTRIBUTION

3.1. Introduction

Cities in the world are growing at an unprecedented rate, and with that increase comes the need for sustainable urban spaces (Kabisch & van den Bosch, 2017). One of the most important elements of creating such environments is the conservation and enhancement of urban green spaces (UGS). Green spaces do more than make cities pretty. Cities need greenery to improve the air, manage flooding, capture carbon and lower temperature (Hansen et al., 2019). "UGS also has important social benefits apart from environment." Parks littered throughout cities can give them a space to hang out outside of the house, unable to head towards cafes and restaurants. Many rapidly growing cities around the globe, especially in the developing world like Pakistan, are putting huge pressures on the green spaces which are disappearing or being overlooked in the face of urbanization and increased populations (Haq et al., 2020; Kabisch & van den Bosch, 2017; Zaman-ul-Haq et al., 2022).

The capital of Pakistan, Islamabad, was planned to have big green areas for improving livability and sustainability (Bokhari et al., 2018; Breuste et al., 2013; Saeed et al., 2022). The city was designed in the 1960s as a response to this development in modem structure for the integration of nature and city. Islamabad, with a population of over two million (Government of Pakistan, 2021), continues to exhibit green infrastructure as a defining feature. But the quick expansion of the city has put pressure on these green areas. The green areas which used to be prominent have become poorly distributed, poorly maintained or even left to neglect, particularly in the city’s eastern and southern regions (Edlund, 2020; Haaland et al., 2015; *Pakistan Vision 2025: One Nation-One Vision*, 2014). Islamabad's wealthier neighbourhoods, especially near the Margalla Hills, continue to have maintained parks and open spaces as opposed to other areas.

These unequally distributed spaces in Islamabad are true probably to all other growing cities of developing world. Rich places have many beautiful parks. Whereas, poor places do not have many parks or green spaces (Wolch et al., 2014). Islamabad is a well-planned city but access to green spaces remains uneven. It begs the question: how to make sure that all residents, rich and poor, close-in and far-flung, can fairly access open spaces as the city gets bigger?

One of the greatest difficulties in addressing this issue has been outdated and inaccurate information available about the mapping, accessibility and condition of UGS in Islamabad. The existing data is more often outdated or far too general, making it difficult for city planners to make informed decisions (Atif et al., 2018; Bokhari et al., 2022). Islamabad is not the only city facing the issue as many cities in South Asia and outside face the same. Cities are developing rapidly and the traditional maps and planning tools simply do not keep up with this pace. There is a gap between urban planners' goals and the force of the green infrastructure project. Geographic Information Systems (GIS) can make a difference here (Heckert et al., 2016).

As Islamabad expands, one of the biggest challenges is how to control the growth of green areas? If you do not have proper information on where are green spaces present and how they are being utilized, future development will become tough. In addition, green spaces in Islamabad are distributed unequally as the richer neighbourhoods have more overall green spaces as compared to the denser areas. When this study was carried out, no GIS-based UGS mapping was done in Islamabad, so there is high demand for better tools to inform decision and policy makers and urban planners.

This research is hypothesized that there is an uneven distribution of UGS across Islamabad. Richer areas had bigger, more elaborate green spaces which were well-maintained. However, poorer or denser ones lacked these. Also, UGS like urban green belts, institutional green spaces, and playgrounds were underuse whereas these spaces could significantly contribute towards urban sustainability transitions. This study thought that focusing on these areas which are ignored will show their significance for sustainability. The study included qualitative observations of various themes. The social side of UGS, particularly relating to parks, is heavily influenced by the available facilities. These elements were important in supporting the transition and promoting community participation, which was vital for long-term sustainability.

In order to resolve those issues, this study aimed at the following. To begin, it aimed to draw a comprehensive, high-resolution GIS map of the public green spaces in Islamabad using satellite imaging. In order to better understand the green infrastructure of the city, it classifies UGS into parks and gardens, playgrounds, forests, lakes, institutional green. In the third study, the authors examined the distribution of these spaces across different areas. Which neighbourhoods had too few or too many such spaces?

The study was guided by research questions: What is the present situation of UGS in Islamabad? What are the differences in green spaces across Islamabad? These spaces are serving the needs of those who use them but how well maintained are these spaces? Could mapping tools help make decisions about managing urban green spaces? What measures can be taken to improve UGS distribution?

To get a better insight into these questions, this study utilized GIS-based mapping. Researchers developed a base map with high-resolution satellite images of the city's green spaces, which was then merged with land use, population density and zoning information. The green spaces were classified according to their type and function also a field survey was carried out to validate the data so that the map accurately represented the real state of UGS on the ground.

By doing a spatial analysis, we were able to spot divergent green space patterns, with some spaces having an excessive quantity while others are lacking. The findings served as an important grounding for recommendations on improvements in UGS management of the city.

This investigation is both very much-needed and vitally important. The data will be used to help city planners manage UGS. It will also help ensure equitable distribution of UGS so that it can meet the needs of the growing population of Islamabad. In simpler terms, this research will help to guide the actions of the city of Tbilisi, in terms of how it manages its green spaces. The findings from this research can form a template for similar cities facing problems of a balanced growth with sustainable development (Jiménez et al., 2020; Waheed et al., 2010).

Measuring Urban Green Spaces (UGS) is crucial for fostering sustainability transitions, that is, a shift towards resilience and equity in urban systems. Urban data on the distribution, typology and functionality of UGS enables planners to design strategies that mitigate ecological degradation, social inequity, and urban heat island (Hansen et al., 2015). Cities like Islamabad experiences unplanned urban development that hamper their ability to meet sustainability goals due to uneven distribution of green spaces.

UGS can be integrated into frameworks that prioritize their multifunctional benefits, including support for biodiversity, flood regulation, and social well-being, through quantification. This data-driven approach is the foundation of sustainability transitions in which organize and maximize the potential of UGS (Frantzeskaki et al., 2017). This talks about GIS Mapping and Analysis of UGS in Islamabad to Offer Policy Recommendations for Sustainable Urban Development. It aims to give insights that can be useful for policy makers and planners to achieve sustainable urban development. Countries all over the world are getting more urbanized. The model, then, focuses on the provisioning of green spaces. This study's results will help not just Islamabad but also cities worldwide as they face the obstacles brought on by fast urbanization. In years to come, how we plan green spaces will determine the degree to which cities can be livable, resilient and equitable.

3.2. Material and Methods

3.2.1. Study Area

A planned urban center in Pakistan, Islamabad, was chosen for study. In terms of urban agglomeration, it is the 9th largest in the country. The 1960-established city of Islamabad is a modern, planned city compared to others. In 1963, it became Pakistan's capital after Karachi (Bokhari et al., 2018; Frantzeskakis, 2009). In the middle of the Potohar Plateau, between 457 and 610 meters above sea level, it lies beneath the Margalla Hills (Figure 3.1). Since 1963, Islamabad's population has grown from 0.117 million to 2.4 million and covers 917.80 sq.km (Aslam et al., 2021; Doxiadis, 1965, 2005). As a humid subtropical climate (CWA in Köppen climate classification), the city experiences hot summers, monsoon seasons, and mild winters (Peel et al., 2007). The Islamabad Capital Territory is systematically organized into eight distinct zones: the Administrative Zone, Commercial District, Educational Sector, Industrial Sector, Diplomatic Enclave, Residential Areas, Rural Areas, and Green Area (Doxiadis, 1965, 2005). The city of Islamabad itself is divided into five primary zones: Zone I, Zone II, Zone III, Zone IV, and Zone V, with Zone IV encompassing the largest area (Table 3.1.). Zone I primarily includes the fully developed residential sectors, while Zone II comprises sectors that are still under development. Each residential sector is denoted by an alphabetical letter combined with a numerical designation, covering approximately 2 km^2 each. For an in-depth study of urban green spaces, the focus is mainly on sectors within Zone I, known for their advanced development status. These sectors include recently developed D-12 and surrounding rural and allocated area, E-7 to E-11, F-6 to F-11, G-4 to G-11, H-8 to H-12, I-8 to I-12 among others (Figure 3.1). Prominent green spaces within these sectors are exemplified by Fatima Jinnah Park in sector F-9, along with various green belts and parks dispersed throughout these areas. The selection of these sectors is designed to provide a comprehensive overview of urban green space distribution and their influence on the quality of life in Islamabad. This selection ensures a representative evaluation of how green spaces contribute to the urban environment, fulfilling both recreational and ecological needs of the city's residents.

Table 3. 1. Zoning regulations and development characteristics of Islamabad.

Zones	Development Authority	Permitted Activities	Key Features
Zone 1	CDA	Land acquisition and development exclusively by CDA	High-quality infrastructure, government buildings, and planned residential areas.
Zone 2	Private Sector	Development by private housing societies	Modern housing societies, commercial areas, and amenities like parks and schools.
Zone 3	CDA	Restricted development, conservation-focused	Green belts, forest reserves, and protected environmental zones.
Zone 4	Varied	National Park, agro-farming, educational institutions, research and development	Margalla Hills Natonal Park, agricultural lands, universities, and research centers.
Zone 5	Private Sector	Development by private housing societies	Residential housing schemes, commercial zones, and recreational facilities.

(Source: Capital Development Authority (CDA) Ordinance 1960; Zoning Regulation 1992)

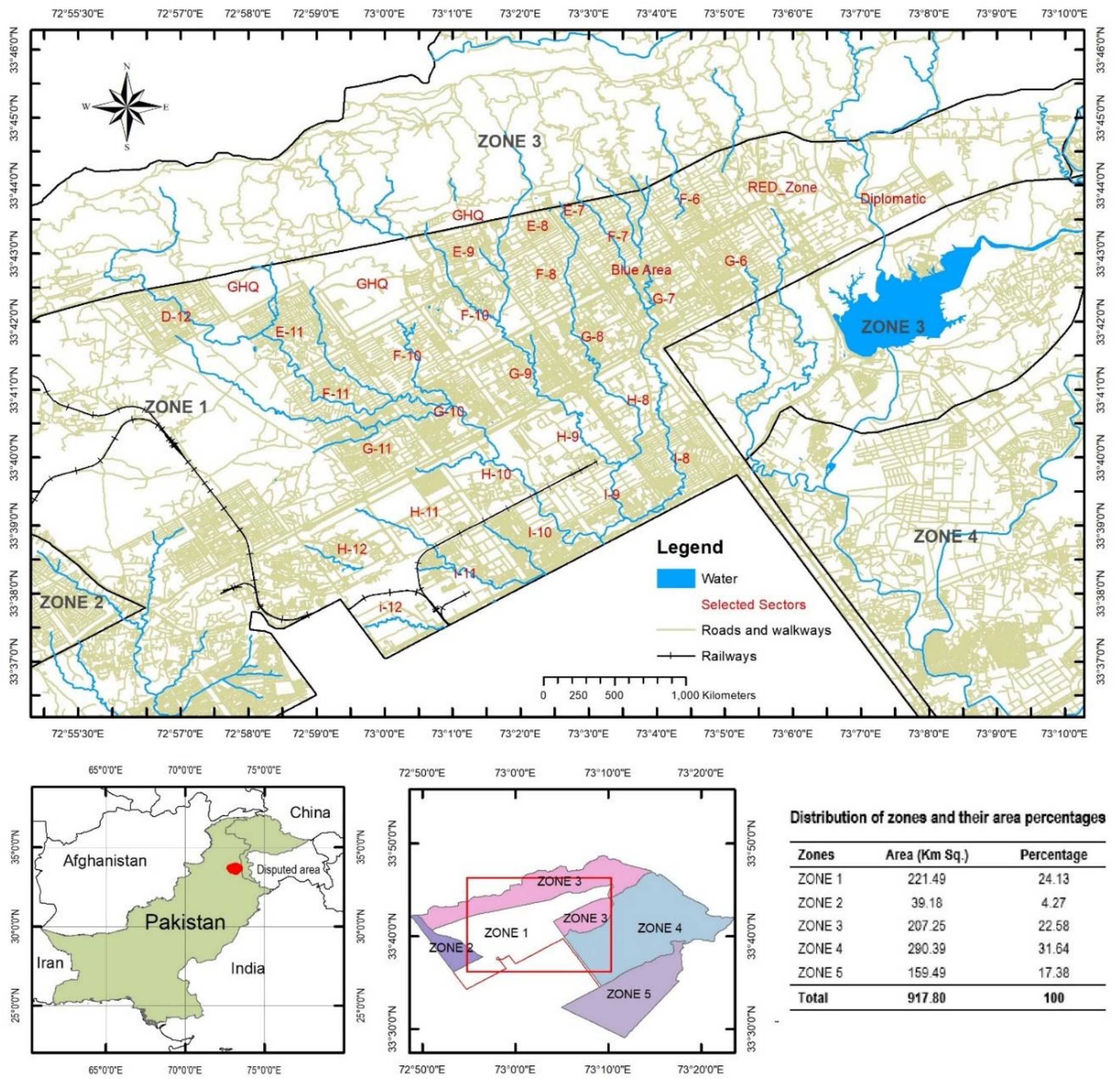

Figure 3. 1. Geographic location of the study area and selected sectors for detail study of UGS of Islamabad, Pakistan.

3.2.2. Variations in temperature and rainfall patterns in Islamabad

The temperature pattern in Islamabad shows significant seasonal variations, with the coldest temperatures occurring in January (min 2.7°C) and the hottest temperatures in June (max 40.4°C). During the winter months (December - February), Islamabad experiences the lowest temperatures of the year, with January being the coldest month. The minimum temperatures can drop to around 2.7°C, while maximum temperatures can go up to about 18.5°C. In the spring months (March - May), temperatures start to rise, with significant warming observed from March to May. By May, the maximum temperature reaches around 40.3°C, indicating the onset of the hot season. The summer months (June - August) are the hottest, with maximum temperatures frequently exceeding 38°C. The minimum temperatures during this period also remain high, often above 20°C. In the autumn months (September - November), temperatures begin to cool down in September, with a gradual decrease through November. By November, the temperatures range from a minimum of 8.9°C to a maximum of 26.4°C. Overall, the chart demonstrates that Islamabad experiences a wide range of temperatures throughout the year, with distinct hot summers and cold winters, reflecting a continental climate with significant seasonal temperature variations. Figure 3.2. illustrates the significant seasonal variations in temperature in Islamabad, highlighting the coldest months in winter and the peak temperatures during summer. The trend lines show the increasing mean monthly temperatures over the years, indicating a warming climate pattern.

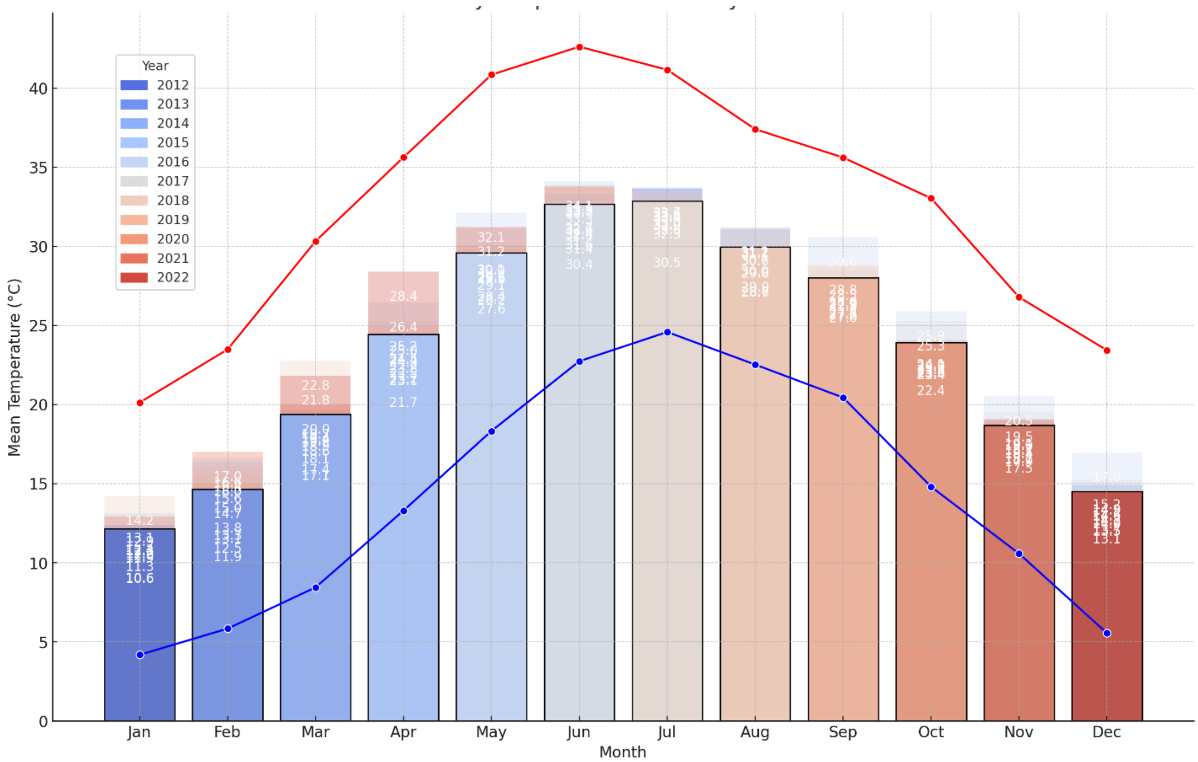

Figure 3. 2. Monthly mean temperature variations in Islamabad (2012-2022).

The rainfall pattern in Islamabad shows significant variability throughout the year. The highest rainfall occurs during the monsoon season, particularly in July and August, where the rainfall can reach up to 392.3 mm and 362.0 mm respectively, contributing a significant percentage of the annual rainfall. Conversely, the winter months (November to January) and pre-monsoon months (March to May) receive relatively less rainfall. January experiences minimum precipitation values around 27.5 mm and maximum values around 60.4 mm, while May has minimum precipitation values around 24.8 mm and maximum values around 41.9 mm. The summer monsoon season (June - September) is marked by a sharp increase in rainfall, peaking in July and August. Autumn months (October - November) show a decline in rainfall, with

October having minimum precipitation around 19.1 mm and maximum around 75.2 mm. The data highlights the pronounced seasonal variation in rainfall, with peak values during the summer monsoon and lower values in winter, reflecting the typical climate pattern of the region. Figure 3.3. presents the monthly mean rainfall in Islamabad, emphasizing the substantial variability throughout the year. The highest rainfall is observed during the monsoon season, particularly in July and August, with a marked decrease in the winter months. The data reflects the typical climatic conditions of the region, characterized by a distinct wet and dry season.

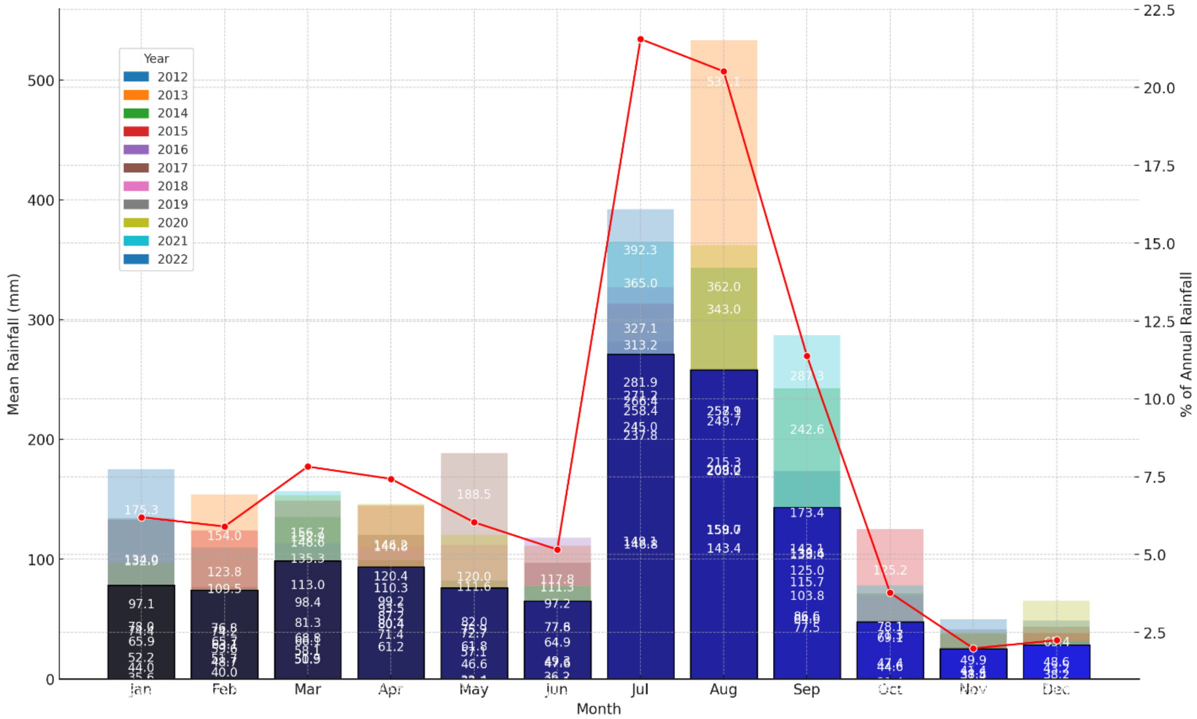

Figure 3. 3. Monthly mean rainfall patterns in Islamabad (2012-2022)

3.2.3. Workflow of thematic mapping of UGS

Thematic mapping support data (Table 3.2 and Figure 3.4) was obtained and imported into ArcGIS 10.7.0.10. The soft copies of boundary data (Administrative, zonal, sectoral boundaries) were available (dwg. extension). The extension file was imported into ArcGIS and converted from line format to polygon by using the “feature-to-polygon tool” available in “Data Management Tools” of ArcGIS. Once the feature had been changed, it had to be projected into the projected coordinate system "WGS_1984_UTM_Zone_43N" using the "Project" feature in Data Management Tools. In order to use as a base reference data in GIS, a hard copy land use map / sector-based planning maps was scanned and georeferenced (Table 3.2).

Table 3. 2. Utilize data for thematic mapping of Urban Green Space (UGS).

Sn.	Data description	Source
1	Administrative boundary of Islamabad city	CDA
2	Zonal division	CDA
3	Developed Sector boundaries	CDA
4	Land use plan	CDA
5	Water corridors, lakes	OSM
6	Roads	OSM
7	Building	World Atlas

Capital Development Authority (CDA); Open Street Map (OSM).

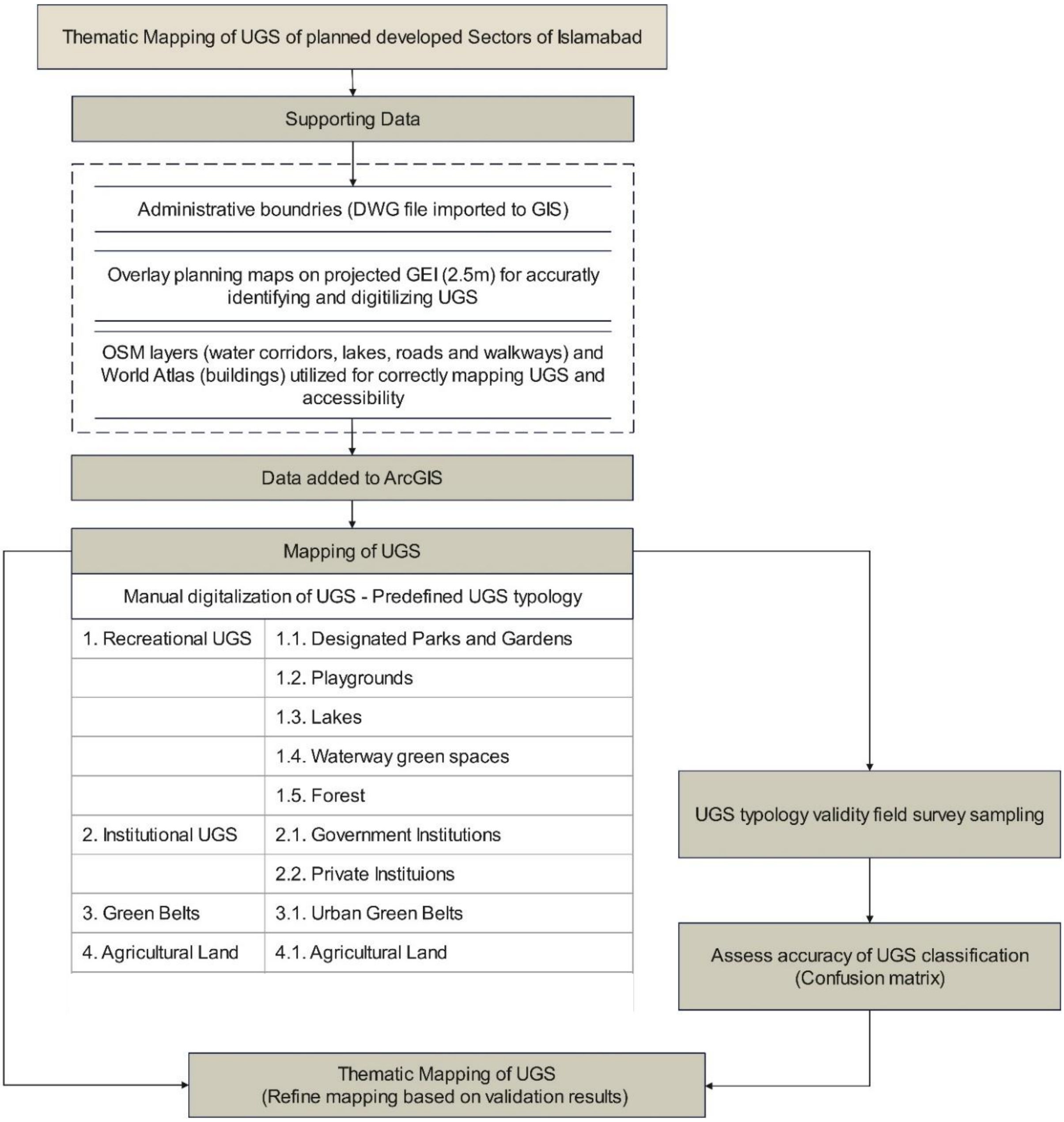

Figure 3. 4. Methodological flow for thematic mapping of UGS in the selected developed sectors of Islamabad.

3.2.4. UGS Typologies and Classes for thematic Mapping

The study employed the framework by Coles and Grayson (Coles et al., 2004), which emphasizes access and functionality to define urban green spaces (UGS). Consequently, only public green spaces characterized by vegetation and utilized for recreation or those enhancing the quality of urban life in Islamabad were included in the analysis. Private UGS, despite their significance, were excluded due to their variable accessibility and potential for change. Based on usage functionality, the research categorized UGS into distinct typologies relevant to Islamabad's context. Each typology was digitized, and their attributes were integrated as separate layers in the thematic map. This detailed classification of public UGS provides a comprehensive understanding of their diverse ecosystem functions and benefits, contributing to a holistic view of urban greenery in Islamabad (Table 3.3).

Table 3. 3. USG typology, related land use class and detailed description (Coles et al., 2004).

Level - I: Typology	**Level - II:** Land Use Class	**Description**
1. Recreational UGS	1.1. Designated Parks and Gardens	Specially designed areas for recreation with flower beds, trees, and walking paths, including city, neighborhood, and botanical parks.
	1.2. Playgrounds	Spaces equipped with play structures and outdoor sports facilities for children's and community well-being.
	1.3. Lakes	Natural urban water bodies offering recreational opportunities and enhancing biodiversity.
	1.4. Waterway Green Spaces	Natural streams and watercourses essential for drainage, stormwater management, biodiversity, and urban aesthetics.
	1.5. Forests	Wooded areas improving air quality, providing wildlife habitats, recreational spaces, and supporting urban biodiversity.
2. Institutional UGS	2.1. Institutions and Campuses	Restricted-access green areas within educational, governmental, or research institutions that support biodiversity and urban ecology.
3. Green Belts	3.1. Urban Green Belts	Vegetated areas reducing urban sprawl, enhancing air quality, providing wildlife corridors, and offering recreational spaces.

3.2.5. Georeferenced base imagery for digitization of UGS

Data from high-resolution Google Earth imagery is a valuable resource, especially in urban areas where land cover patterns are complex mosaics of different land uses. GEI high resolution (2.5 m) was adopted as the base layer for identifying ground objects and allocating UGS typology land classes. Due to its open source, this data source is ideally suited for a thematic mapping approach involving manual classification (Figure 3.4). The mosaic was produced in ArcGIS 10.7.1 using GE images captured using the software (Scott et al., 2010) on December 13, 2020, since no high-resolution images are publicly available. Shape2Earth plugin for MapWindow was used to georeference the JPEG images (Lu et al., 2012). Since there were fewer than 500 GEI images, the unregistered demo version worked perfectly. As part of the plugin, the current view in the GE window is saved along with a world file with WGS-84 coordinates. Based on the georeferenced GEI data, a single image was created in ArcGIS 10.7.1 using the geoprocessing tool, as shown in Figure 3.5(a). By implementing the "Mosaic" tool, the raster dataset was transformed into "GCS_WGS_1984" coordinates. Through the "Project" functionality of Data Management Tools, this was converted to WGS_1984_UTM_Zone_43N projected coordinates.

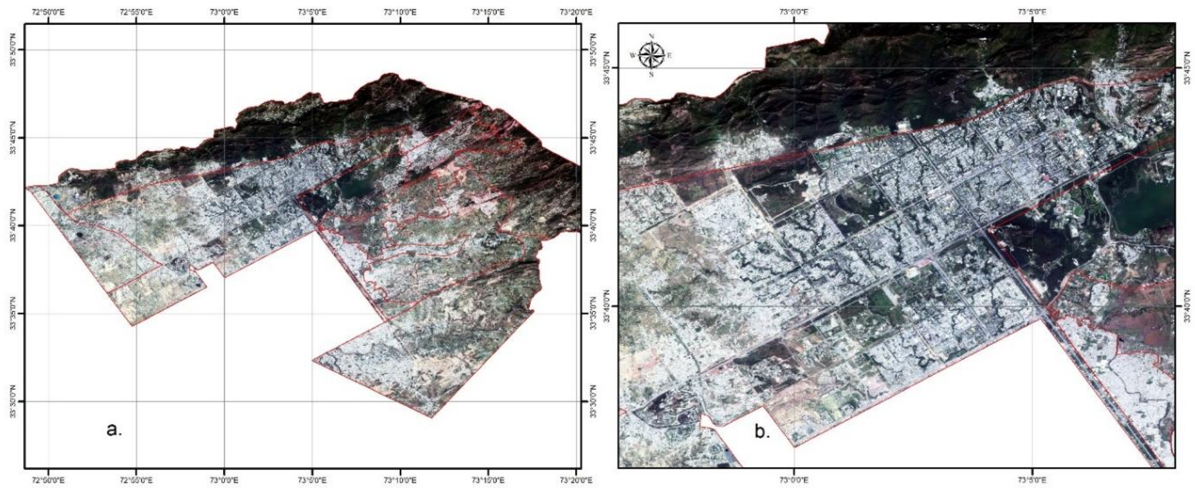

Figure 3. 5. (a). High-resolution raster image of the Islamabad; (b). Selected area for detailed thematic mapping of UGS.

The high-resolution GEI provided by satellite sensors allows for mapping of UGS. Due to outdated imagery and overlay inaccuracies of the hard copy of the land use map, mapping UGS was a challenging. By visual interpretation, UGS were vector mapped in GIS using GEI as the base layer, and the polygons were assigned manually. Furthermore, a georeferenced land use plan, zone boundaries, buildings, and OSM road network data shapefile were added to the mapped layer.

2.5.3. Reference map accuracy and ground truth validation

To conduct random sampling within the selected sectors of Islamabad, a grid-based approach was utilized. A detailed graticule grid with 1-minute intervals for both parallels and meridians were created using ArcGIS, providing a systematic framework for sampling (Figure 3.6). This grid was used to generate a fishnet that covered the extent of the study area, ensuring comprehensive spatial coverage. Random sampling points were then generated within this fishnet, providing a robust and unbiased sampling methodology (Ramsdale et al., 2017). This approach facilitated the collection of spatially distributed samples (Theobald et al., 2007), enabling a thorough analysis of the selected sectors in Islamabad (Figure 3.6).

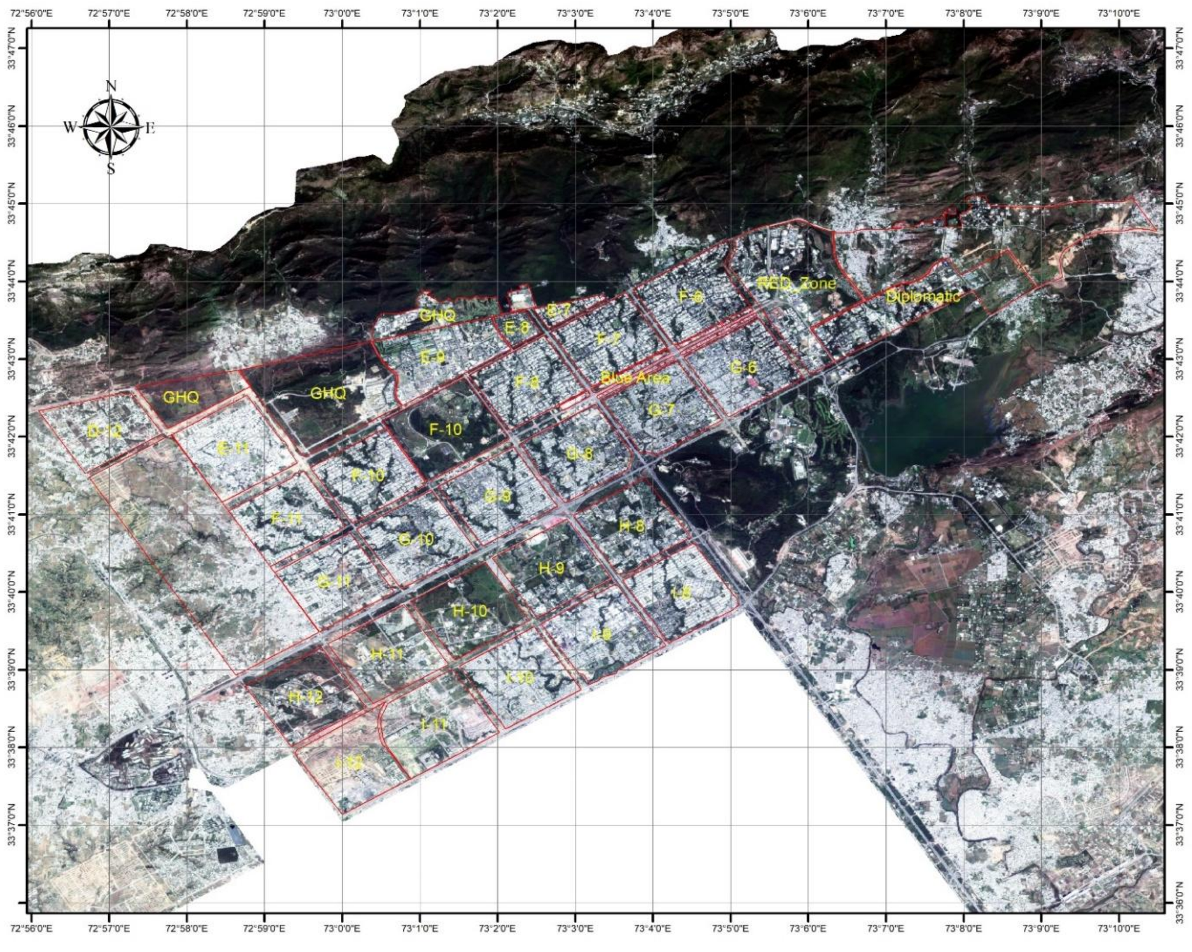

Figure 3. 6. Girded high-resolution GEI for filed data collection and random sampling.

Overall, 301 ground truth GPS points were collected representing UGS three typology and seven classes were added into ArcGIS as a shape file. The GPS points were retrieved from the Garmin (eTrex 30X) as track points and exported into ArcGIS as a shape file using GPS trackmaker version 13.9. The distribution of ground truth points representing different classes are shown in Figure 3.6. Figure 3.7. Base reference gridded map was utilized for random sampling.

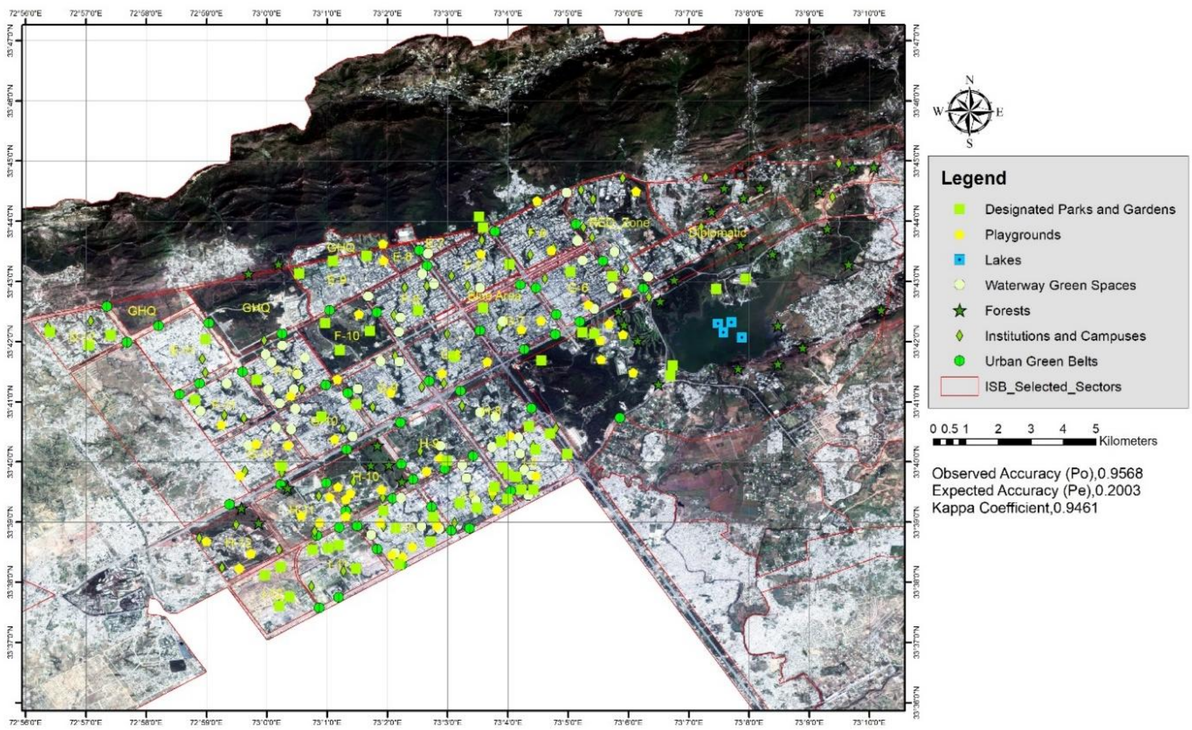

Figure 3. 7. Map of ground-truth validation random sampling.

3.2.6. Accuracy and validity of UGS thematic mapping

There are many factors that affect the accuracy of a thematic map, including classification, mapping unit, and image quality (Radoux et al., 2011). As a measure of accuracy, accuracy indicates how well the attributes of the map match the truth reference dataset. Hence, quantified error serves as a tool for communicating the validity of results. Most commonly, confusion or error matrix is used for descriptive and statistical analysis to measure accuracy (Liu et al., 2007). Following the addition of the reference map, thematic map file was converted to a raster map using "feature to raster". Rasters were created from the classified polygons (vectors) of thematic maps (Wade et al., 2003). From the classified raster, we extracted values and compared them with truth points using ArcGIS. Next, the "frequency tool" was used to calculate the frequency of two values (truths and predictions). Every point is shown how many of the predictions were correct. After building the confusion matrix using equations (Equations (1) - (4)), kappa statistics were calculated using the pivot table tool.

$$\text{User's accuracy in the UGS class } i = \frac{n_{ij}}{n_i} \qquad \text{Eq.1}$$

$$\text{Producer's accuracy in the UGS class } i = \frac{n_{ij}}{n_{\cdot i}} \qquad \text{Eq. 2}$$

$$\text{Overall accuracy} = \frac{\sum_{i=1}^{k} n_{ii}}{n} \qquad \text{Eq. 3}$$

$$\text{Kappa coefficient} = \frac{n\sum_{i=1}^{k} n_{ij} - \sum_{i=1}^{k} n_i n_j}{n^2 - \sum_{i=1}^{k} n_{i.} n_j} \qquad \text{Eq. 4}$$

where *k* represents the number and the map nomenclature to be 1, 2,…, k; n_{ij} = number of Sample units in the map belong to class i and in the reference belong to class j; $n_{i.}$ = sum of the elements in row i, i.e., the number of sample units classified into class *i* in the remotely sensed classification; *n.j* = sum of the elements in column j, i.e., the number of sample units classified into class j in the reference; *n* = total number of sample units.

3.2.7. Optimizing UGS based of small and large patches

This study analyzes and highlights small and large patches of urban green space (UGS) for targeted recommendations and optimization. Using satellite imagery and GIS data, we created a histogram with custom bins to visualize the distribution of UGS. This analysis informs categorical recommendations to enhance the utility of UGS.

3.3. Results

3.3.1. Validity and reliability of the thematic mapping of UGS

As a result of our thematic map accuracy assessment, Table 3.4 presents a confusion matrix and the Kappa coefficient based on the raster map's predictions (Eq. 1 to Eq.4). In each row, the predicted values are represented by the raster map, while in each column, the reference data is presented. A diagonal entry in the matrix indicates the predicted value matches the reference value, while an off-diagonal entry indicates a mismatch. The recreational typology land use class "Parks and Gardens" is 97% accurate with 56 correct predictions out of 58, whereas the "Playgrounds" class shows 48 correct predictions out of 50, giving a 96% accurate score. As a result of GPS points obtained through an on-site visit using a boat, the "Lakes" class obtained 100% accuracy, with all four instances predicted correctly. In contrast, the "Waterway Green Spaces" and "Forests" classes are 96% and 94% accurate. Users' accuracy for the "Institutions and Campuses" class is 93%, while the "Urban Green Belts" class is 98%. The producer's accuracies also indicate a high level of reliability across most classes, with the "Lakes" class achieving 100% accuracy. Based on the sample size of 301 points, the thematic map was observed to be 95.68% accurate overall. It indicates a very high level of agreement between predicted classifications and reference data, as measured by the Kappa coefficient, 94.61%. In this study, the thematic map accurately represents the spatial distribution of land cover classes and is reliable and valid. In addition to its high Kappa coefficient and overall accuracy, the classification model is effective at distinguishing classes, making it a useful tool for spatial analysis.

Table 3. 4. Kappa coefficient of the thematic map constructed using a confusion matrix.

Classification	Parks and Gardens	Playgrounds	Lakes	Waterway Green Spaces	Forests	Institutions and Campuses	Urban Green Belts	Row Total	User's accounts
Parks and Gardens	56	1	0	0	0	1	0	58	97%
Playgrounds	1	48	0	0	0	1	0	50	96%
Lakes	0	0	4	0	0	0	0	4	100%
Waterway Green Spaces	0	0	0	48	0	1	1	50	96%
Forests	0	0	0	0	30	1	1	32	94%
Institutions and Campuses	1	1	0	1	1	52	0	56	93%
Urban Green Belts	0	0	0	0	1	0	50	51	98%
Column Total	58	50	4	49	32	56	52	301	
Producer's acc.	97%	96%	100%	98%	94%	93%	96%		
Observed Accuracy (Po)	95.68%								
Point Sampled (n)	301								
Kappa coefficient	94.61%								

A pivot table was utilized to display the Kappa coefficient of the thematic map, constructed using a confusion matrix. In this matrix, the columns represent the reference data (truth points), the rows represent the raster map values (predicted values), the diagonal entries indicate the correct matches, and the off-diagonal entries represent the mismatches.

3.3.2. Thematic categories and spatial analysis of UGS

In-depth thematic mapping of Islamabad's urban green spaces (UGS) reveals their spatial distribution and classification. UGS categories are visualized in a comprehensive approach on the generated successive maps Figure 3.8 (a), (b), (c), and (d). Recreational UGS include designated parks and gardens, playgrounds, lakes, waterways green spaces, and forests. It enhances urban aesthetics and offers valuable recreational opportunities. Institutional UGS, located on government and educational campuses, support biodiversity and ecology. Providing recreation opportunities and improving air quality mitigates urban sprawl. As indicated by the spatial distribution, there are significant designated parks and gardens (12.45 km^2), playgrounds (3.58 km^2), lakes (6.26 km^2), green spaces along waterways (4.99 km^2), forests (2.38 km^2), institutional campuses (17.05 km^2), and green belts (9.82 km^2). UGS plays a crucial role in maintaining a sustainable urban environment, providing recreation, environmental benefits, and aesthetic benefits for Islamabad residents because of meticulous mapping and categorization. Besides improving urban life quality, this detailed analysis highlights the need to maintain and expand green spaces.

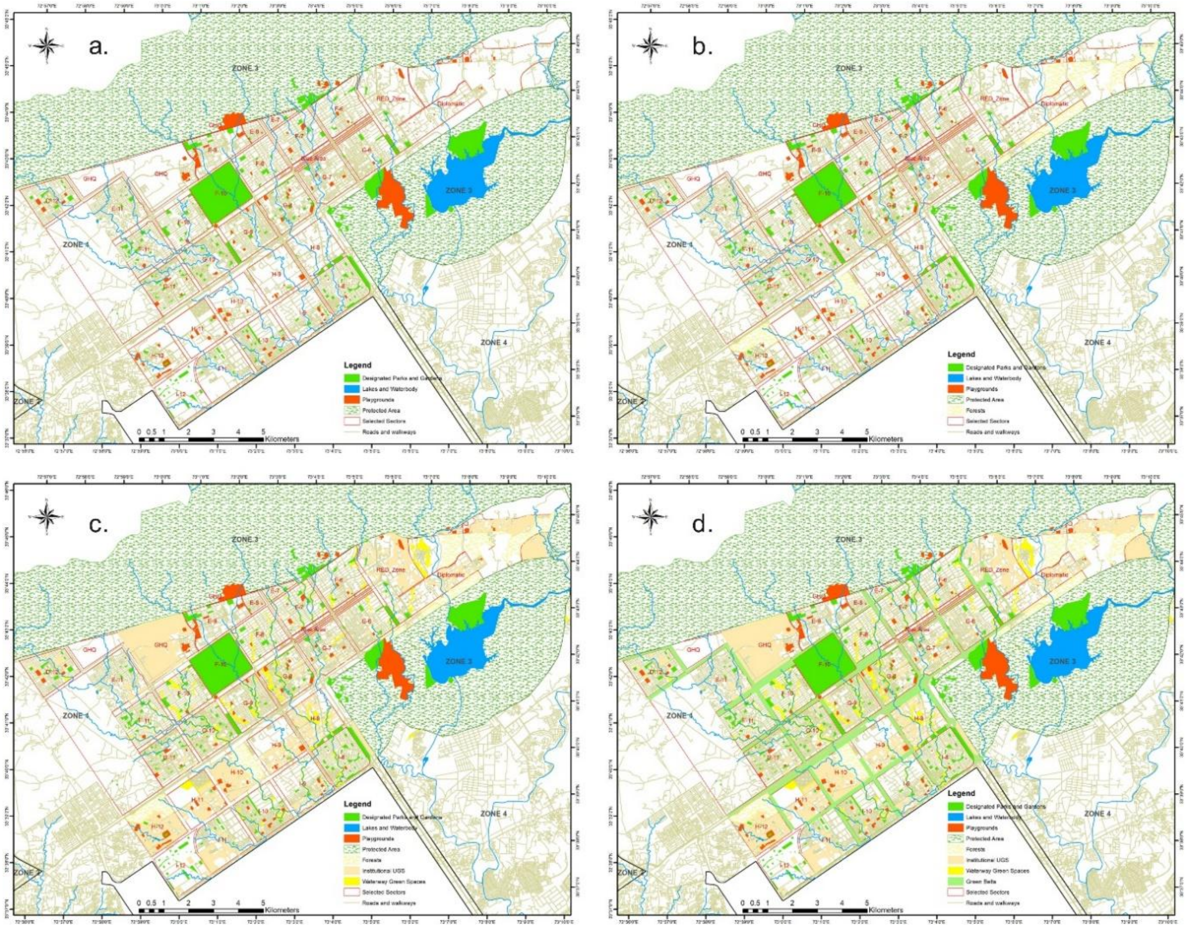

Figure 3. 8. Thematic mapping illustrating the successive layers of public urban green spaces (UGS).

(a) Designated parks and gardens, including playgrounds and lakes; (b) Forest buffer zones surrounding urban settlements specifically allocated as buffer zones: (c) Institutional green spaces and water corridors following natural drainage lines; (d) Green belts specifically allocated between planned sectors.

3.2.1. Recreational UGS – Designated parks and gardens

The provision and maintenance of parks and gardens within Islamabad's planned residential sectors of Zone-I are managed by the Capital Development Authority (CDA). As depicted in the figure, the parks and gardens vary significantly in size and layout across different sectors (Figure 3.8 (a), and Figure 3.9). These green spaces typically include amenities such as walking tracks, children's play sections, gym areas, open lawns, and setting benches, with the level of maintenance differing from one sector to another (Figure 3.10 (a) to (f). The frequency distribution graph based on area (km^2) indicates that smaller parks are more prevalent, predominantly located in residential neighborhoods (Figure 3.8 (a)), whereas larger parks, though fewer in number, are strategically placed to serve broader community needs across different sectors (Figure 3.9). The provision of outdoor gym equipment is a recent addition, and is widely used, however at some places the position is random. As very few parks have more area (Figure 3.8(a)), such as *F-9 Park*, *Lake View Park*, *Japanese Children Park*, *Rose and Jasmine Garden*, and *Kachnar Park* are added with more facilities (Figure 3.10).

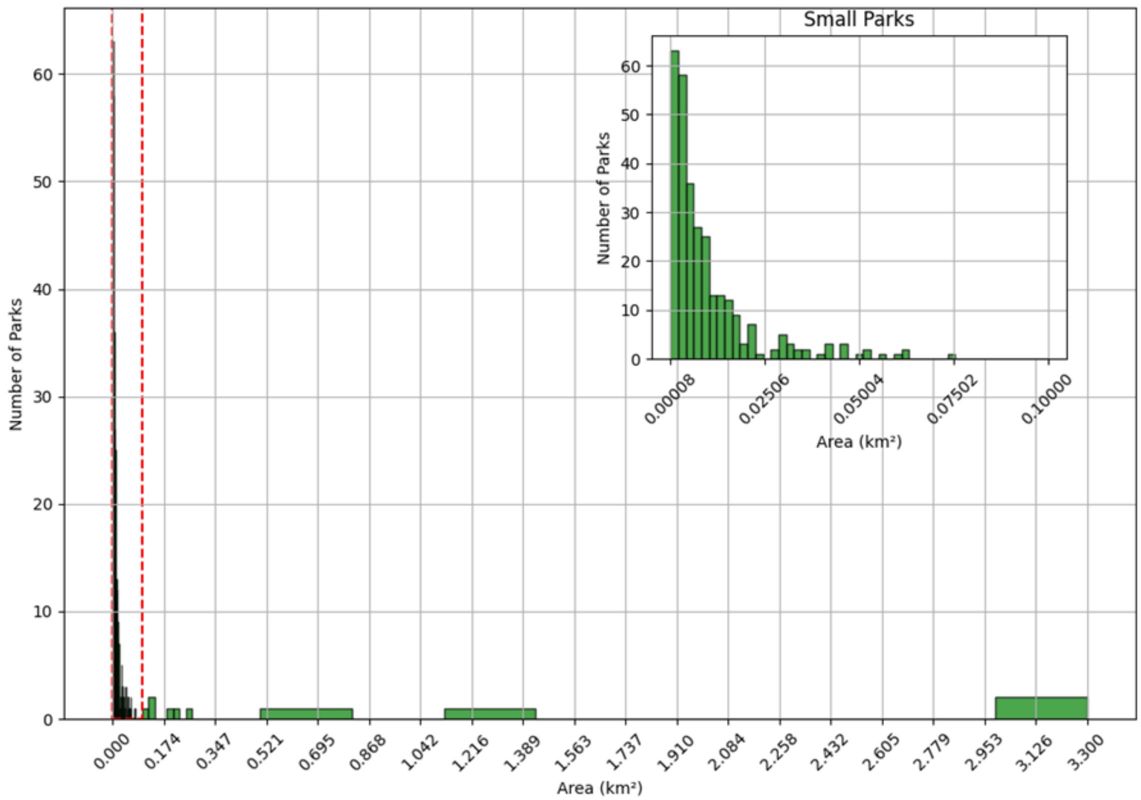

Figure 3. 9. The frequency distribution of parks and gardens coverage across the area under study.

Figure 3. 10. Typical facilities in Islamabad parks.

include (a) seating areas, (b) walking and jogging paths, (c) outdoor gym equipment, (d) children's play areas, (e) open lawns and landscaped gardens, and (f) shaded platforms.

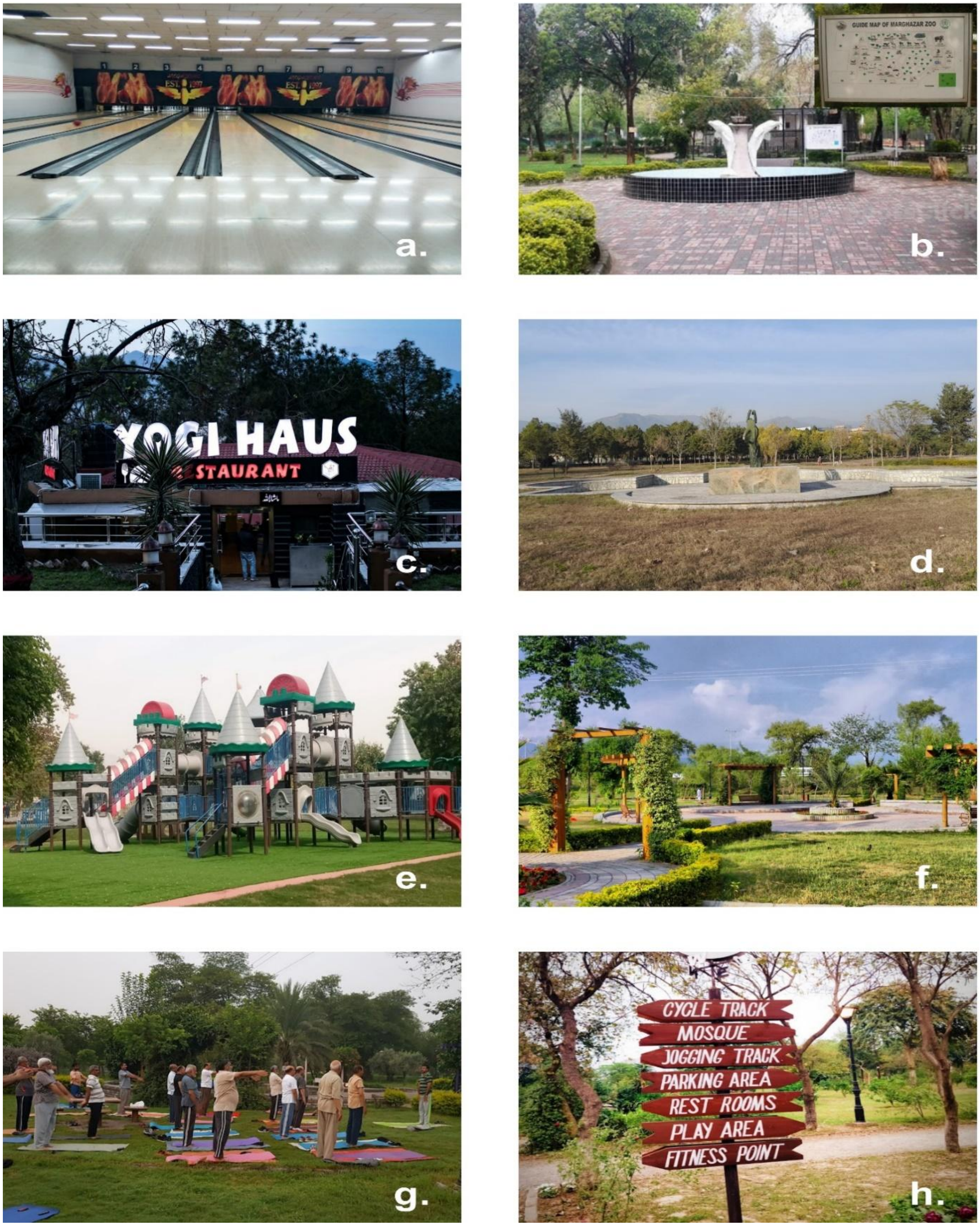

Figure 3. 11. Unique facilities in Islamabad parks

include (a) indoor recreational sports activities, (b) zoo and animal enclosures, (c) restaurants and cafes, (d) sculpture and art installations, (e) themed playgrounds, (f) beautifully landscaped gardens, (g) yoga and exercise areas, and (h) comprehensive signage for multiple facilities.

The qualitative survey reveals that park accessibility in Islamabad varies based on gender, age group, designated hours, and proximity to residential areas. Small parks with limited facilities, located within residential localities, were found generally accessible to the public all the time and heavily influenced by community involvement for the purpose of maintenance and provision of facilities. The CDA, cleanliness and maintenance only subject to the involvement of local, no regular basis services of such activities are provided, in many sectors (I and G series), nominated groups of residents manage these parks, address facility issues, and oversee maintenance with the help of CDA. Conversely, large parks are directly managed by the CDA and maintained by designated staff. Additionally, some parks are adopted by third parties for development and maintenance, ensuring higher standards of care and facility management (Figure 3.11). Most of the large Parks charges nominal fee for the entrance and parking areas and for the recreational facilities owned by the private sectors.

Figure 3. 12. Islamabad Parks and gardens signage featuring general park rules.

(a) Gender-specific parks (c), governing bodies for development and maintenance (d), public access and conservation (e), and accessibility duration (f).

A detailed qualitative survey revealed that quality of life of residents of Islamabad has been significantly enhanced by parks and gardens through their provision of ecological services. Undoubtedly, parks and gardens have played a pivotal role in this improvement. Indigenous plants such as Neem (*Azadirachta indica*), Amaltas (*Cassia fistula*), and Chir pines (*Pinus roxburghii*) are found very common (Figure 3.13), along with sessional shrubs to enhance the recreation like Jasmine (*Jasminum officinale*) and Hibiscus (*Hibiscus rosa-sinensis*), contribute to carbon dioxide sequestration. These parks and gardens also maintain ecological balance by providing habitats for birds and insects, while simultaneously offering water management services that mitigate climate-related impacts. Strategically planned, most parks and gardens effectively reduce surface runoff, recharge groundwater, and prevent soil erosion. Moreover, parks regulate urban microclimates, lowering ambient temperatures and creating comfortable outdoor spaces, thereby counteracting the urban heat island effect (Figure 3.13). Beyond their environmental benefits, parks positively influence mental and physical health. By promoting physical activity, reducing stress, and offering natural recreational opportunities, green spaces contribute to climate adaptation.

Figure 3. 13. Socioecological health and wellness of Parks

Trees illustrates the benefits of air quality improvement and carbon sequestration (a). Shows the cooling effect of green spaces on urban microclimates. (b) Shows deployment of recharge groundwater and manage stormwater in Kachnar Park (c). Park vegetation support urban biodiversity. (d), Water bodies reducing surface runoff (e). Shows aesthetic and recreational value of a park and promoting mental and physical health (f).

Table 3. 5. Table Native and Ornamental Plant Species in Islamabad's Urban Green Spaces

Ref	Plant Name	Ref	Plant Name	Ref	Plant Name	Ref	Plant Name
A	Asparagus	E3	Euphorbia (Lalpati)	M3	Melia	T	Tradescantia
A1	Aurocaria	E4	Exoecaria	M4	Magnolia	T1	Triangular Palm
A2	Amaltas	F	Ficus Black	M5	Melaluca	T2	Tube Rose
A3	Ajuga	F1	Ficus Starlite	M6	Monsterea	T3	Tulip Tree
A4	Alexander Palm	F2	Ficus Golden	M7	Mehndi	T4	Tecoma
A5	Amaralys	F3	Ficus Amstel (King)	N	Nenthra	T5	Termenelia
A6	Alastonia	F4	Farocaria	P	Ptunia	U	Umbrella Palm
A7	Albizia	F5	Fern	P1	Phoenix Palm	V	Vinca Major
B	Bottle Brush	F6	Flame of the Forest	P2	Panzy	V1	Vrrigated Ruber Plant
B1	Bismarkia Palm	F7	Fruit Plant	P3	Puttosporum	V2	Vinca Minor
B2	Bird of Paradise	F8	Fig	P4	Pine	W	Wild Verbena
B3	Black Grass	G	Gardenia	P5	Plumbego	W1	Washingtonia Palm
B4	Bougan Bush	G1	Gul-e-Chein	P6	Pedilenthus	W2	Water Pond
B5	Beaucarnia	G2	Gravelia	P7	Patchy Podium	W3	Weeping Willow
B6	Brachycation	G3	Guava	P8	Prunus	W4	Water Lilly
B7	Bouganvillia	H	Hibiscus	P9	Planters (Asparagus+Jarbeo+ Vinca Minor)	W5	Westeria
B8	Bamboo (Leafcurl)	H1	Hypericum	P10	Palms	Y	Yucca
B9	Buddha Tree	H2	Hemia	P11	Putagen		
B10	Bomentia	H3	Honey Suckle	P12	Piikhan		
C	Cylorophytum	H4	Hemia	P13	Pomegranate		
C1	Crasula	I	Irecene	P14	Plum		
C2	Clonia	I1	Italian Palm	R	Rat Ki Rani		
C3	Chandani Varigated	I2	Ilaichi	R1	Rose		
C4	Cotton Flower	I3	Iris	R2	Rocks		
C5	Chinar	J	Jerbera	R3	Rofia		
C6	Canna	J1	Jasmine	R4	Ribbon Grass		
C7	Cactus	J2	Jacranda	R5	Russelia		
C8	Cassia nudosa	J3	Juniper	R6	Rangoon Creeper		
C9	Clerodendrum	J4	Jatropha	S	Seasonal Plant		
C10	Coronda	K	Kengi Palm	S1	Suck Chain		
C11	Citrvs	K1	Kachnar	S2	Sapium		
D	Doronta Golden	L	Laltana	S3	Secrew Palm		
D1	Day Lily	L1	Locat	S4	Sunny Show (Yellow)		
D2	Doronta White	L2	Lemmon Grass	S5	Shrimp Plant		
D3	Dracenea	L3	Lugustrin	S6	Silvery		
D4	Deodar	L4	Lagerstromia	S7	Singonium		
E	Euphorbia Milli	M	Molsary	S8	Sterculia		
E1	Euonymus	M1	Motia	S9	Setcreasea		
E2	Exocaria	M2	Marva	S10	Star Jasmine		

3.2.2. Recreational UGS – Playground

The study revealed a diverse range of recreational UGS, primarily focused on sports facilities, across selected sectors Islamabad (Figure 3.14). While many sectors provided football and cricket grounds, contributing to urban heat mitigation and ecosystem services, the distribution of other sports facilities was uneven. Tennis and basketball courts were present in some sectors, promoting physical activity and social cohesion. Specialized facilities like karting, paintballing, and skating were limited and often required extensive travel. A significant gap was identified in the provision of gender-specific playgrounds and facilities, with most catering to young males. Additionally, many public spaces were overcrowded due to a lack of designated sports areas, and existing facilities often suffered from poor maintenance, inadequate safety measures, and limited vegetation. The study also highlighted the challenges of managing and maintaining recreational UGS, with varying levels of public and private involvement (Figure 3.15).

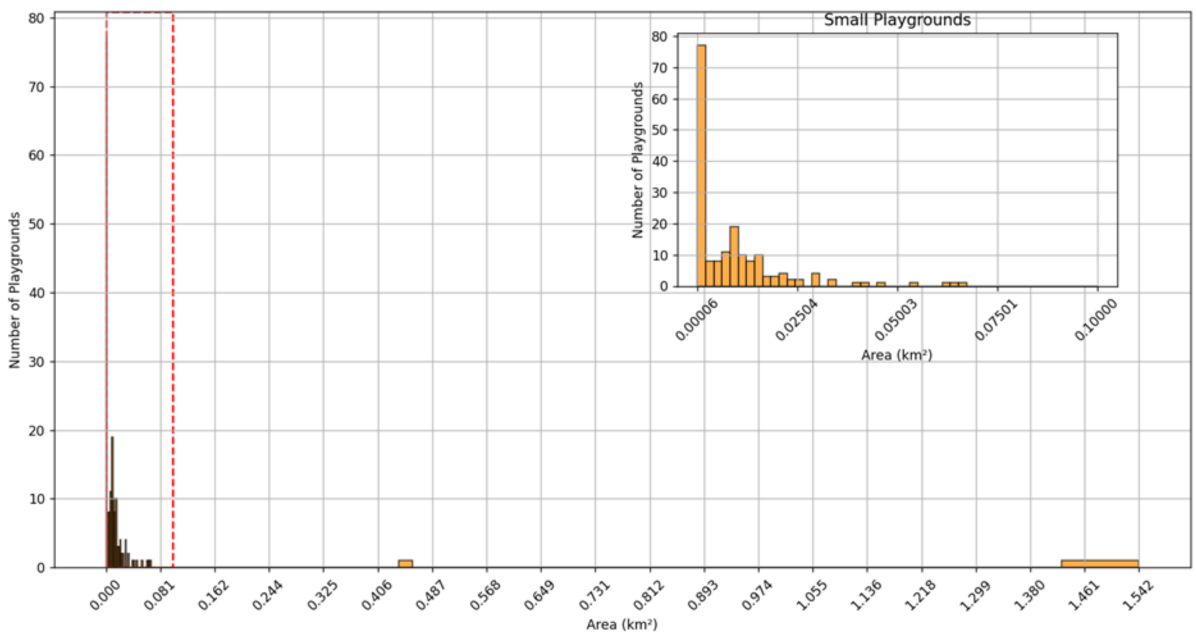

Figure 3. 14. Area wise frequency distribution of playground across the selected sectors of Islamabad.

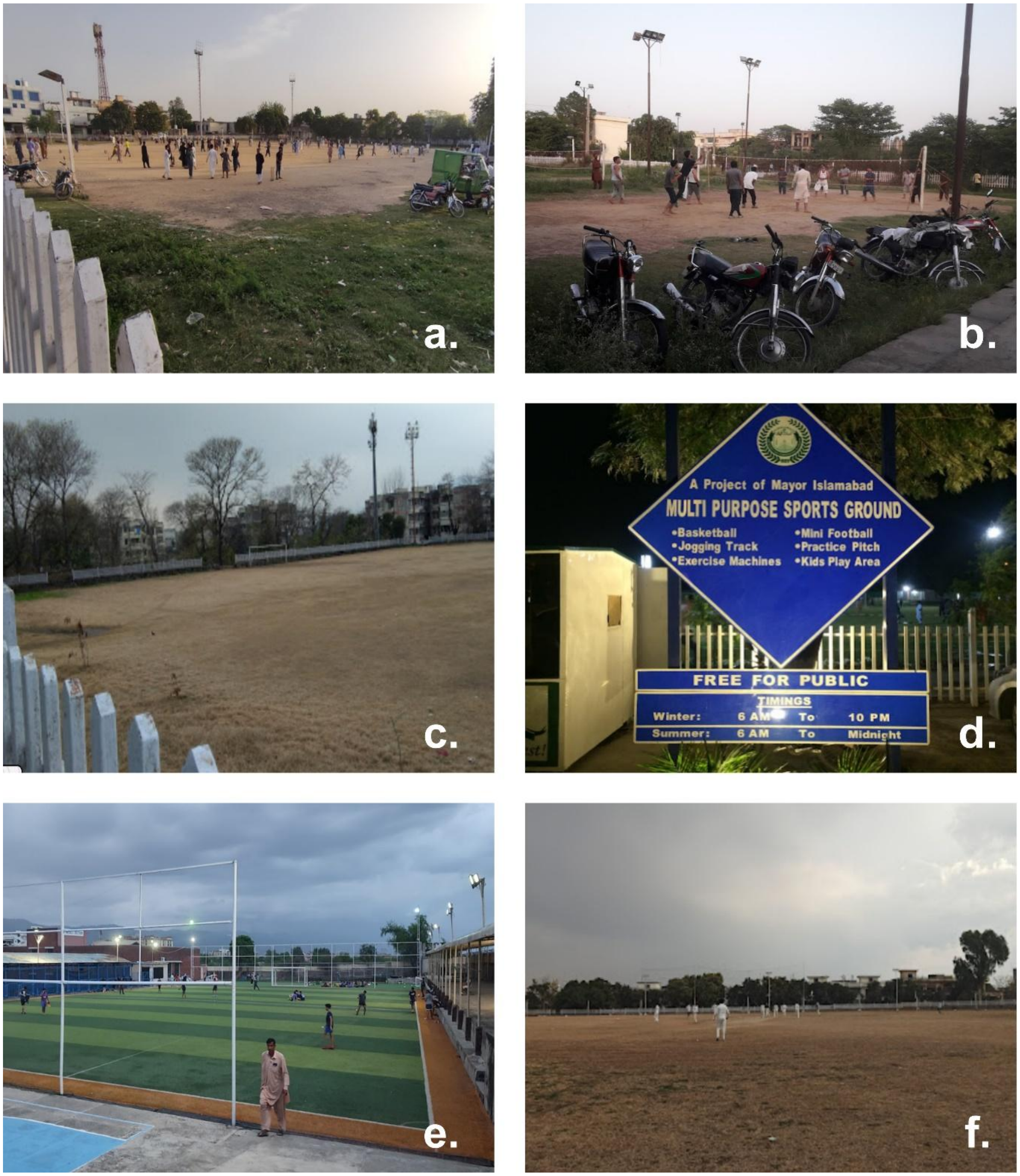

Figure 3. 15. Recreational UGS - playground and sports facilities.

(a) Overcrowded community playground with sports activities. (b) Evening sports activities at a local playground with basic infrastructure. (c) Underutilized playgrounds with poor facilities and maintenance. (d) A multipurpose sports ground, offering a variety of recreational activities. (e) Providing a venue for organized sports, with artificial turf. (f) Club involved in cricket, reflected in the use of a cricket ground.

3.2.3. Recreational UGS Typology—Lakes

The lakes in Islamabad serve as significant recreational urban green spaces, providing both ecological and social benefits. Prominent lakes such as Rawal Lake, located in the Margalla Hills National Park, are developed with attached parks and gardens to fulfill recreational needs (Figure 3.16). These areas cater to a diverse population, offering activities such as boating, picnicking, and bird watching, thus enhancing the recreational landscape of the city. However, accessibility issues and maintenance challenges can limit their optimal use.

Figure 3. 16. Recreational facilities at Lake View Park in Islamabad.

(a) Boating activities and the pier at Rawal Lake, highlighting the park's attraction for water-based recreation. (b) Signage indicating various amenities within Lake View Park, including a BBQ area, kids' play area, and a train track. (c) Entrance to the Bird Park, featuring the world's third-largest walk-in aviary, located within Lake View Park. (d) A well-maintained area within Lake View Park, showcasing vibrant flower beds and the park's aesthetic appeal.

One of the notable water bodies in Islamabad is the Korang River, which originates from the Murree Hills and flows through Islamabad into the Rawal Lake (Figure 3.17(b)). The Korang River plays a crucial role in the hydrology of the region, supplying water to Rawal Lake, which in turn provides drinking water to the residents of the twins cites (Rawalpindi and Islamabad). Despite its importance, the Korang River faces significant pollution challenges. Urban encroachments, industrial discharge, and untreated sewage have severely impacted the river's water quality, posing environmental and health risks. Efforts to mitigate pollution include regulatory measures and public awareness campaigns, but enforcement remains inconsistent.

Figure 3. 17. Korang river

(a) The Korang River flowing through a lush green area in Islamabad, highlighting its significance in the region's hydrology. (b) Map showing the location of the Korang River in relation to Islamabad and Rawalpindi (*source: google maps*).

Within the city, other lakes and water bodies also face underutilization due to urban congestion and environmental degradation. Despite efforts by local authorities to revitalize these water bodies, such as creating promenades and leisure areas, the provisions often remain underutilized due to poor maintenance and limited public engagement. Additionally, some lakes suffer from pollution and are used as dumping sites for sewage and garbage, detracting from their ecological and recreational potential.

Efforts to enhance the appeal and usability of Islamabad’s lakes include the development of better access points, regular maintenance, and public awareness campaigns to promote environmental stewardship. The potential of these lakes to serve as key urban green spaces can be fully realized through integrated management approaches that address both ecological health and recreational infrastructure. The transformation of these lakes into vibrant public spaces would contribute significantly to the city's sustainability and the well-being of its residents.

3.2.4. Recreational UGS Typology—Water Ways Green Spaces

A vital component of Islamabad green infrastructure left along natural drainage lines, such as Nullah Lai. The plant communities in these areas are distinct as a result of soil properties and human activities, and feature a variety of native and invasive species (Ali et al., 2010). Higher moisture content areas tend to support native species like *Populus euphratica* and herbaceous plants, while disturbed sites tend to support invasive species like *Broussonetia papyrifera* (Table 3.6). In urban ecosystems, these green spaces provide wildlife habitat, increasing their ecological resilience. Our close observations indicate that these areas are often underutilized due to poor maintenance and public awareness despite their ecological importance. It is important to preserve native species, control invasive species like *Broussonetia papyrifera*, and monitor soil properties. Green spaces can be fully realized if they are accessible and sustainable. There are distinct distributions of small and large patches, covering area of 4.99 km^2 , the majority are relatively small (0.1 km^2) (Figure 3.18). Despite their small size, these patches contribute significantly to urban biodiversity, flood mitigation and other ecosystem services. In spite of their fewer numbers, larger patches play a significant role in urban ecological resilience and provide greater recreational opportunities and habitat. Islamabad's environmental health and sustainability depend on the conservation and enhancement of waterway green spaces, both small and large.

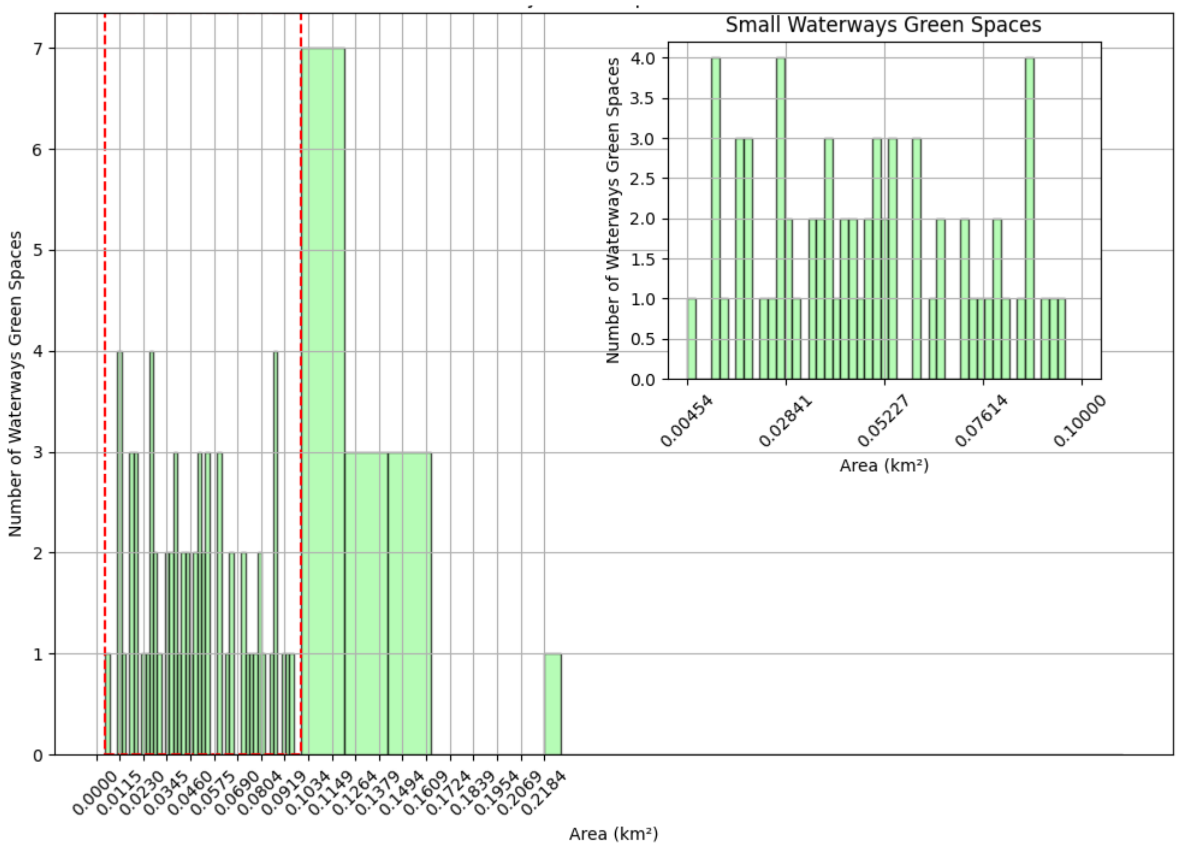

Figure 3. 18. Area wise frequency distribution of water ways green spaces across the selected sectors of Islamabad.

Table 3. 6. List of plant species available in waterways green spaces.

Species (Field names)	**Species Name (Botanical)**	**Abbrev**	**Family**
Acacia nilotica	*Acacia nilotica*	An	Mimosaceae
Alternanthera pungens	*Alternanthera pungens*	Ap	Amaranthaceae
Albizia procera	*Albizia procera*	Al	Fabaceae
Broussonetia papyrifera	*Broussonetia papyrifera*	Bp	Moraceae
Cynodon dactylon	*Cynodon dactylon*	Cy	Poaceae
Cannabis sativa	*Cannabis sativa*	Cb	Cannabaceae
Coronopis didymus	*Coronopus didymus*	Cd	Brassicaceae
Dicanthium annulatum	*Dicanthium annulatum*	Da	Poaceae
drekh	Azadirachta indica	Dr	Meliaceae
Dalbergia sissoo	Dalbergia sissoo	Ds	Fabaceae
Desmostachya bipinnata	Desmostachya bipinnata	De	Poaceae
Ficus glomerata	Ficus glomerata	Fg	Moraceae
Grewia captiva	Grewia captiva	Gc	Tiliaceae
Ipple Ipple	Ipple Ipple	Ipl	-
Jacaranda Mimosifolia	Jacaranda mimosifolia	Jm	Bignoniaceae
Lantana camara	Lantana camara	Lc	Verbenaceae
Malvestrum coromendilianum	Malvestrum coromendilianum	Mc	Malvaceae
Mimosa himaliyaca	Mimosa himaliyaca	Mh	Fabaceae
Morus nigra	Morus nigra	Mn	Moraceae
Panicum spp	Panicum officinale	Ps	Poaceae
Populus	Populus euphratica	Pc	Salicaceae
Parthenium histeriphorus	Parthenium histeriphorus	Pt	Asteraceae
Pinus (chir pine)	Pinus roxburghii	Pu	Pinaceae
Ricinus communis	Ricinus communis	Rc	Euphorbiaceae
Rumex chalapensis	Rumex chalapensis	Ru	Polygonaceae
Rumex dentatus	Rumex dentatus	Rd	Polygonaceae
Selibum marianum	Selibum marianum	Sm	Compositae
Sapium sebiferum	Sapium sebiferum	Sp	Euphorbiaceae
Eucalyptus globulus	Eucalyptus globulus	Sd	Myrtaceae
Zizyphus sativa (Ber)	Zizyphus sativa (Ber)	Zs	Rhamnaceae
Zizyphus mauritiana	Zizyphus mauritiana	Zm	Rhamnaceae

3.2.5. Recreational UGS Typology—Urban Forest

Maintaining urban biodiversity and ecological balance in areas surrounding developed regions is essential, particularly in urbanized area. These densely vegetated areas were purposely left undeveloped during city planning as buffer zones (Figure 3.8 (b)). Unlike the designated green belts, and water ways green spaces these regions remain pristine, undeveloped land that significantly contributes to the health and well-being of the city. Planning documents from the

CDA revels that, strategic importance of these buffer zones in mitigating urban sprawl and preserving natural landscapes. During our field survey, we identified these densely vegetated areas in H-12, H-10, and north-east side of the diplomatic enclave, and classified them as urban forests. The vegetation in these areas is similar to that found in waterway green spaces and urban green belts, including native plants that thrive in undisturbed natural environments.

3.2.6. Institutional Urban Green Spaces

In an urban matrix, allocated space for institutions, and proportion of the green areas serve as important ecological refuges. In addition to purifying air, they sequester carbon and regulate temperature. Additionally, green areas on educational campuses serve as living laboratories for environmental education. Thus, urban biodiversity is enhanced. These green spaces facilitate a deeper connection with nature and provide students and faculty a natural setting for learning and relaxation. The aesthetic appeal of institutional buildings is also enhanced by maintain gray and green structure. Ornamental and native plants improve urban sustainability and livability by supporting local biodiversity and mitigating the urban heat island effect. UGS management is essential to maximising their ecological benefits.

Substantial areas have been allocated to public and private universities and institutions (Figure 3.19), reflecting the commitment to education and research. Such as H-10 sector, designated for the International Islamic University, Islamabad (IIUI), spans a significant expanse and includes extensive green areas that contribute to urban biodiversity and ecological balance. Similarly, the most sustainable campus in Pakistan and world top ranked (101-200 in Time Higher Education impact ranking), the National University of Sciences and Technology (NUST) occupies a large campus with well-maintained lawns and diverse plantings that support a variety of fauna. Similarly, Quaid-i-Azam University (QAU), with its sprawling campus set against the backdrop of the Margalla Hills, serves as a crucial ecological and educational hub. The Allama Iqbal Open University (AIOU) also covers a vast area, incorporating green spaces that enhance the urban environment. Beyond these major universities, numerous schools, colleges, and government departments are strategically situated throughout Islamabad (Figure 7), each contributing to the city's green infrastructure (in total 17.05 km^2). These educational and governmental institutions not only foster learning and research but also play a pivotal role in maintaining the city's ecological resilience and sustainability by integrating substantial green spaces within their campuses.

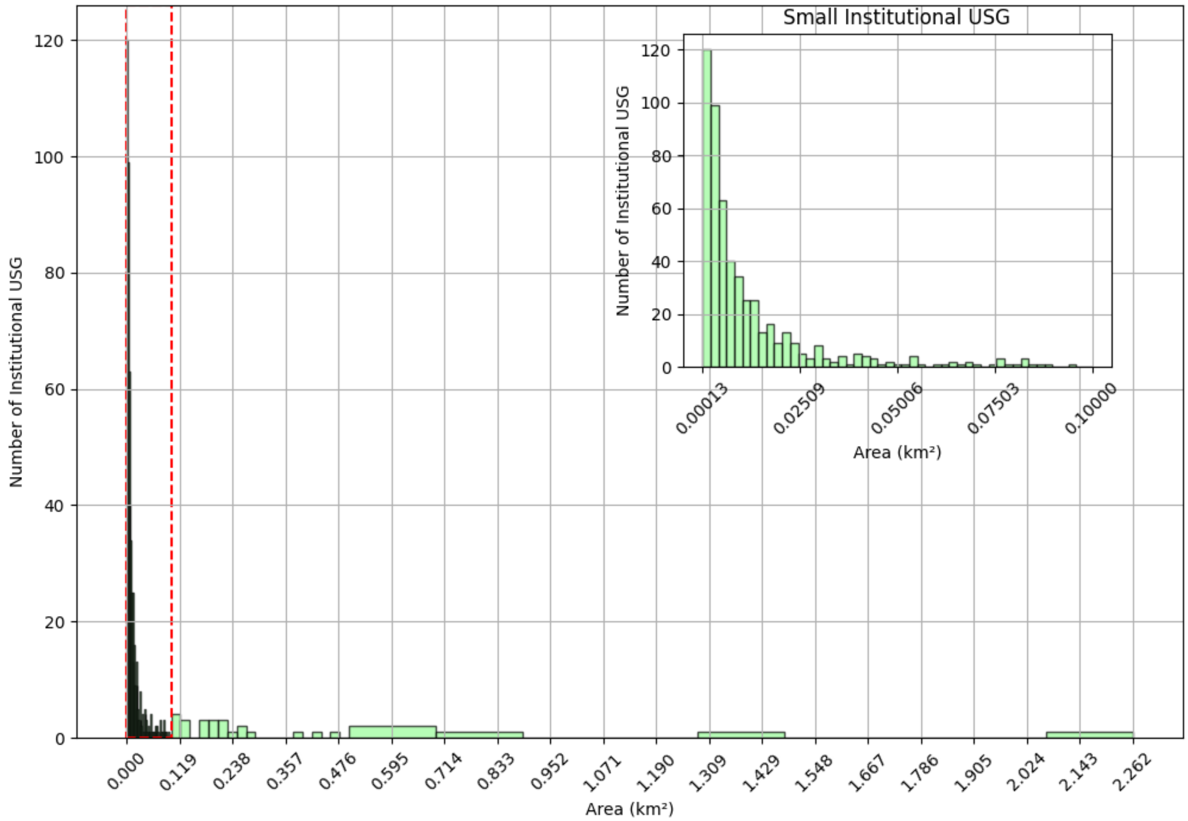

Figure 3. 19. Area-wise frequency distribution of institutional green spaces across the selected sectors of Islamabad.

3.2.7. Urban Green belts

The green belts in Islamabad were strategically included in the Master Plan to act as buffers between different urban sectors, preserving aesthetic appeal and maintaining ecological balance. Field observations indicate that, despite their ecological significance, these green belts face challenges from infrastructure development and informal settlements. Encroachment from road construction and other development projects has reduced their size and functionality. Regular maintenance, preservation of native species, control of invasive species, and monitoring of soil properties are essential to sustain the ecological functions of these green belts (Ali et al., 2010). Their strategic placement and diverse vegetation make them indispensable components of the city's green infrastructure, significantly contributing to the environmental health and sustainability of Islamabad. The concept of using green belts to prevent the merging of rural and urban areas dates back to World War II (Toft, 1995). The reasons for implementing green belts around cities varied: in England, they were used to stop urban expansion, while in Jerusalem, they served political purposes (Amati et al., 2010). In Islamabad, green belts serve a unique purpose. According to the

Master Plan of Islamabad, green belts were incorporated along every service road and highway. These green belts were intended for future road expansions and to act as barriers, separating residential areas from the roads. Thematic observations reveal that these green belts are underutilized, highlighting the need for better management and utilization strategies to maximize their ecological and social benefits.

The graph illustrates the distribution of green belt areas in Islamabad, highlighting their frequency of occurrence across different size categories. This study identifies the area of current green belts (9.82 km2) (Figure 3.20). Most green belts are relatively small, with the highest frequency observed in areas less than 0.1 km².

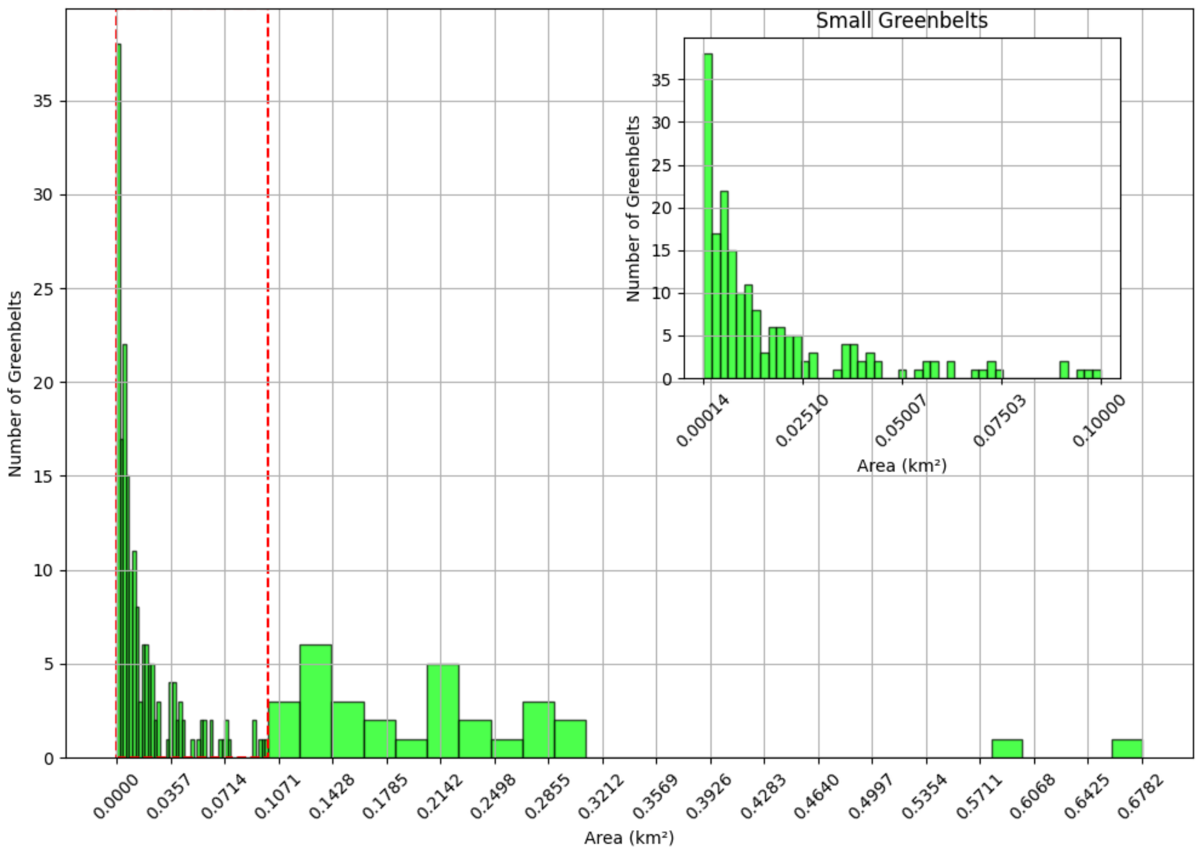

Figure 3. 20. Distribution of Green Belt Areas highlighting the prevalence of small green spaces within the urban landscape.

3.3.3. Thematic quantification of UGS

Distribution and sizes of different Urban Green Space (UGS) types were qualified based on thematic observation and mapping (figure 3.20. and figure 3.21) The Urban Green Belts and Institutional UGS categories dominate, with total areas of 19.64 km² and 17.05 km², respectively

(Figure 3.20). Recreational Parks and Gardens also hold significant space at 12.45 km^2. The mean area values indicate the average size of individual spaces, while the maximum values show the largest spaces within each type. The figure 3.21 complements this by showing the proportional distribution of each UGS type, with urban green belts (UBG) and institutional green spaces (IGS) making up over half of the total UGS area, highlighting their importance in urban planning and sustainability. This combined analysis underscores the focus on extensive green belts and institutional spaces, while also noting the substantial role of recreational parks.

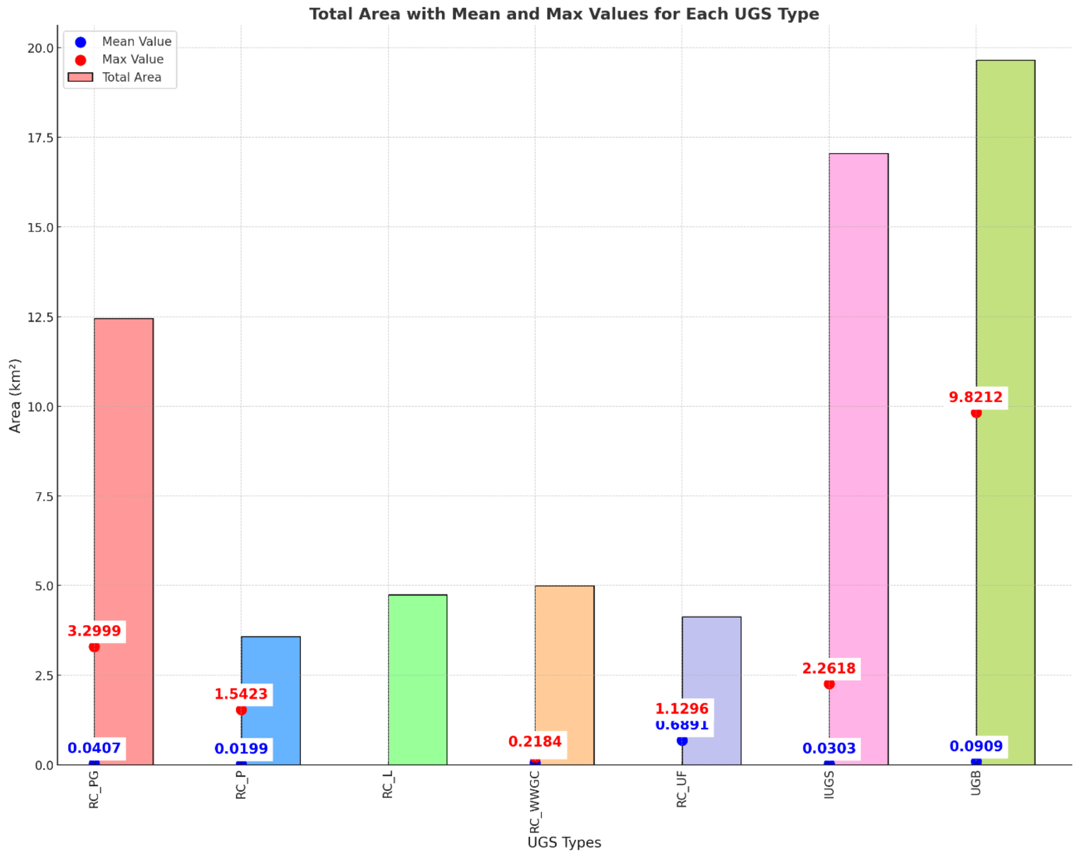

Figure 3. 21. Each UGS class area, mean and maximum size of the patch.

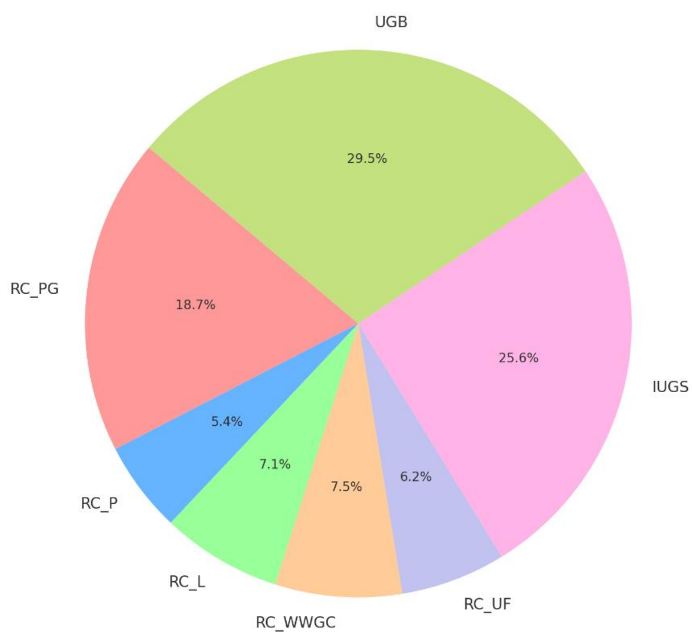

Figure 3. 22. The proportion of each UGS class.

3.4. Discussion

It's important to quantify Urban Green Spaces (UGS) to understand how these spaces are distributed in space and how accessible they are. According to earlier studies, the results exemplify that the spatial mapping of UGS sites using GIS and remote sensing tools provides useful information for urban planning and sustainability. Similar to Gill et al., (2007) and Tzoulas et al., (2007), the spatial analysis of UGS may help policymakers assess the availability of green space and help indicate potential gaps in access to it, particularly in rapidly urbanizing areas.

Study finding indicates a significant spatial distribution of UGS in Islamabad which is consistent with the urban core-periphery model meaning concentrated in low-density urban setting and rare in high-density urban setting. The same distribution pattern is observed in other metropolis areas (Haaland et al., 2015). Urban densification generally cuts down on green space in the centre area. As a result, this causes the uneven spread of accessibility to urban residents more concentrated on satellite cities.

Quantifying UGS, as exhibited in this research, is a vital step towards implementing sustainability transitions at the urban level. Understanding variations in green spaces can help urban planners take adequate measures to boost the effectiveness of a city. The result of this study shows that the disparities in UGS availability reflect socio-environmental inequalities seen in developing cities. Working on these inequalities is essential to facilitate an equitable transition towards sustainability. Insights from UGS quantification that is data driven can capture urban policies that are supportive of sustainability transitions, namely ecological, social and climate. For example, the integration of UGS into zoning policies or development plans to increase their potential as Nature-Based Solutions (NBS) can help address urban flooding and air pollution while improving residents' quality of life (Hansen et al., 2015). This study shows how quantification can connect planning and sustainability by ensuring UGS deliver environmental and social benefits in the long-term.

Such spatial analysis of UGS has amply proven their significance in enhancing the quality of air, controlling temperature and managing stormwater. These greenspaces help reduce urban heat islands and air pollution according to Demuzere et al., (2014) and Nowak et al., (2014). Prioritizing trees in UGS with aboveground biomass will help in carbon sequestration and absorption of pollutants. This is particularly important in urban areas with high vehicular emissions. Yet while the study distinguished the ecological benefits of UGS, it also found obstacles to optimizing these services due to uneven spatial distribution. With fewer well-planned areas, the environmental contribution and ecological effectiveness will be a lot lesser. This observation is supported by Kabisch et al. (2016), who affirm that the ecological value of UGS may be ruined due to a lack of spatial planning and other built environments.

Besides helping nature, UGS offer important social benefits that improve communities, encourage play, and promote mental wellness. The research revealed that Islamabad's UGS encourages all sorts of recreational activities that can renew our commitment to physical activity. These benefits are widely noted in urban studies because easy access to them improve mental health, reduce stress and increase physical activity (Peters et al., 2010; Zinia et al., 2018). This is especially true for urban places like Islamabad, where the cities do not allow the cities' inhabitants access to any natural landscape, thus making the UGS important for continuing social as well as mental well-being. Even with all these benefits, it became apparent that in high-density areas, the lack of availability of green space limits residents' use of UGS. According to studies, the unequal distribution of green spaces is a contributory factor to social inequalities, given that residents of low-density, suburban areas generally have much better access to high-quality green spaces than those who live in central, high-density areas (Maas et al., 2009; Rigolon, 2016). To fix these inequalities, different urban planners and owners have to make sure that there are equal UGS in residential buildings so that all can benefit from it.

UGS provide value by improving the value of properties, improving tourism and reducing health costs. The research shows that how near green spaces are to a property does affect the prices in Islamabad. This is also supported by (Crompton, 2001) and Donovan et al., (2010). Properties which are near well-looked after green spaces tend to be more valued. This value reflects the wider economic benefits UGS provide. We ought to ensure the sustainable funding and maintenance of UGS by looking into indirect economic benefits like healthcare savings as a result of better lifestyles. Yet, most residents do not recognize these benefits, using UGS mostly for recreational and aesthetic purposes, rather than for economic gains. Making people more knowledgeable about UGS's long-term contribution will help the community become more supportive of their investment in green infrastructure which is especially important in urban area where financial resources for maintenance is limited (Jim et al., 2006).

Even if the UGS systems have multiple ecological, social and economic benefits, their maintenance and sustainability pose to be an ongoing challenge. It is mainly because of their presence in densely populated urban areas. According to this study, the under-maintenance and over-crowdedness negatively affect the UGS in Islamabad and similar conclusions were drawn by Gill et al., (2007) and Haase et al., (2014) that dysfunctionality and inoperability occurs if green spaces are poorly maintained. For UGSs to be safe, accessible, and ecologically productive, a regular maintenance regime including litter removal, pruning and pathway upkeep is required. Too many people will bring other problems too. More feet on the ground means damage to vegetation, soil compaction, and less biodiversity. It is common in cities with little UGS, where small areas must serve large populations (Jansson et al., 2013). To address these problems, urban planners can try to widen green spaces or introduce measures to disperse visitor pressure. For instance, introducing multiple UGS in different neighborhoods can help, as can making pleasant, functional public spaces to complement existing green spaces.

Islamabad's UGS quantification study can inform policy in several ways. To manage UGS effectively, it is important to spatially plan, engage communities, and provide continuous funding. Spatial planning should provide UGS for all neighborhoods as per this study to ensure equitable distribution of UGS across all neighborhoods. Rigolon, (2016) stated that Such efforts would help to achieve equitable access to green space for all individuals irrespective of where they live and how much they earn. Involving the community is also vital for sustainable UGS management. Research shows if green spaces are planned and developed with the input of local communities, it fosters a sense of ownership and responsibility among them, thereby better management and sustainability (Włodarczyk-Marciniak et al., 2020; Zaman-ul-Haq et al., 2024; Zaman-Ul-haq et al., 2022). Community gardening programs or local "friends of parks" initiatives are examples of public participation which may help in the management of UGS and encourage residents to engage in the safety of environment. It is necessary the consistent funding of UGS in order to resolve maintenance issues and further future green space expansion. Policymakers can consider various methods to fund UGS. For instance, they can create public-private partnerships, raise green bonds or ask the community for financial help (Jim et al., 2006). It is crucial to have Sustainable Funding in rapidly urbanizing cities like Islamabad that rely on a UGS and face competing land use issues that might threaten their future.

Chapter-4

VALUATION OF MULTIFUNCTIONALITY OF UGS

4.1. Introduction

Urban green spaces (UGS) are more than just patches of greenery in cities—they are critical for sustaining urban environments. These spaces provide essential services such as regulating climate, improving air quality, managing water, and supporting biodiversity (Kabisch, Korn, et al., 2017; Zaman-ul-Haq et al., 2022). With cities around the world expanding rapidly, especially in developing regions, there is growing concern over the shrinking availability of UGS. As more natural landscapes are converted to built-up areas, the ability of these spaces to provide crucial ecosystem services is being compromised (Hansen et al., 2019). In this context, understanding the role of UGS in promoting urban sustainability transitions is more important than ever.

Islamabad, the capital of Pakistan, offers a clear example of the challenges faced by rapidly urbanizing cities. Originally planned with generous green spaces to balance urban life and nature, the city has experienced significant changes in land use over the last two decades. As this study shows, the built-up area in Islamabad has more than doubled between 2000 to 2025, expanding from 191.07 km² to a projected 404.73 km². This urban growth has come at the cost of natural landscapes, including forests and green spaces, which have declined by 29.68% and 72.9 km², respectively. Such drastic changes are not unique to Islamabad; they are part of a global trend where urban expansion often leads to the degradation of natural landscapes, threatening the very services that these spaces provide (Thomas Elmqvist et al., 2013).

The reduction in UGS has profound implications for Islamabad's environmental health. Forests, green belts, and playgrounds that once supported biodiversity, regulated temperatures, and offered recreational spaces are now under increasing pressure. According to this study, the total ecosystem service value (ESV) of Islamabad's UGS has declined from $388.3 million in 2000 to $301.2 million by 2025. Similar to studies in other urban centers, these findings underscore the urgent need to rethink how we manage and protect green spaces in cities (Costanza et al., 2014). Despite their potential, UGS in Islamabad—especially forests and managed green spaces—have experienced significant reductions in their capacity to provide ecosystem services. These spaces, which are essential for regulating environmental processes, are increasingly under threat due to urban encroachment. Similar patterns have been observed in other cities in South Asia, where UGS are increasingly pressured by urban sprawl and insufficient land-use planning (Chaudhry et al., 2010).

This study was designed with several key objectives that aimed to evaluate the role of UGS in Islamabad in promoting sustainability through the ecosystem services they provide. First, the study aimed to assess the ecosystem services provided by UGS in Islamabad, particularly focusing on the ecological functions these spaces perform, such as climate regulation, air purification, and water management, and their overall contribution to urban resilience. The second objective was to conduct a detailed land-use classification to map and track the changes in UGS, forests, and other land-use types in Islamabad from 2000 to 2025, using advanced remote sensing techniques and satellite imagery. By mapping these changes, the study aimed to provide a clear picture of how urban expansion has impacted UGS and other natural landscapes. Lastly, the study sought to quantify the economic value of ecosystem services using the Benefit Transfer Method (BTM) (Rahman et al., 2021; Zaman-ul-Haq et al., 2022), putting a monetary value on the ecosystem services provided by UGS in Islamabad, which could inform policy decisions regarding land-use management.

To achieve these objectives, the study employed a combination of satellite imagery and economic valuation methods. Using Landsat 7 ETM+ and Landsat 8 OLI/TIRS satellite imagery processed on Google Earth Engine, the study mapped land use and classified green spaces, forests, water bodies, and built-up areas. The Classification and Regression Trees (CART) algorithm provided accurate land classification, allowing the study to monitor changes over time (Loukika et al., 2021; Zhao et al., 2024). This approach is widely recognized in urban sustainability research, offering valuable insights into how urbanization impacts natural landscapes(Li et al., 2021; Zhao et al., 2024). In parallel, the study used the Benefit Transfer Method to estimate the economic value of ecosystem services provided by these UGS. The BTM approach, commonly applied in similar ecosystem service evaluations, helped quantify the monetary value of various ecological functions, ranging from climate regulation to recreational services(Christie et al., 2008; Costanza et al., 2014; Manes et al., 2012). This combination of ecological assessment and economic valuation provided a comprehensive framework for understanding the importance of UGS in urban environments.

One of the key findings of this research was the significant decline in ecosystem service values associated with UGS in Islamabad. The reduction in forest cover and green spaces has decreased their ability to provide regulating services like climate control and water purification. Additionally, cultural services—those that provide recreational and aesthetic value—have also suffered, with a 31.5% decline in value. These findings align with research from other rapidly urbanizing cities, demonstrating how urban sprawl can negatively impact ecosystem services(Rahman et al., 2021; Tang et al., 2018). The study hypothesized that by evaluating land-use changes and the corresponding ecosystem service losses, this research could provide valuable insights into how UGS can be better managed to support urban sustainability. By focusing on both the ecological and economic aspects of UGS, this study contributes to the growing body of literature that emphasizes the need for integrating ecosystem services into urban planning frameworks (T. Elmqvist et al., 2015).

This study offers valuable insights for both policymakers and urban planners. The assessment of UGS in Islamabad not only reveals the challenges posed by rapid urbanization but also highlights the untapped potential of these spaces to contribute to sustainability. By incorporating ecosystem services into urban planning frameworks and optimizing the use of UGS, cities like Islamabad can pave the way for more resilient and sustainable urban futures. As cities across the world continue to grow, leveraging the benefits of UGS will be key to creating livable, sustainable environments for future generations.

4.2. Methodology

43.2.1 Data acquisition and LULC classification

In this study, main objective was to assess ecologically important land cover classes instead of covering all impossible classes that can either cause impact on urban vegetation or the vegetation itself. To meet this approach, pixel-based image classification technique was utilized (Phiri et al., 2017; Zerrouki et al., 2014). We segregate imperious (buildup) and pervious (Natural Forest and Managed UGS) land cover, and waterbody as separate class (Anderson et al., 1976; Digra et al., 2022) (Table 4.1).

Table 4. 1. Land cover classes and description.

Land Use Class	Description
Forest	Dominant cover of natural vegetation, exhibiting minimal human interference. Includes various formations such as forests, woodlands, and tall shrub lands.
Green Spaces	Area deliberately nurtured for cultivation, aesthetic, or recreational purposes. Includes crops, pastures, orchards, parks, gardens, and playgrounds.
Buildup	Area with high population density and low vegetation cover are characteristics of human-dominated landscapes, made up mostly of impervious surfaces such as residential, commercial, industrial, roadways, housing estate, and suburb.
Water	Areas covered by water, including natural (rivers, lakes, and ponds) and artificial (reservoirs) water bodies.

The land cover changes over the last two decades were analyzed with Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) imagery, retrieve and analyses in Google Earth Engine (GEE) Platform (Kumar et al., 2018; Tamiminia et al., 2020). Our analysis used images from 2000, 2005, 2010, 2015, and 2020 that have a consistent spatial resolution of 30 meters, making them suitable for land cover classification (Table 4.2). The Images were rigorously processed prior to classification (Figure 4.1). To ensure accuracy and consistency across datasets, geometric and radiometric corrections were performed (Vicente-Serrano et al., 2008). Cloud masking was also applied to prevent interference with the analysis (Foga et al., 2017).

Table 4. 2. Imagery and sensor characteristics for land use analysis.

Year	Landsat Mission	Sensor	Radiometric Resolution
2000	Landsat 7	ETM+	8-bit
2005	Landsat 7	ETM+	8-bit
2010	Landsat 7	ETM+	8-bit
2015	Landsat 8	OLI/TIRS	12-bit
2020	Landsat 8	OLI/TIRS	12-bit

Furthermore, spectral indices were utilized to enhance pixel values for more accurate and informed selection of training samples extraction (Annextures-1). The LULC classification was performed using CART (Classification and regression Trees) algorithm in the GEE. LULC-based maps were cross-validated and reasonably assessed against kappa statistic (Loh, 2008; Loukika et al., 2021;

Zaman-ul-Haq et al., 2022) (Annextures-2). The methodology involved calculating transition probabilities between consecutive LULC maps using a Markov chain model, followed by the application of Cellular Automata (CA) to predict future land cover (Gharaibeh et al., 2020; Ghosh et al., 2017) for year 2025. The rasters were pre-processed for alignment, stacked, and the model was trained on historical data to generate the future prediction (Figure 4.1).

3.2.2. Ecosystem services of the UGS and their functional linkages in LULC valuation

Additionally, this study evaluates ecosystem services and ecosystem function using the Benefit Transfer Method (BTM) (Johnston et al., 2015). In this instrument, reported ecosystem services are used as proxy values (Richardson et al., 2015). Evaluations using BTM are heavily influenced by the choice of metrics and measurement accuracy (Plummer, 2009). To evaluate ES, proxy values were assumed and modified in accordance with Costanza et al., (2014) for the framework and parameters. For selected LULCs, Ecosystem Services (ES) were valued using reported coefficients (Table 4.3). In order to calculate the monetary value of an ecosystem service, the land area of a selected category is multiplied by the reported coefficient value (Rahman et al., 2021; Tripathi et al., 2019).

$$ESV = \sum (A_k \times VC_k) \tag{1}$$

In Eq.1. to calculate the total value of ecosystem services (*ESV*), '*k*' category of the land cover class, *'A'* area (hectares), and the value coefficient (US \$ $ha^{-1}yr^{-1}$) presented with VC_k.

The assessment of the value of ecosystem services of the USG was done by calculating the estimations about each LULC category for the selected years 2000, 2005, 2010, 2015, 2020 and 2025 (Table 4.2) in the following way (Rahman et al., 2021; Zaman-ul-Haq et al., 2022). (Eq 2).

$$ESV_{cr} = \frac{ESV_j - ESV_i}{ESV_i} \times \frac{1}{T} \times 100\% \tag{2}$$

In the equation 2, for the estimation of the annual change in ecosystem service, ESV_{cr}, were 'ESV_i' and 'ESV_j' show initial and final values of ecosystem service and *'T'* sands for time, respectively

The land cover class based functional value of the UGS were estimated using coefficients using Eq.3.

$$ESV_f = \sum (A_k \times VC_{fk}) \tag{3}$$

where ESV_f refers to the estimated value of ecosystem service function (*f*); for each LULC category, *'k'* A_k is the area (ha), and VC_{fk} is the value for the coefficient of *f* (US \$ $ha^{-1}yr^{-1}$).

A function value (*f*) for ecosystem services is represented by ESV_f . As indicated by *'k'*, each Land Use and Land Cover (LULC) category has a hectare (ha) area (Table 4.5), and VC_{fk} indicates the coefficient value (Table 4) of the function (*f*) in US dollars per hectare per year (US $ ha-1 yr-1). To determine whether proxy-based results are valid, we performed a Sensitivity Analysis (SA). Therefore, we calculated the Coefficient of Sensitivity (CS). Based on the variation in value coefficients for a given LULC type (Gashaw et al., 2018; Z. Wang et al., 2020), the change in ESV is calculated (Equation 4)

$$CS = \frac{\left(ESV_j - ESV_i\right) / ESV_i}{\left(VC_{jk} - VC_{ik}\right) / VC_{ik}} \tag{4}$$

Table 4. 3. Biome equivalent for assessed Land Use Land Cover (LULC) types and coefficient as per Costanza et al., (2014)

LULC	Equivalent biome	The Coefficient Value of Ecosystem Services (USD $ ha-1 yr-1)
Forest	Tropical Forest	5381
Water	Wetland	12512
Buildup	Urban	921
Green Spaces	Grass / Range land	4166

To this end, a benchmark for assessing the monetary contribution of the ESS from 17 land-cover biomes was considered sufficient (Table 3.4). The methodological framework (Figure 4.1) allows researchers to determine the context-specific monetary value of ecosystem services based on LULC information. An adjustment was made in the selection of built-up areas. Costanza et al., (2014) assigned high values to cultural services; however, in our study, this was not considered. In the case of Islamabad, the cultural services are predominantly linked to the aesthetic value of the city, which is associated with water bodies, green spaces, and forest areas. These elements were already accounted for and deemed sufficient for representing the cultural services value in Islamabad (Table 4.4).

Table 4. 4. Values coefficient per unit area of ecosystem services and their associated function adopted from Costanza et al., (2014)

		Each LULC types ES values (USD $ ha^{-1} yr^{-1})			
Ecosystem Services	**Function**	**Forest**	**Water**	**Buildup**	**Green Spaces**
Provisioning Services	Water supply	27	1,808		60
	Food production	200	106		1192
	Raw materials	84			54
	Genetic resources	1517			1214
Regulating Services	Gas regulation	12			9
	Climate regulation	2044		905	40
	Disturbance regulation	66			
	Water regulation	8	7,514	16	3
	Erosion control	337			44
	Waste treatment	120	918		75
	Biological control	11			31
Supporting Services	Soil formation	14			2
	Nutrient cycling	3			
	Pollination	30			35
	Habitat/ refugia	39			1214
Cultural Services	Recreation	867	2,166	0	26
	Cultural	2			167
Total		**5381**	**12511.8**	**921**	**4166**

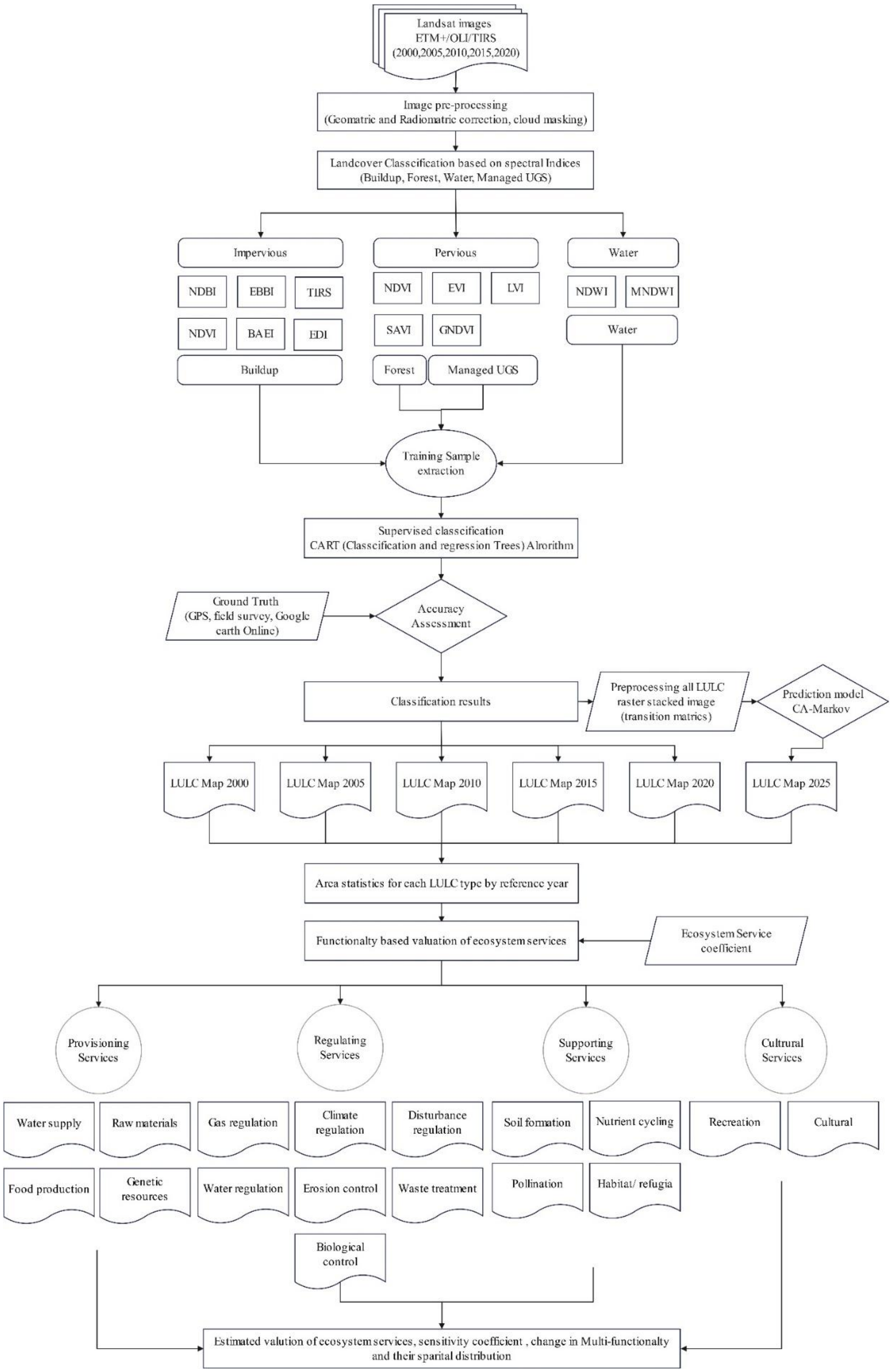

Figure 4. 1. Detail methodological framework adopted to conduct this study

4.3. Results

4.3.1 Spatiotemporal transformation in land cover

Based on a Land Use and Land Cover (LULC) assessment conducted over 25 years from 2000 to 2025 (Figure 4.2 and Table 4.5), the landscape of Islamabad has undergone profound changes. According to classified satellite imagery and statistical data, Islamabad has changed dramatically. There has been an increase in builtup in the city over the years, growing from 191.07 km2 in 2000 to 404.73 km^2 by the year 2025. It is clear from this growth spurt that Islamabad has experienced rapid urbanization and infrastructure development, especially during the periods 2000-2005 and 2020-2025 (Figure 4.3), when the most substantial growth occurred. The city has expanded extensively in all directions, especially in the south-east and south-west, to meet the growing population and infrastructure needs. There have been significant reductions in natural landscapes because of this expansion, especially in the northern and eastern parts of the city where urban development has been most intense. As a result, the forest cover has steadily declined since 2000. By 2025, it is projected that the area of forested land will be 348.62 km^2, a reduction of approximately 29.68% from 2000. As a result of increasing urban areas, agriculture, and other human activities, deforestation is likely to be ongoing, according to this consistent decline. Similarly, green spaces—such as parks and other vegetative areas not classified as forests—have shrunk, from 231.79 km^2 in 2000 to an estimated 158.89 km^2 by 2025. During the period 2000-2005 through 2020-2025, the most significant reductions occurred (Figure 4.3), demonstrating the continuous encroachment on these vital areas as the city grows. However, Islamabad's water bodies have remained relatively stable throughout the assessment period, with only slight variations occurring. By 2025, the water area will decrease slightly from 8.88 km2 in 2000 to 8.11 km^2, a modest 8.61% reduction. The LULC assessment reveals a clear trend towards urbanization, often at the expense of natural areas. It was found that forests and green spaces have been converted into built-up areas, which has significant impacts on the environment, biodiversity, and sustainability.

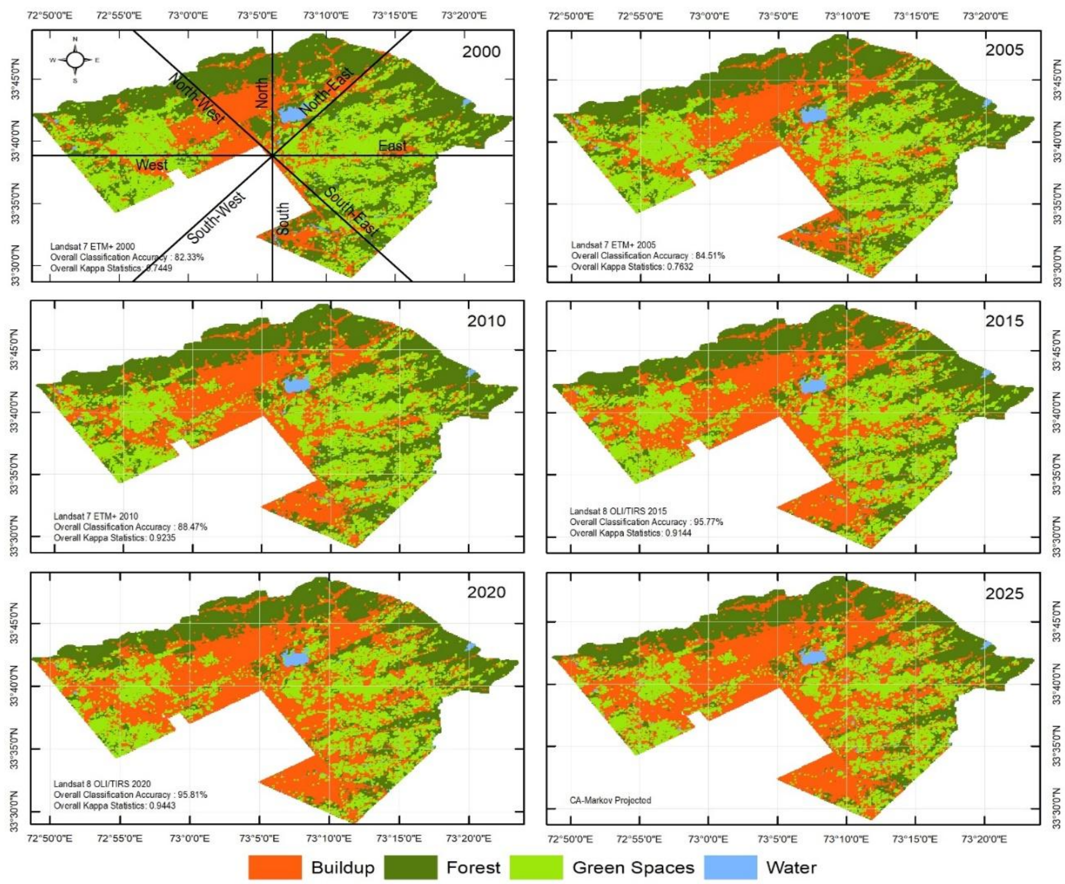

Figure 4. 2. Spatiotemporal changes in Land Use Land Cover in Islamabad (2000-2025)

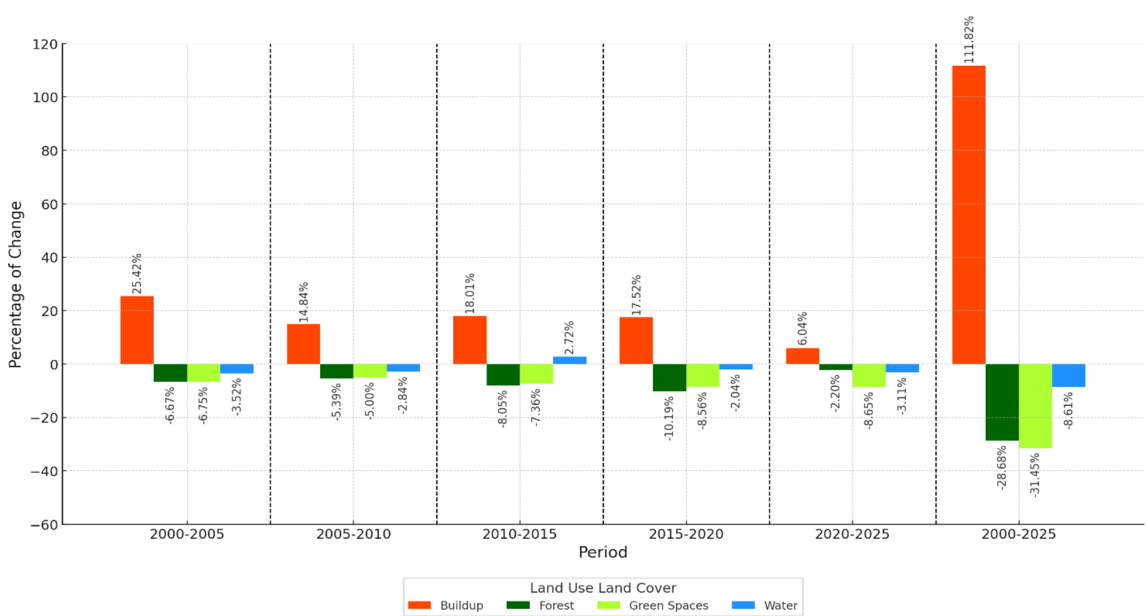

Figure 4. 3. Periodic landcover transition (2000–2025).

Table 4. 5. Area calculation of the LULC over the period of 2000-2025.

LULC / Year	Area	Buildup	Forest	Green Spaces	Water	Total
	km^2	191.07	488.82	231.79	8.88	920.56
2000	ha	19107.29	48881.93	23178.85	888.24	92056.3
	%	20.76	53.1	25.18	0.96	100
	km^2	239.64	456.24	216.14	8.57	920.58
2005	ha	23963.69	45623.6	21613.81	856.94	92058.04
	%	26.03	49.56	23.48	0.93	100
	km^2	275.2	431.64	205.34	8.33	920.51
2010	ha	27520.18	43164.48	20533.81	832.61	92051.09
	%	29.9	46.89	22.31	0.9	100
	km^2	324.78	396.92	190.23	8.55	920.48
2015	ha	32477.89	39691.9	19022.59	855.24	92047.61
	%	35.28	43.12	20.67	0.93	100
	km^2	381.69	356.46	173.93	8.38	920.46
2020	ha	38168.67	35645.99	17393.38	837.82	92045.86
	%	41.47	38.73	18.9	0.91	100
	km^2	404.73	348.62	158.89	8.12	920.35
2025	ha	40472.61	34861.78	15889.29	811.75	92035.43
	%	43.98	37.88	17.26	0.88	100

4.3.2. Trends in ESV's (2000 -2025)

Over the years from 2000 to 2025, Islamabad has seen a steady decline in its total Ecosystem Service Value (ESV), dropping from 388.3 million USD in 2000 to a projected 301.2 million USD by 2025 (Figure 4.4). This decline is largely driven by the significant reduction in forest cover, which were assessed and found fell from 263.0 million USD in 2000 to an estimated 187.6 million USD in 2025, and the decrease in green spaces from 96.6 million USD to 66.2 million USD over the same period. Meanwhile, the ESV for built-up areas has consistently increased, reflecting the constant urbanization, rising from 17.6 million USD in 2000 to a projected 37.3 million USD in 2025. These trends highlight the continued expansion of urban areas at the expense of natural landscapes, resulting in a diminished capacity of ecosystems to provide essential services. The Figure illustrates a consistent decline in ESV across each interval from 2000 to 2025, with the most significant reductions occurring between 2010-2015 (-20.14 million USD) and 2015-2020 (-23.53 million USD) (Figure 4.5). These declines were primarily driven by substantial losses in forest cover and green spaces. Overall, from 2000 to 2025, the total ESV is projected to decrease by -87.09 million USD, reflecting the ongoing impact of urban expansion on natural landscapes of Islamabad and the diminishing capacity of the city to provide essential ecosystem services.

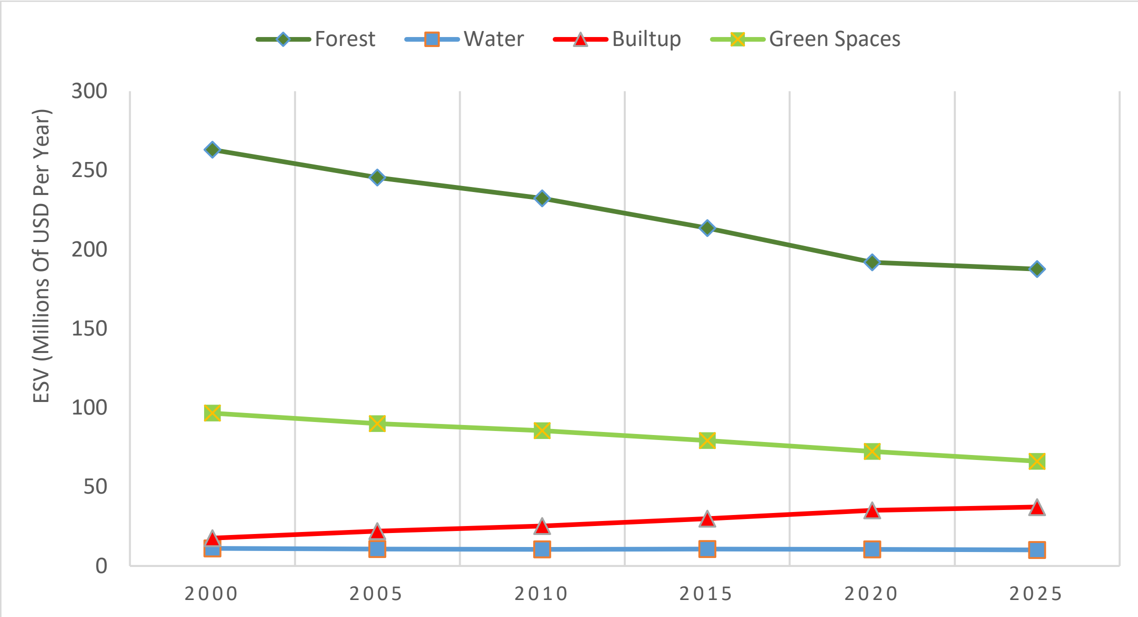

Figure 4. 4. Trends of total EVS during the year 2000-2025.

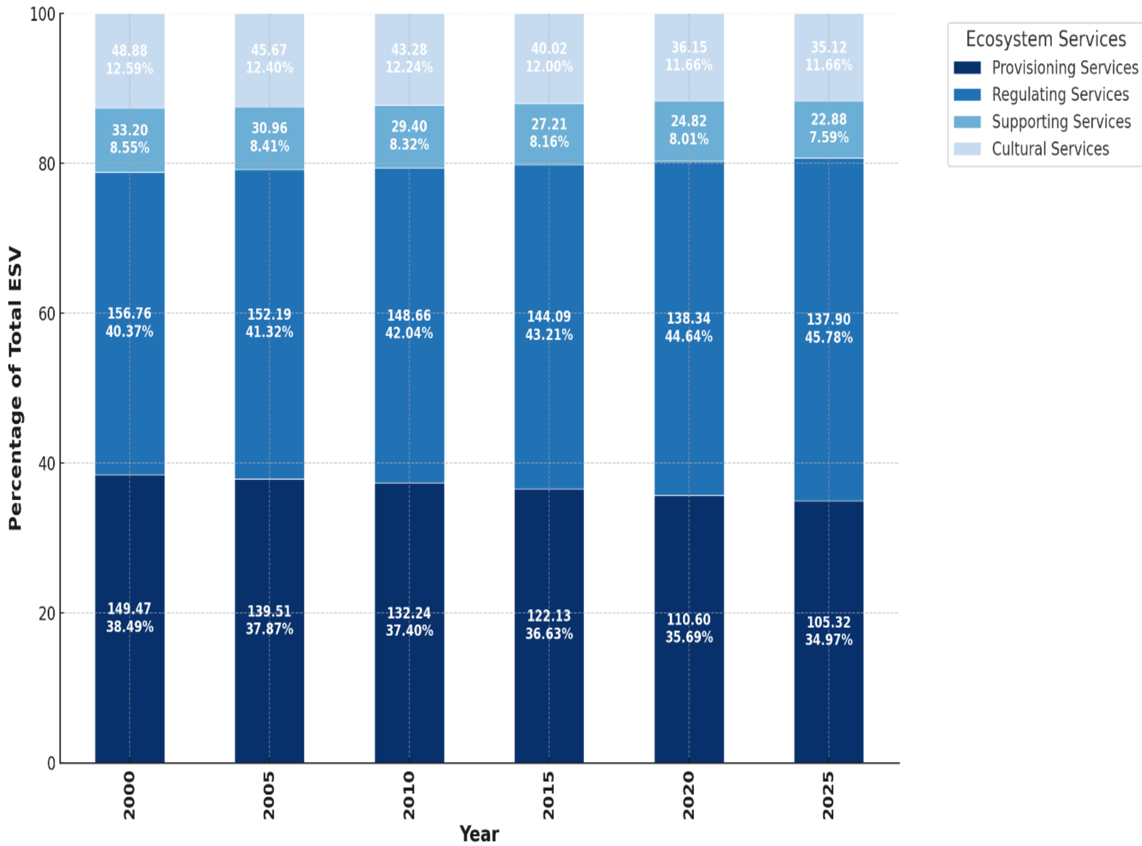

Figure 4. 5. Proportional share of EVS of the UGS based classified ecosystem services.

4.3.3. Valuation of ecosystem services and their associated functions

3.3.1. Valuing Provisioning Ecosystem Services (PES)

As part of this study, to estimate ESV value associated with provisioning ecosystem services like water supply, food production, raw materials, and genetic resources, we examined changes between 2000 and 2025 (Figure 4.6. and Figure 4.7). The findings revealed a troubling pattern. Water supply, valued at 4.32 million USD in 2000, has steadily decreased, reaching 3.52 million USD by 2020. It is predicted that it will further decline to 3.36 million USD by 2025. Between 2000 and 2005, ESV was found to have decreased (-0.55 million USD). They continued to decline, though at a slower rate, between 2005 and 2010. Similar downward trends were observed in the function of food production, which initially estimated at 37.50 million USD in 2000 but dropped to 30.70 million USD in 2015 and continued to fall to 27.95 million USD by 2020. Between 2000 and 2005, there was a sharp decrease of 2.52 million USD, while between 2015 and 2020 there was a -2.93 million USD reduction. Over time, raw material availability has also decreased. Starting at 5.36 million USD in 2000, it fell to 4.36 million USD in 2015. By 2025, it is expected to decrease to 3.79 million USD. The sharpest drop occurred between 2015 and 2020, with a reduction of -0.98 million USD, highlighting the unsustainable extraction and depletion of natural resources caused by urban growth. In 2015, genetic resources were valued at 83.31 million USD, a sharp decline from 102.29 million USD in 2000. By 2025, they are expected to be valued at 72.17 million USD. In terms of genetic diversity losses, the largest losses occurred between 2000 and 2005 (-6.89 million USD) and between 2015 and 2020 (-9.17 million USD), indicating the profound impact habitat loss and urban encroachment have had. Across different intervals, we found that the most severe impacts on these critical ecosystem services occurred in the early 2000s, and this occurred again as we approached 2020.

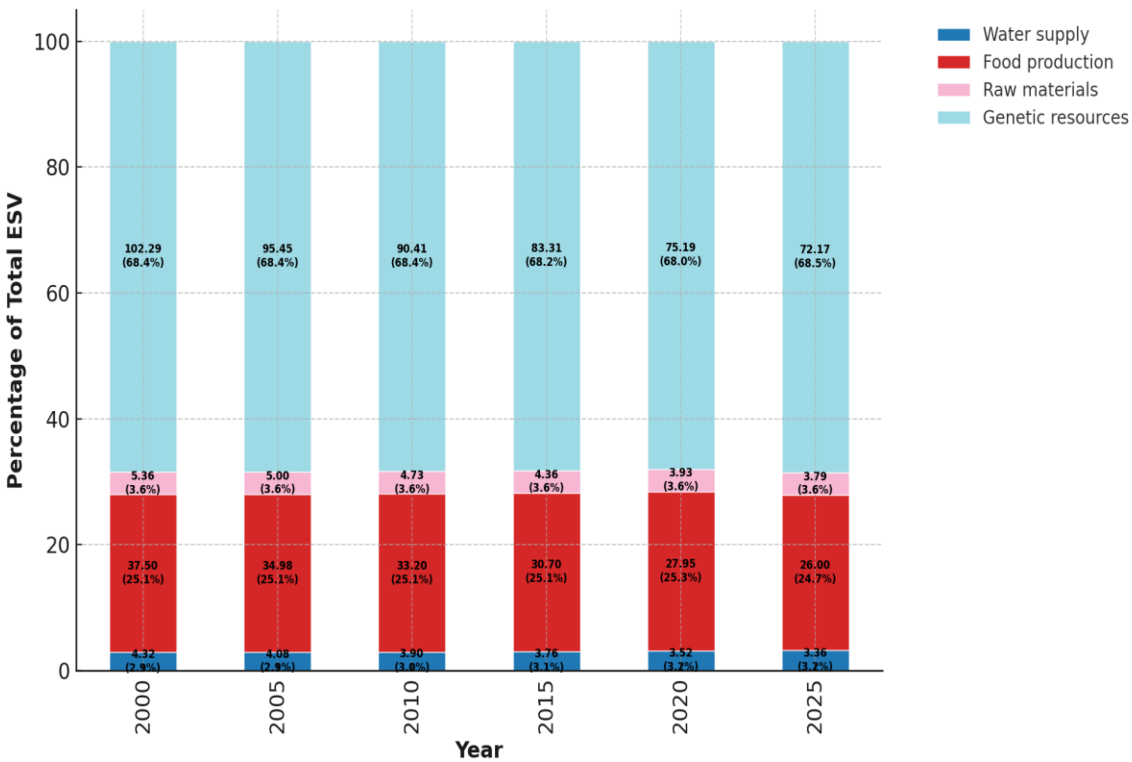

Figure 4. 6. Temporal distribution of functional EVS of PES.

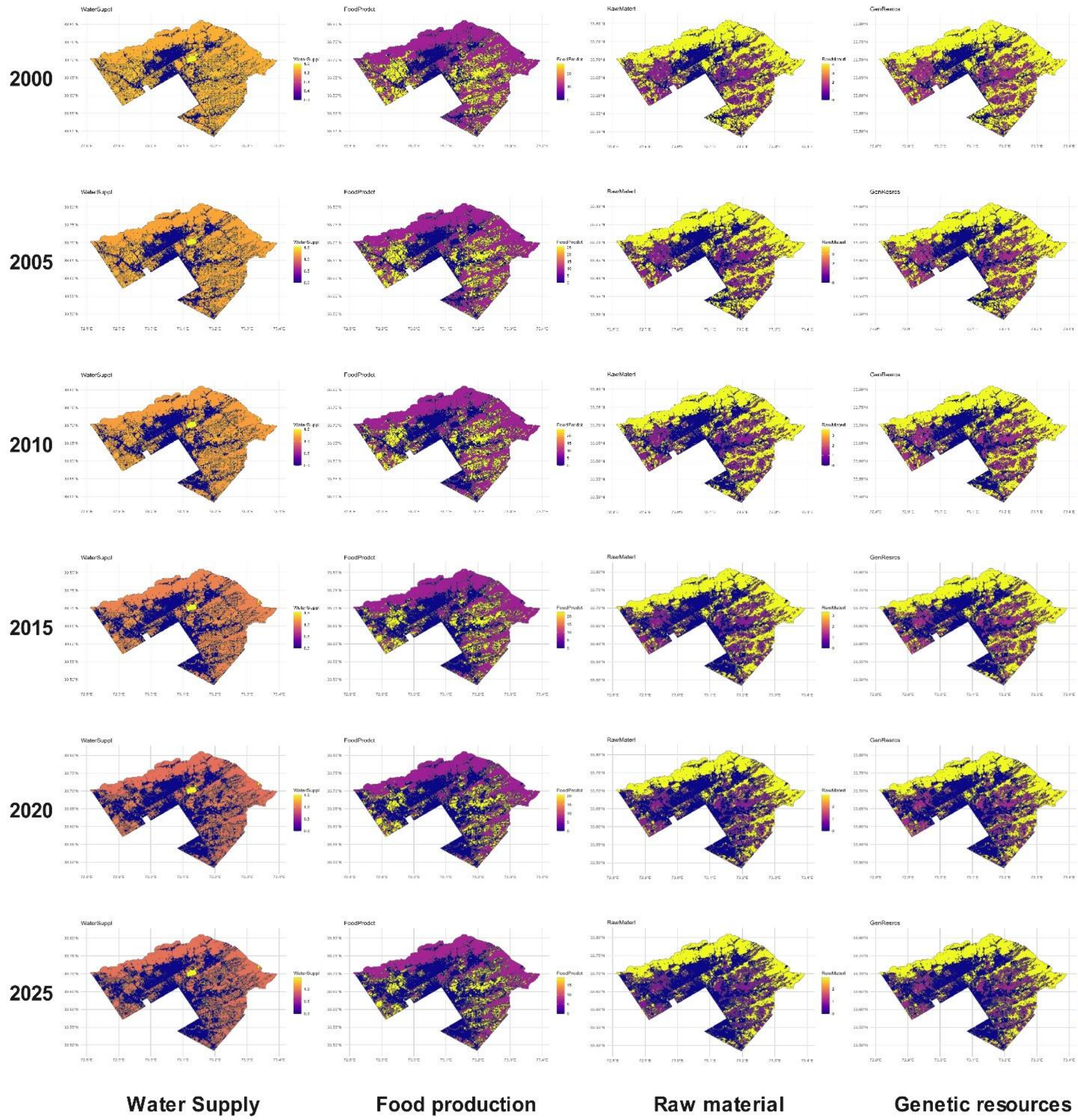

Figure 4. 7. Spatial distribution of functional EVS of PES.

3.3.2. Valuing Regulating Ecosystem Services (RES)

Figures 4.8 and 4.9 (a), (b) show trends between 2000 and 2025 about the different functions related to regulating ecosystem services. Based on LULC data, Islamabad has changed significantly in regulating ecosystem services. Regulation services include gas regulation, climate regulation, disturbance control, water regulation, erosion control, waste treatment, and biological control. To maintain environmental stability and ecosystem health, these services are crucial. Over the years, gas regulation has steadily decreased in ESV from 0.80 million USD in 2000 to 0.65 million USD in 2015. It is projected to fall to 0.56 million USD by 2025. There was a significant decline in ESV between 2000 and 2005 (-0.20 million USD) and continued between 2005 and 2010 (-0.13 million USD). A key service, climate regulation, peaked in 2000 at 118.13 million US dollars. It gradually declined to 111.28 million US dollars in 2015 and is forecast to decrease to 108.52 million US dollars by 2025. The most notable reductions occurred in the early 2000s, particularly between 2000 and 2005 (2.32 million US dollars), followed by a gradual decline between 2005 and 2010 (-1.85 million US dollars). There is a slight slowdown in the rate of decline between 2020 and 2025 (-0.39 million USD). As an estimations result, disturbance regulation is also decreasing steadily. By 2025, it is projected to drop to 2.30 million USD from 3.23 million USD in 2000. The most significant reductions occurred between 2010 and 2015 (-0.80 million USD) and between 2015 and 2020 (-1.02 million USD), indicating the city's decreasing ability to buffer against environmental shocks as urbanization intensifies. Over time, water regulation decreased from 7.44 million USD in 2000 to 7.24 million USD in 2020, with a projected value of 7.07 million USD by 2025. In contrast to other services, water regulation experienced a brief period of stability between 2010 and 2015. It increased by 0.11 million USD because of targeted water management efforts. It was estimated that erosion control cost 17.49 million USD in 2000, but it dropped to 14.21 million USD by 2015, then to 12.45 million USD by 2025. During the period it was found that significant reductions between 2010 and 2015 (-0.80 million USD) and between 2015 and 2020 (-1.01 million USD). A consistent decline occurred in waste treatment, which was initially estimated at 8.42 million USD in 2000 and fell to 6.97 million USD in 2015. It is projected to fall to 6.12 million USD by 2025. As urban populations grow and natural waste capacity diminishes, the sharpest drop occurred between 2015 and 2020 (-0.89 million USD). It is estimated that the value of biological control in 2000 was 1.26 million USD. Nevertheless, that number has steadily declined, reaching 1.03 million USD in 2015, and is projected to fall to 0.88 million USD by 2025. As a result of the loss of natural habitats that support these functions, the most significant reductions occurred between 2000 and 2005 (-0.07 million USD) and between 2015 and 2020 (-0.93 million USD). From 2000 to 2025, all categories of regulated ecosystem services have shown a steady decline. This is primarily a result of urbanization impacts. During periods of rapid urban growth from 2000-2005 and 2015-2020, the most significant reductions occurred.

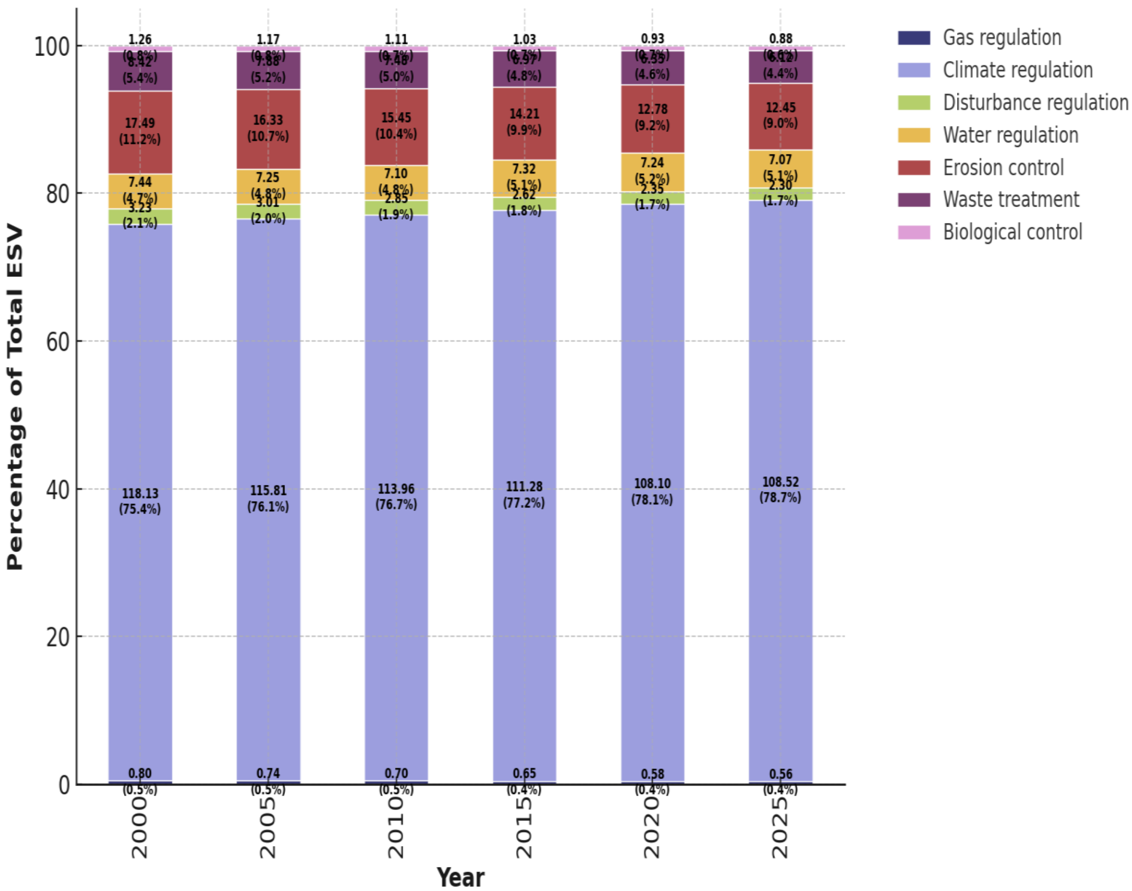

Figure 4. 8. Temporal distribution of functional EVS of RES.

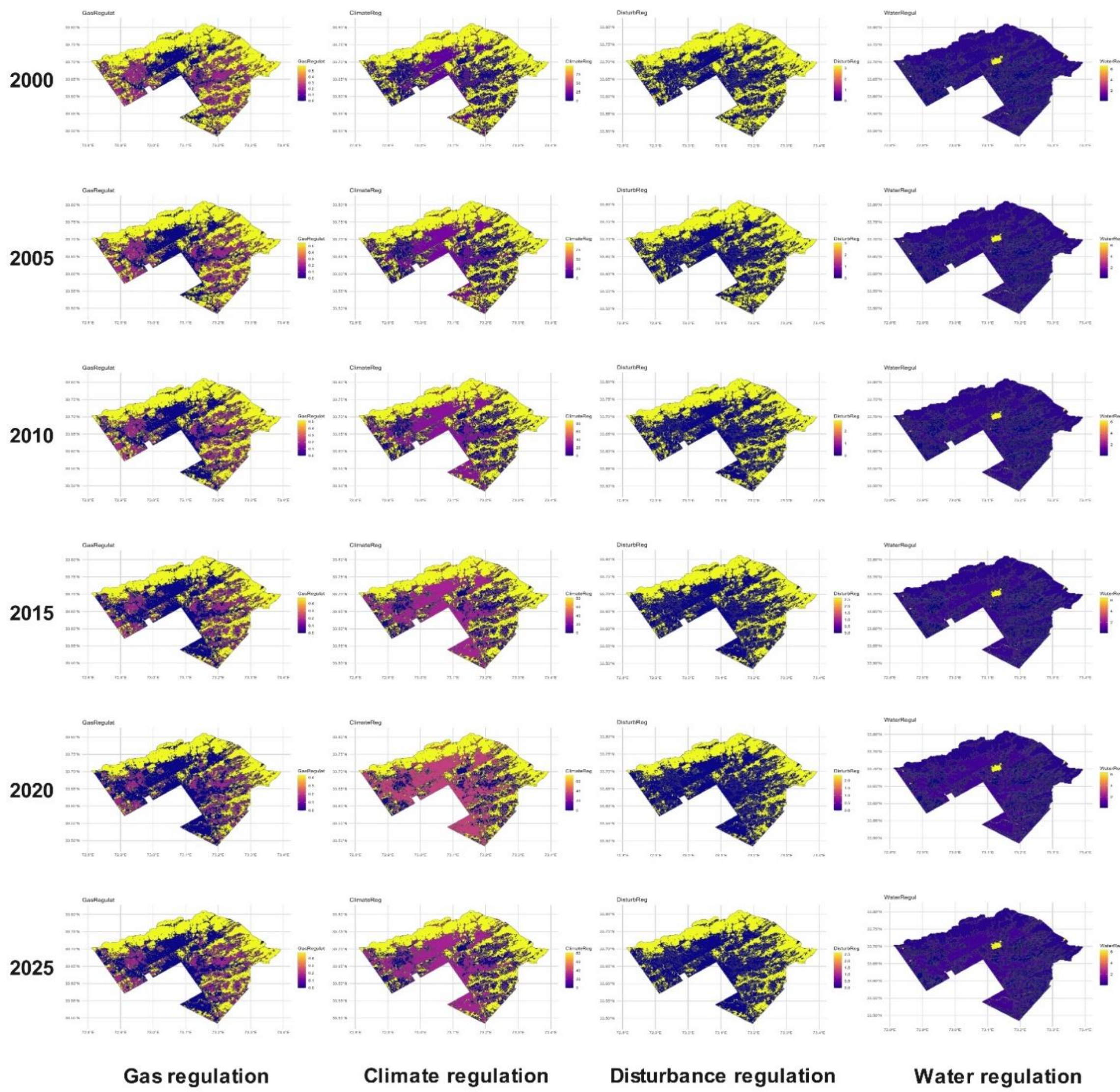

Figure 4. 9. Spatial distribution of functional EVS of RES.

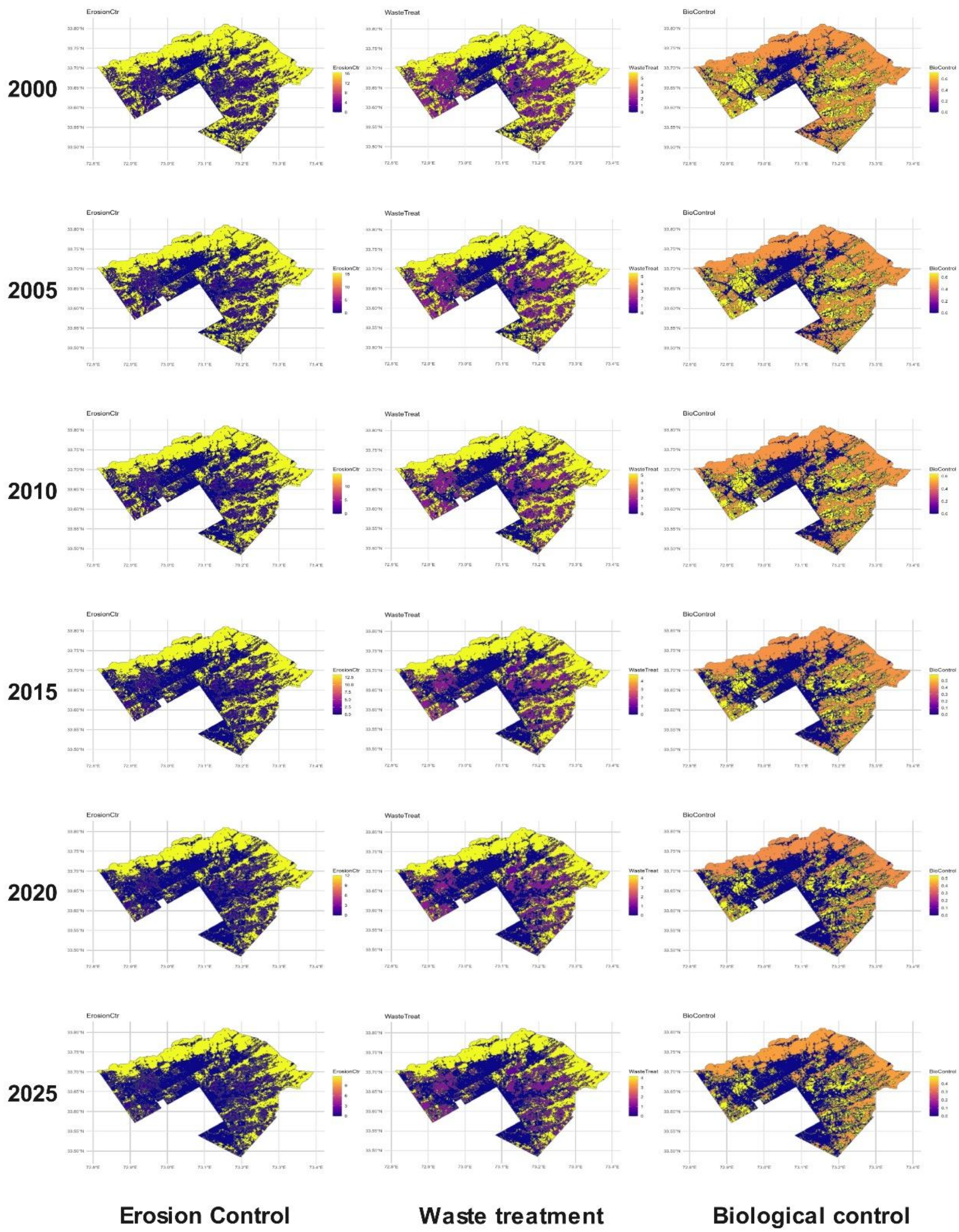

Figure 4.9 (b). Spatial distribution of functional EVS of RES.

3.3.3. Valuing Supporting Ecosystem Services (SES)

All assessed functions in the supporting services, including soil formation, nutrient cycling, pollination, and habitat/refugee, have been experiencing a gradual but significant decline (Figure 4.10 and 4.11). As soil health is a crucial component of any thriving ecosystem, this decline reflects the increasing pressure on it. It was 0.73 million USD in 2000. It is expected to decline to 0.52 million USD by 2025. As a result of significant stress on soil formation during 2015-2020 (ESV lost over 1 million USD), nutrient cycling, and another function of supporting services, experienced downward trends as well. In 2000, it was estimated at 0.15 million USD, but by 2025 it had fallen to 0.10 million USD. There was also a sharp decline in pollination services between 2015 and 2020, at around 1.02 million USD. During the period 2000 to 2025, the ESV value decreased by approximately 0.96 million dollars. Between 2000 and 2005, the value decreased by 0.67 million dollars. From 2000 to 2025, the habitat/refuge functional value declined from 30.05 million USD to 20.65 million USD. It was observed that the value declined sharply between 2000 and 2005 (-0.675 million USD) and between 2015 and 2020 (-0.866 million USD).

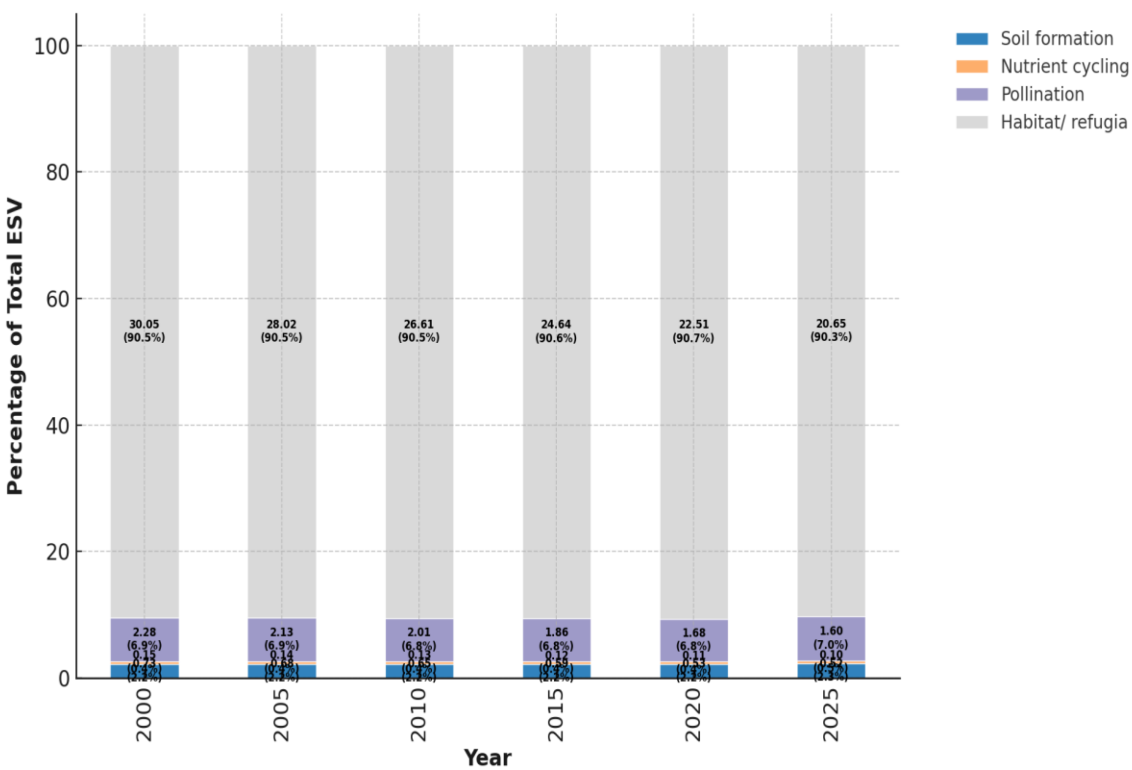

Figure 4. 10. Temporal distribution of functional EVS of SES.

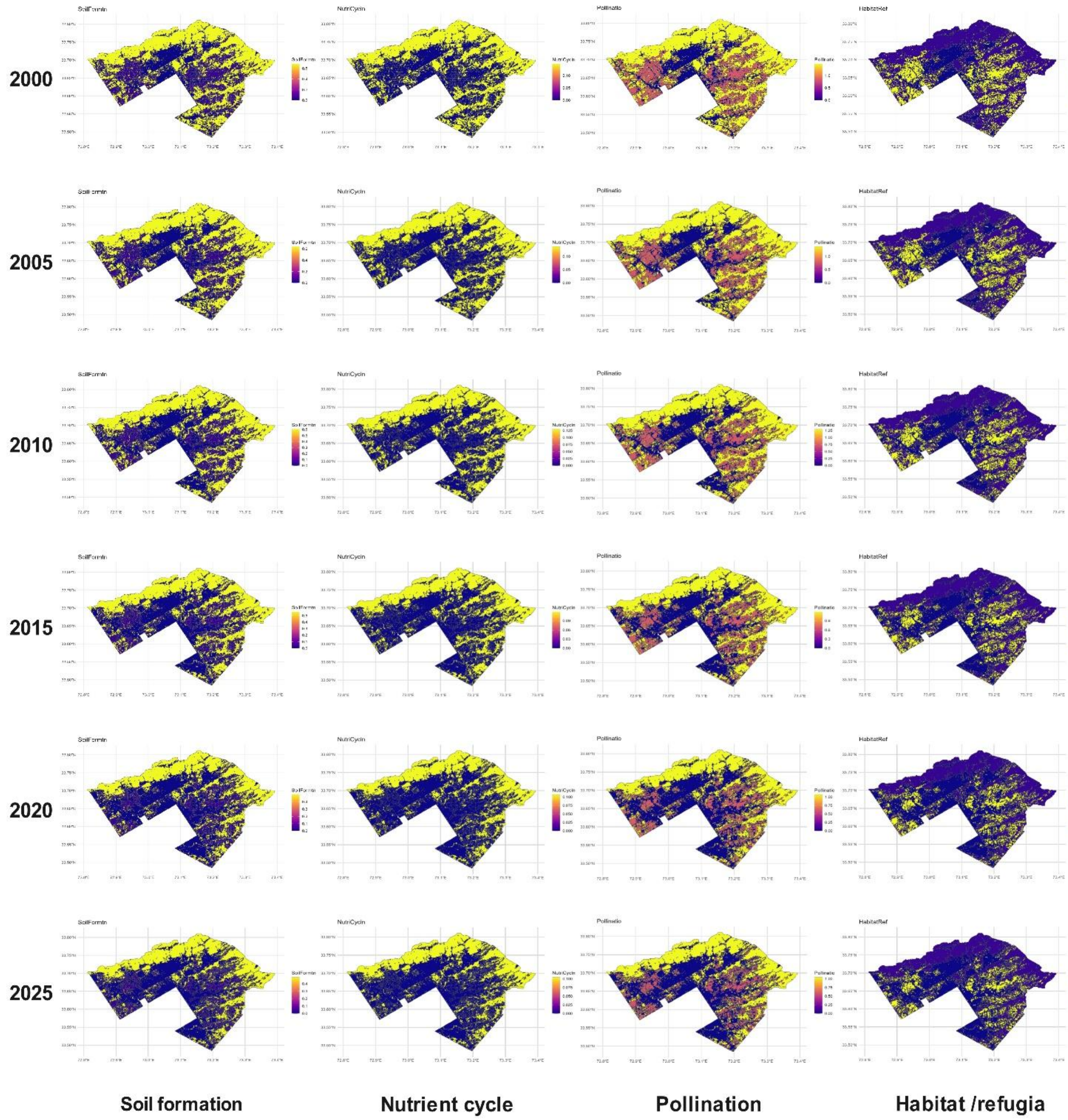

Figure 4. 11. Spatial distribution of functional EVS of SES.

3.3.3. Valuing Cultural Ecosystem Services (CES)

Cultural services, particularly those related to recreation and cultural value, have also shown a steady and worrying decline (Figure 4.12 and 4.13). For example, recreation services had an estimated ESV of 44.91 in 2000, but gradually decreased to 32.40 by 2025. There were significant declines between 2015 and 2020, when the service value fell by 0.98 units, and from 2000 to 2005, when the service value declined by 0.65 units. These decreases illustrate that our natural landscapes are under increasing pressure. The ESV for cultural services was also declining between 2000 and 2025. Using coefficient value, the ESV of cultural services was 3.97 in 2000, but dropped to 2.72 in 2025. In 2015 and 2020, there was a 0.86 unit decrease, while in 2000 and 2005, there was a 0.67 unit drop.

Figure 4. 12. Temporal distribution of functional EVS of CES.

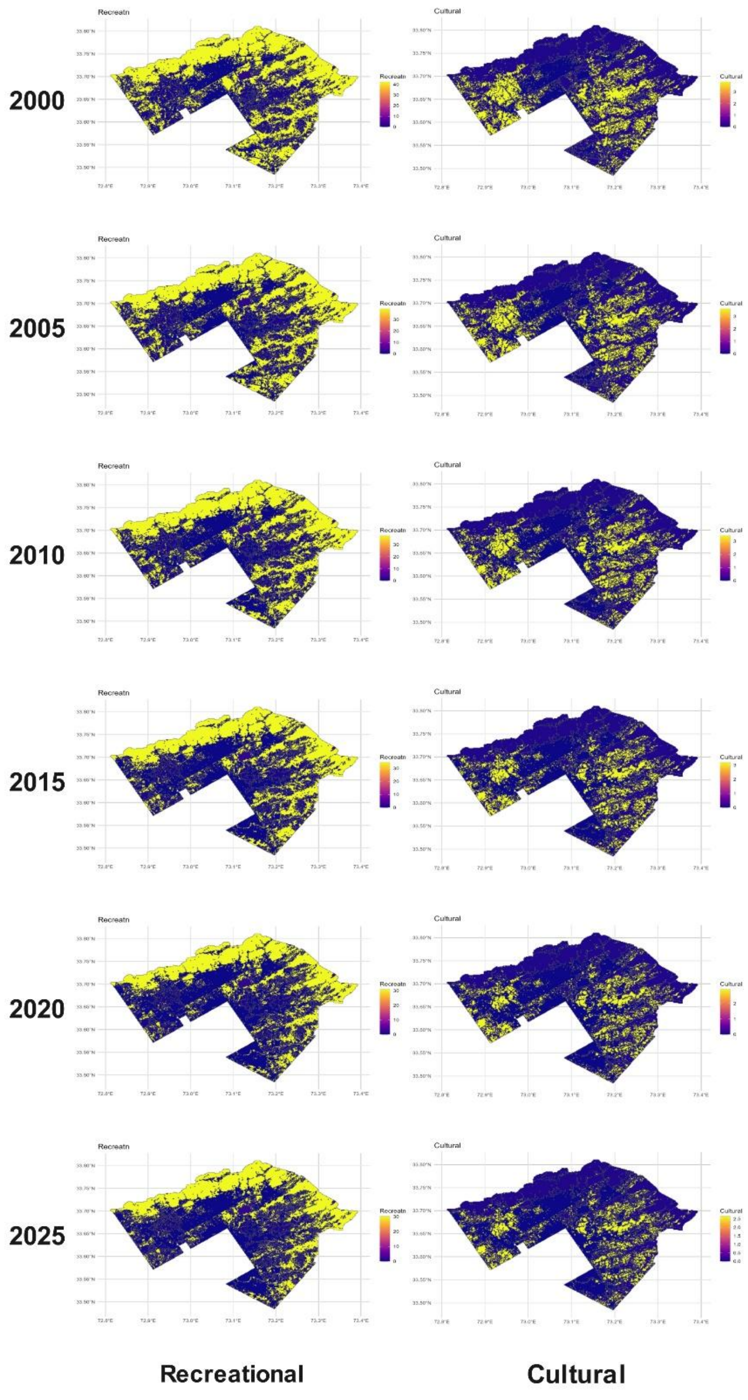

Figure 4. 13. Spatial distribution of functional EVS of SES.

4.3.4. Sensitivity analysis

To ensure the reliability of our estimates, we conducted a sensitivity analysis. We calculated the sensitivity coefficient (CS) to assess the impact of variations in value coefficients for each land use type. By adjusting these coefficients by ±50%, we refined our estimates of ecosystem service value (ESV) and CS. A CS value less than 1 indicates that our ESV estimates are robust and not overly sensitive to changes in input values (Table 4.6).

Table 4. 6. Estimated change in total ESV and coefficients of sensitivity (CSs) based on adjustments.

Adjusted value coefficient	2000		2005		2010		2015		2020		2025	
	CS (%)	CS	CS (%)	CS	CS (%)	CS	CS (%)	CS	CS (%)	CS	CS (%)	CS
Built-up ± 50%	2.265960503	0.04531921	2.995980112	0.059919602	3.584253805	0.071685076	4.485345665	0.089706913	5.671579208	0.113431584	6.187431391	0.123748628
Forest ± 50%	33.86920463	0.677384093	33.32561618	0.666512324	32.84561192	0.656912238	32.02678657	0.640535731	30.94646151	0.61892923	31.13881657	0.622776331
Green Spaces ± 50%	12.43382821	0.248676564	12.22295341	0.244459068	12.09696919	0.241939384	11.88330776	0.237666155	11.69070196	0.233814039	10.98786215	0.219757243
Water ± 50%	1.431006658	0.028620133	1.455450307	0.029109006	1.473165084	0.029463302	1.604560009	0.0320912	1.691257324	0.033825146	1.685889881	0.033717798

4.4. Discussion

Urban Green Spaces (UGS) are now being valued by urban planners as cities are searching for sustainable solutions to manage natural resources in man-made environments. This study demonstrates the economic value of UGS in Islamabad using the Benefit Transfer Method (BTM) (Rahman et al., 2021; Zaman-ul-Haq et al., 2022). UGS yield various ecosystem services and are thus valuable for the generation of ecosystem services. Costanza et al., (2014)also showed that ecosystem services have a huge global value. Policymakers can monetize ecosystem services in order to make sure that UGS is an affordable solution and will not hinder development. According to de Groot et al., (2012) tribute essential regulating services air purification, water regulation and temperature moderation. Although these services are not tangible, they can save money on healthcare and reduce the heat in cities. For example, trees and vegetation oversee air quality regulations and health issues caused by pollution will be solved as it reduces public health spending (Jim et al., 2006). Furthermore, the economic assessment emphasizes the risk of flooding which contributes to the value of UGS due to increasing urbanization in Islamabad.

The assessment of Urban Green Spaces (UGS) is critical to sustainability transitions which represents the convergence of the economic and ecological frames and changes to urban planning. The ecosystem services UGS provide could lead to long-term systemic change whose co-benefits build resilience in cities (Adu Boateng et al., 2023). For example, the economic valuation of UGS in Islamabad illustrates the contribution of these spaces to climate change mitigation, air quality improvement, and biodiversity support. They aim to promote nature-based solutions that create social and environmental benefits, as well as sustainable development, which is an important focus of sustainability transitions.

If you add Economic Valuation to Sustainability Transition Models, it further justifies the allocation of resources towards green infrastructure. The results of this study indicate that the total ecosystem service value (ESV) of UGS of Islamabad has significantly decreased and, thus, demanding intervention. By incorporating UGS valuation into policies, planners prioritize green spaces as environmental capital as well as essential components of sustainable urban systems (Haase, 2021). Explaining UGS as agents of sustainability transitions can help cities gain its economic and ecological value to further aim for many transformative goals– carbon neutrality, better health, more just cities, etc.

Urban Green Spaces (UGS) play an important role in supporting biodiversity and enhancing the resilience of urban ecosystems. Furthermore, they have great economic importance too. The value of UGS for providing essential ecosystem services like habitat provision and carbon fixation was significantly underappreciated in urban policies and strategies. The studies by Haase et al., (2014) and Frantzeskaki et al., (2016) correspond with what you observed as a necessity for cities to value their green spaces ecologically in an increasingly urbanizing world. In UGS of Islamabad, different plants support many species contributing to urban biodiversity which is a kind of ecosystem service has ecological and cultural value. The results also highlight difficulties in balancing the conservation of UGS with urban development pressures. Due to its rapid development, the land use of Islamabad has changed. This is putting existing green spaces' ecological potential and their ecosystem services at risk. Many researchers like (Gill et al., 2007) and Andersson et al., (2014) gear up against the seeming contradiction between development and ecology in cities. The words in the phrase above refer to terms that emphasizes the need for conserving urban green spaces as part of urban planning.

The economic valuation of urban green spaces also the importance of social and health benefit. Getting to green places help people mentally, lessen stress, and help with physical activity, all of which make cities better places to live in (Hartig et al., 2014; Maas et al., 2009). The way people do the valuation in the study shows that health benefits have economic value because when people are healthier, the public health costs go down and their productivity goes up. UGS in Islamabad provide recreational spaces and venues for social interaction which are essential for promoting community cohesion and social well-being. Still, the study finds that access to UGS and UGS quality differ between neighborhoods, suggesting doubts about environmental justice. If you live in an area with limited access to green space, you may not enjoy the health benefits of UGS. According to (Rigolon, 2016) and (Wolch et al., 2014), for UGS to maximize their social impact, their distribution needs to be equitable. To reduce the differences, we need urban planners to focus on extending access to underprivileged areas, so everyone can reap the social and health benefits from UGS.

These findings offer important insights for the policymakers of rapidly urbanizing cities such as Islamabad. Putting a price on UGS helps policymakers acquire the information to push for the conservation and expansion of green spaces and that green infrastructure component is an important one of urban sustainability (Tzoulas et al., 2007). The valuation data could help policymakers justify funding for UGS maintenance and expansion so that they remain accessible and functional for future generations. As Gómez-Baggethun et al., (2013) argue, integration of ecosystem services into economic analysis may shift policy in more sustainable directions; this illustrates the type of assessment ideally offered by our paradigm.

Different financing options are necessary for the long-lasting sustainability of Urban Green Spaces (UGS). The study emphasizes that while the economic valuation of UGS increases their importance, funding consistency remains a challenge in rapidly urbanising areas. Cities like Islamabad may use public-private partnerships, green bonds, and community-funded initiatives to ensure the cost-effective sustainability of UGS. In their academic work, Jim et al., (2006); Donovan et al., (2010) are found to suggest that public-private partnerships offer sustainable funding and encourage community participation in UGS maintenance. Also, UGS can access environmental grants and international funding when integrated into wider urban resilience and adaptation to climate change plans, as they help with climate regulation and biodiversity. The strategy relates to Alavipanah et al., (2017), and Schetke et al., (2016) who recommend integrating UGS into climate action plans. If cities see green spaces as infrastructure to aid urban resilience, it may provide them with an additional funding stream, as well as potential elevation of political priority of UGS. This will help with their protection against competing urban developments.

Though the BTM used in this study offers practical utility for valuing UGS, its application involves limitations regarding this valuation method. BTM depends on value estimates from studies carried out in different contexts, which may not fully represent local ecological, social or economic conditions. Changes in the kinds of species, climate and level of urbanization may alter the ecosystem services provided by UGS and therefore their monetary value. To resolve this issue, more studies that use primary valuation studies, tailored to the unique environmental and social characteristics of Islamabad, are needed in order to assist urban planners. UGS valuation still does not capture the non-monetary values like cultural and historical significance, which impact the full understanding of their advantages. Gómez-Baggethun et al., (2013) note that economic metrics may ignore community values associated with green spaces, which is a limitation of this approach. By incorporating qualitative assessments into valuation frameworks, the comprehensive valuation of UGS could be enhanced, assisting policymakers in affirming the importance of UGS.

Chapter-5

PERCEPTION OF UGS UTILITY

5.1. Introduction

Urban Green Spaces (UGS) are increasingly gaining prominence in today's environmental research due to their multifunctional benefits in terms of ecology, society, and economy as considered by Haase et al., (2014). As cities expand, these areas provide natural solutions, offering ecosystem services such as climate regulation, air purification, flood management, and recreational spaces, which all enhance quality of life (Kabisch, 2015). Public perception of UGS and their perceived utility in Islamabad. This study gives insight into drivers of satisfaction, perception of safety and access to UGS by assessing perception on its ecological, social and economic aspect.

UGS supports biodiversity and contributes to the health and social well-being of communities. Natural areas in cities provide numerous benefits to human health. They promote physical activity, mental health, and community cohesion. But how effective UGSs are depends on public engagement and satisfaction. This is because urban residents' interactions and perceived value largely affect UGS usage. The chapter aims to provide an in-depth analysis of public perception, illustrating the relationship between UGS features and user expectations. This is essential for urban planners and policymakers aiming for sustainable urban development.

Sustainability transitions recognize the transformative impact of how the public perceives urban areas, especially in connection with Urban Green Spaces (UGS). How communities perceive green infrastructure impacts how they relate to it and advocate for it. Communities may use green infrastructure to respond to urban challenges like climate change and social equity (Markard et al., 2020). Looking at UGS through a sustainable lens emerges as a niche and provides good spaces for innovation for transformative changes towards resilient and inclusive urban systems. This chapter will look to evaluate public perceptions in the city of Islamabad to understand how UGS contributes to ecological, social and economic transitions. The chapter underlines the position of UGS as a catalyzer of wider urban sustainability goals (Frantzeskaki et al., 2017).

Urban green spaces are playing a key role in enhancing sustainability and resilience in urban areas through the provision of multi-functional services. Research has shown that UGS provide several ecosystem services such as conserving biodiversity, mitigating climate, purifying air, and regulating flooding (Andersson et al., 2014; Tzoulas et al., 2007). For example, the vegetation in

UGS helps in reducing the heat and purifies the air, both by taking up carbon and filtering pollutants. This is useful for cities suffering from heat islands and air pollution (Demuzere et al., 2014). Also, UGS provides flood-control by providing a sink for rainwater. This happens because rainwater gets absorbed by vegetation canopies which filter and retain water. Hence, UGS prevent floodings and thus protects urban areas that flood during rains.

The ecological functions of UGS also contribute to urban biodiversity. Green spaces promote habitats for various species and provide refuge in the city, thus enhancing the biodiversity of the city (Thomas Elmqvist et al., 2013). Though, the effective delivery of these benefits by UGS depends on good planning and management. The varieties of plant life and the way that green spaces are distributed have an effect on how well these services are provided (Haaland et al., 2015). So, understanding how the public views the ecological benefits can help in identifying and filling the gaps in case there are any, in UGS designs.

UGS does not only function ecologically, but also has a serious social function. That's right! Parks offer areas where people can relax or play, and they also offer space for social interaction. In doing so, they help foster community well-being(Peters et al., 2010). Studies have shown that access to green space enhances mental wellbeing, reduces stress, and increases physical activity among urban dwellers, thereby improving their quality of life (Hartig et al., 2014; S. L. Huang et al., 2011). Besides, UGS gives an area where people from different backgrounds can meet and rejuvenate social ties and reduce social isolation(Maas et al., 2009). Perceptions of UGS utility are closely tied to these social functions, as satisfaction often correlates with the extent to which green spaces meet recreational and social needs (Zaman-ul-Haq et al., 2022). Still, access to and equitable distribution of UGS poses challenges. Lower-income neighborhoods often have limited access to quality green spaces (Rigolon, 2016). This difference shows how important it is to make sure everyone gets to benefit from the social benefits urban green spaces offer.

Besides having an ecological and social function, UGS provide economic value that can be measured. Research has shown that green spaces raise property values, attract tourists and reduce medical cost through a healthier lifestyle (Chiesura, 2004; Donovan et al., 2010). Property values are higher in areas with aesthetically pleasing and accessible green spaces. People want to live or invest there. Moreover, UGS has the potential to attract visitors who can support local businesses as well as the urban economy (Crompton, 2001).

Nonetheless, people have different opinions about the economic value of UGS. For many residents, the direct economic impact may not be visible, unlike the ecological or social benefits. Understanding this perception may help raise awareness of the economic value of UGS (Jim et al., 2006). Knowing how much UGS (Urban Green Space) contribute in economic terms can further add to the budget increase and maintenance of UGS for their sustainability.

Safety is an important consideration in the usability and accessibility of Urban Green Spaces. Studies have long shown that how safe people feel about a green space affects how often and in what way they use it (Kabisch & van den Bosch, 2017). Unsafe UGS are underused, especially by vulnerable groups like women and the elderly. UGSs that have poor lighting, bad maintenance, and isolation give unsafe feeling(Jansson et al., 2013). To ensure that all members of the public have a role in UGS design, design has to incorporate safety features such as proper lighting and regular upkeep, and clear visibility.

Moreover, accessibility issues such as distance from residential areas, lack of facilities, and overcrowded sites can reduce the utility of UGS. Studies have shown that how close the UGS is and how easy it is to access are major determinants of use (Schetke et al., 2016). When physical or social barriers restrict access, residents are less likely to reap the health and social benefits that UGS provides. Planners must address the equitable distribution and strategic location of urban green space (UGS) in order for all urbanites to be able to enjoy these space safely and conveniently (Rigolon, 2016).

How the public view things is vital to UGS planning and management. Knowing what people living in the area appreciate and value can help improve the design, access to and maintenance of UGS (Shackleton et al., 2018). The exploration of public perception in Islamabad in this chapter will provide insights into local community spaces, their preferences, and concerns and will add knowledge to urban environmental planning. When urban planners focus on people's experiences and needs, they can ensure UGS fulfils its intended ecological and social and economic functions. While Islamabad is urbanizing, the incorporation of community perceptions into the development of UGS enhances satisfaction levels and leads to a more sustainable and inclusive urbanization effort. This way dovetails with global urban sustainability strategies emphasizing the importance of nature-based solutions (NBS) and green infrastructure for resilient, livable cities (Kabisch, 2015). So, the aim of the study is to advocate for the provision of UGS facilities that safeguard the welfare of city inhabitants through capturing the opinions of residents.

5.2. Methodology

The primary objective of this chapter was to evaluate the multifunctionality (ecological, social, and economic impacts) of Urban Green Spaces (UGS) in Islamabad, focusing on how these factors influence public perceptions of UGS quality, satisfaction, and safety (barriers and risk associate with personal safety). This study employed a structured, quantitative approach (Ahmad et al., 2019), rooted in established urban environmental sustainability and planning methodologies, to ensure a comprehensive assessment (Herath et al., 2024; Jim et al., 2013; Sa et al., 2024). A questionnaire was meticulously designed (Annexure-3), covering key ecological functions (e.g., climate regulation, biodiversity conservation, flood prevention), social dimensions (e.g., recreation, mental and physical health, community identity), and economic impacts (e.g., property value enhancement, tourism attraction, and healthcare cost savings) (Balram et al., 2005). This approach is aligned with the work of Fornell et al., (1981), who emphasize the importance of designing surveys that encapsulate both objective and subjective dimensions for complex environmental assessments.

The target population comprised residents of Islamabad from various demographic backgrounds. The survey conducted online and in-person, garnered responses from 365 participants, representing diverse age groups, education levels, and occupational sectors (Table 2). This sample size was deemed sufficient based on statistical sampling guidelines for factor analysis and regression modeling (Bachmann et al., 2006; Sparkman et al., 1979), ensuring that the findings are generalizable to the broader population. The data collection was conducted using a structured questionnaire, administered both online and through face-to-face interactions (Annexure-3). The questions were designed to capture both the quantitative performance of the multifunctionality of UGS (e.g., ecological services, social and economic) and subjective user experiences (e.g., satisfaction, quality, and, safety perception). This approach was vital to balance objective environmental measures with human-centered perceptions, in line with recent trends in environmental research that highlight the importance of integrating user experiences into UGS evaluations (Atiqul Haq et al., 2021; Bokhari et al., 2018; Fontán-Vela et al., 2021). The survey also included demographic variables such as age, gender, and occupation to allow for segmentation analysis in subsequent statistical tests.

The analysis was performed in multiple stages, beginning with descriptive statistics to provide an overview of the sample's characteristics. Following this, correlation analysis was conducted to examine relationships between ecological, social, and economic variables and the main dependent variables: UGS quality, satisfaction, and safety. This stage revealed significant associations that informed the subsequent factor analysis (Atiqul Haq et al., 2021; Bokhari et al., 2018; Fontán-Vela et al., 2021). Exploratory Factor Analysis (EFA) was then employed to uncover latent variables representing broader constructs underlying the individual survey responses. Five primary factors were extracted: ecological benefits, social interaction/recreation, economic trade-offs, barriers to UGS access, and safety/restrictions. These factors, retained based on eigenvalue criteria and scree plot analysis (Figure 5.1), were used as independent variables in the multiple regression models.

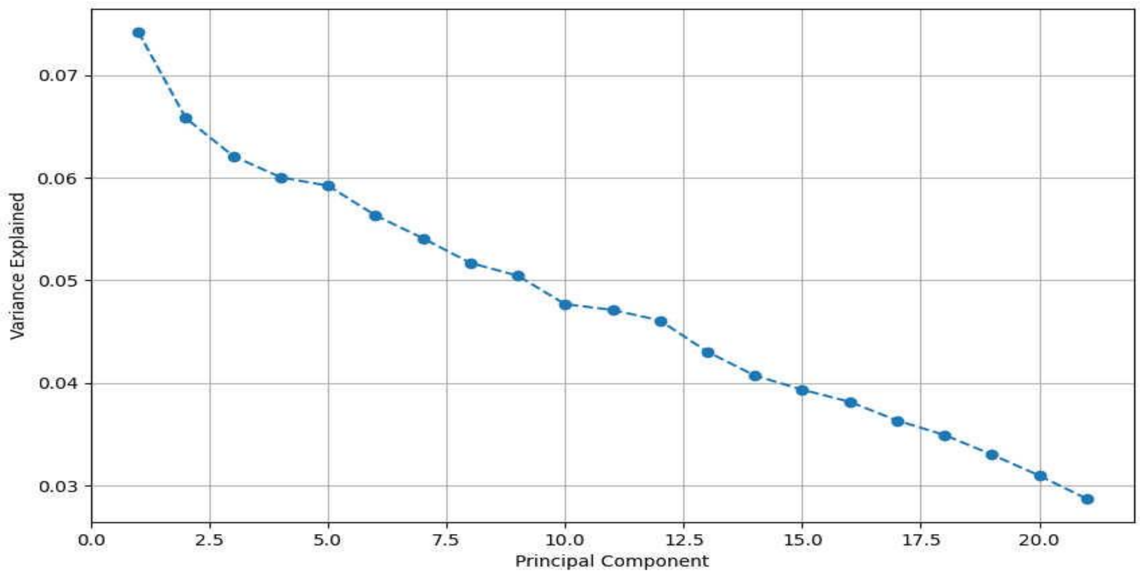

Figure 5. 1. Scree plot depicting the variance explained by principal components.

To ensure the reliability and validity of the extracted factors, Cronbach's alpha and Composite Reliability (CR) tests were conducted (Peterson et al., 2013) (Table 5.1). Cronbach's alpha values for all factors exceeded 0.70, indicating high internal consistency, while CR values confirmed the robustness of the measurement model. Average Variance Extracted (AVE) scores were also calculated to assess convergent validity, with all factors achieving an AVE above the threshold of 0.50, confirming that the factors adequately captured the underlying constructs (Yang et al., 2020). These tests ensured that the factors used in the regression models were both reliable and valid for predicting UGS outcomes. The results from these reliability and validity tests provided a solid foundation for further analysis, indicating that the constructs were both consistent and valid for modeling the relationships between the factors and UGS outcomes.

Table 5. 1. Reliability and validity of latent factors

Factor	Cronbach's Alpha	Composite Reliability (CR)	rho_A	Average Variance Extracted (AVE)
Factor 1	0.82	0.85	0.83	0.64
Factor 2	0.79	0.81	0.80	0.59
Factor 3	0.76	0.78	0.77	0.57
Factor 4	0.75	0.77	0.76	0.55
Factor 5	0.81	0.84	0.82	0.61

Multiple regression models were then used to assess how the latent factors influenced UGS quality, satisfaction, and safety perceptions. Each model identified significant predictors, revealing that ecological benefits and social interaction/recreation were the strongest predictors of UGS quality and satisfaction. These findings are consistent with existing research that highlights the importance of biodiversity and social cohesion in enhancing the perceived value of green spaces (Atiqul Haq et al., 2021; Bokhari et al., 2018; Fontán-Vela et al., 2021). On the other hand, safety perceptions were more strongly linked to barriers and safety concerns, such as perceived restrictions and risks associated with personal safety. The models provided actionable insights for urban planners by indicating that improving accessibility and addressing safety concerns could significantly enhance public satisfaction with UGS. The inclusion of ecological and social factors in the model also underscores the need for integrated UGS planning those balances environmental and community benefits.

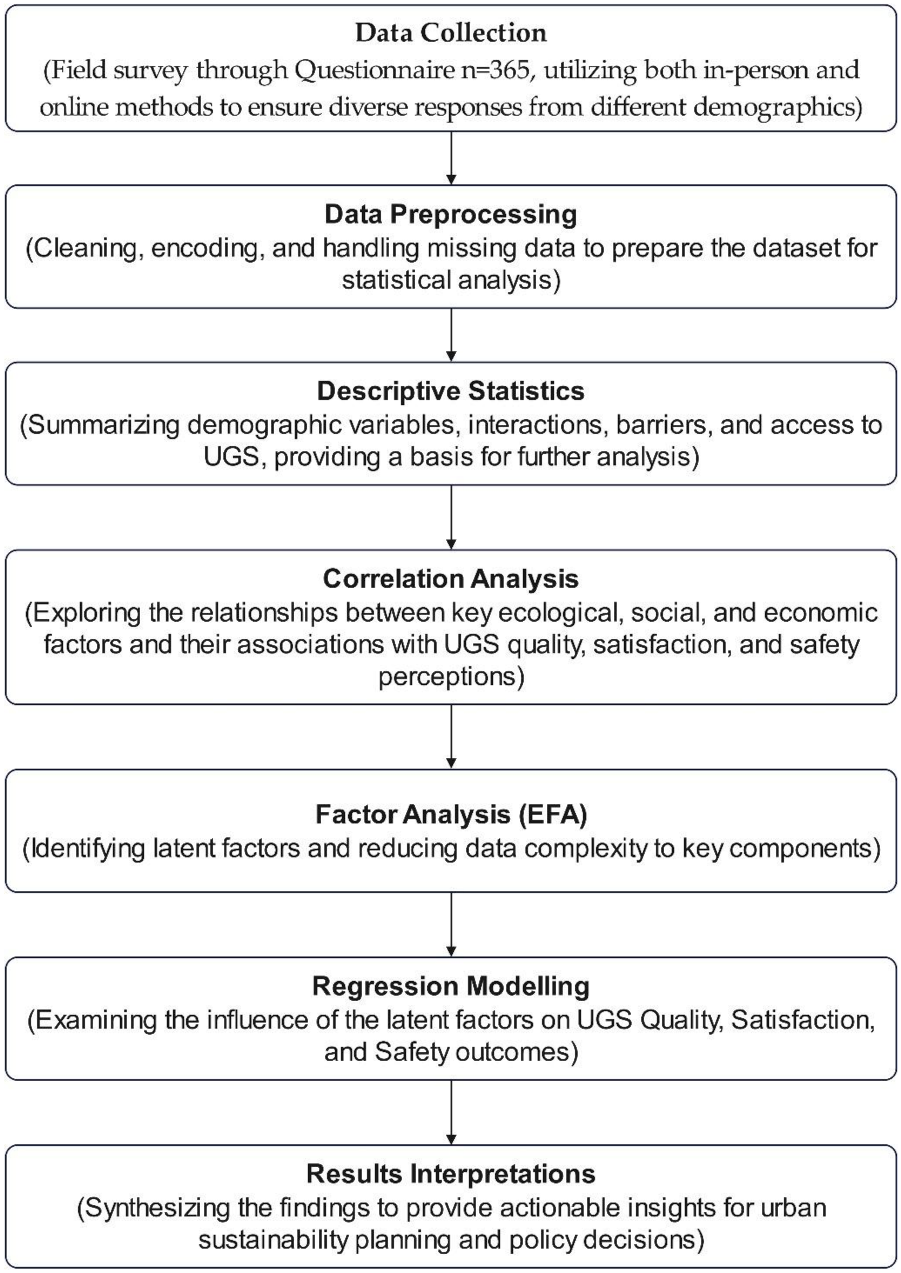

Figure 5. 2. Methodological flow for multifunctional UGS assessment based on respondents' perceptions.

5.3. Results

5.3.1. Demographic insight

As a result of the demographic profile of respondents, key characteristics such as gender, age, education level, and occupation were revealed (Table 5.2). To understand the diversity of UGS perceptions and usage patterns, this breakdown was crucial. There were 60.3% male respondents and 39.7% female respondents, which ensured representation from both genders, which enabled a more nuanced understanding of UGS perceptions. It was found that 73.42% of respondents were between 18 and 30 years old, followed by 21.9% aged 31 to 45. Over 60s and 46–60s were less represented. UGS usage and satisfaction were more likely to be influenced by the prevalence of younger participants, who showed greater engagement with UGS. Among those surveyed, 70.4% had attained higher education, 16.4% had intermediate education, and a smaller percentage had secondary education (9.3%), primary education (3.3%), and no formal education (.5%). Among participants, high levels of education may have impacted their understandings and expectations about UGS. There was a diversity of occupations in the sample, with 48.2% of respondents being students, followed by self-employed individuals (11.0%) and government/private employees (7.7%). Healthcare professionals (3.0%), engineers (6.6%), educators (7.4%), and labor/manual workers (5.2%) made the study more diverse by incorporating perspectives from various economic sectors. In line with the study's objective of capturing a comprehensive view of UGS functionality, challenges, and benefits, the demographic diversity of participants provided a solid foundation for analyzing how different groups perceived and interacted with UGS.

Table 5. 2. Demographic profile of the respondents.

Demographic Category	Subcategory	Percentage (%)	Responses
Gender	Male	60.3%	220
	Female	39.7%	145
Age Group	18–30	73.42%	268
	31–45	22.19%	81
	46–60	3.01%	11
	Over 60	1.36%	5
Education Level	No formal education	.5%	2
	Primary	3.3%	12
	Secondary	9.3%	34
	Intermediate	16.4%	60
	Higher Education (14 Years and above)	70.4%	257
Occupation	Student	48.2%	176
	Healthcare Professionals	3.0%	11
	Engineering & IT	6.6%	24
	Education	7.4%	27
	Business & Self-employed	11.0%	40
	Government/Private Employees	7.7%	28
	Labor & Manual Worker	5.2%	19
	Housewives	6.6%	24
	Other Occupations	4.4%	16

5.3.2. Interactions, barriers, and access to UGS

As shown in Figure 2, respondents' interactions with UGS vary significantly in both frequency and duration. The most frequent visitors (daily users) spent less than 30 minutes per visit, while a significant portion of the population visited once or several times a week, typically staying for 30 minutes to an hour. Those who visited less frequently, such as once a month or a few times a month, exhibited a similar pattern of short stays, emphasizing the time constraints faced by users during their visits. The highest concentration of visits occurs with respondents who visit UGS a few times a month, with 71 respondents spending less than 30 minutes per visit.

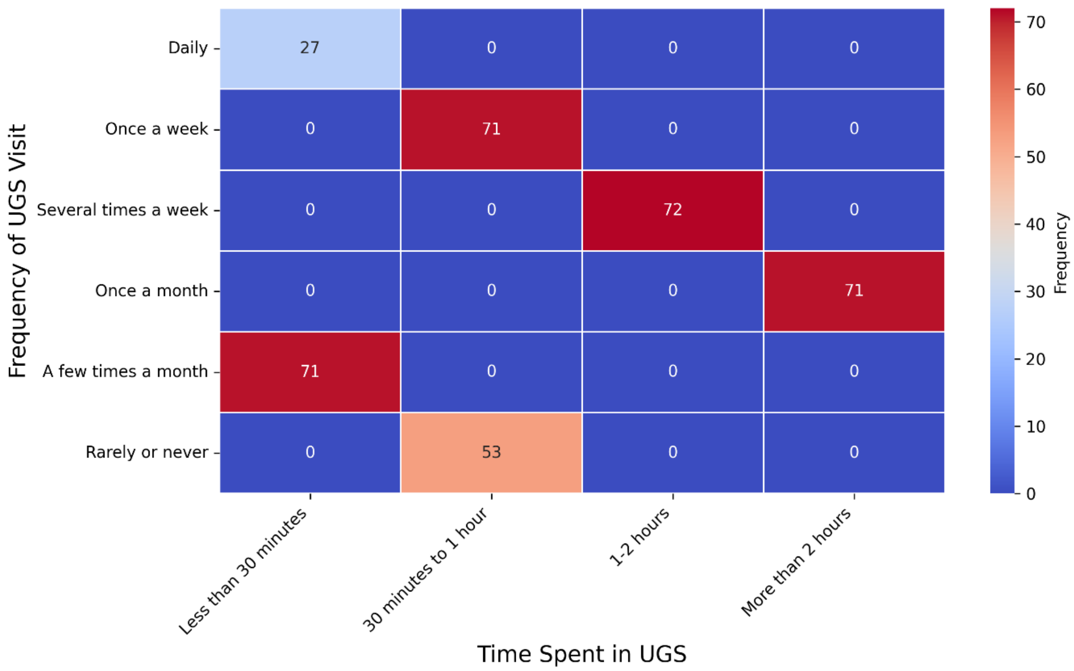

Figure 5. 3. Frequency and duration of respondent's interactions with UGS.

Figure 5.4 highlights the community's perception of UGS sufficiency within their neighborhoods. While the majority (around 160 respondents) believed there was sufficient green space, a substantial proportion expressed dissatisfaction (about 140 respondents). A smaller, yet notable group (approximately 80 respondents) remained unsure, indicating uncertainty or a lack of awareness regarding UGS availability. This indicates a potential gap in communication or accessibility for a portion of the population.

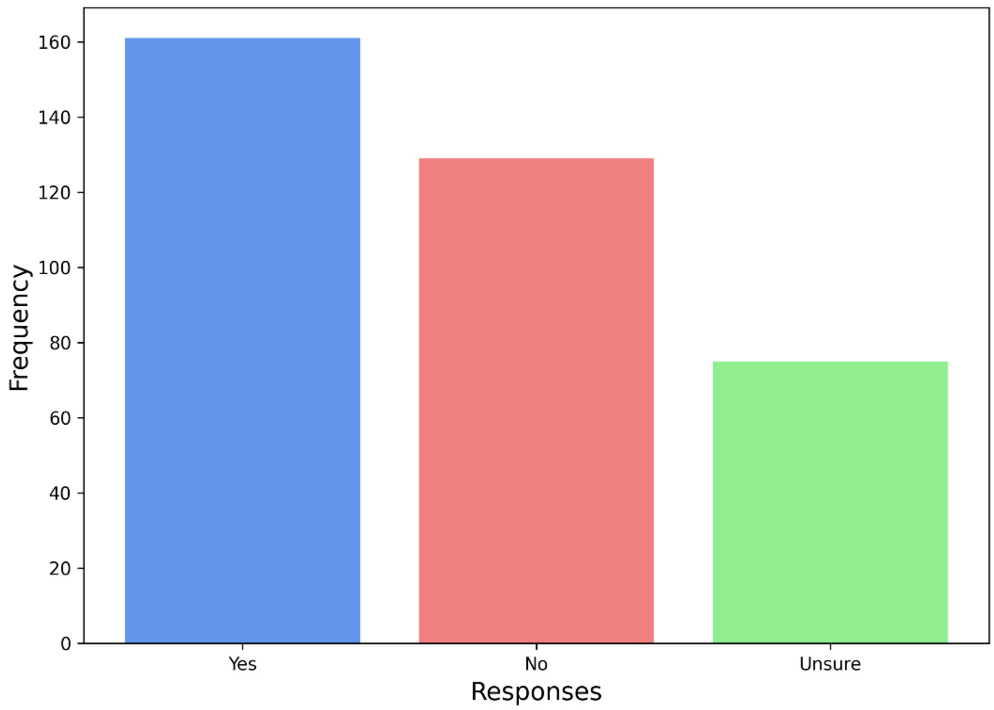

Figure 5. 4. Perceptions of UGS sufficiency among respondents in their neighborhoods.

In Figure 5.5, the barriers to accessing and using UGS are illustrated, with a range of challenges identified by the respondents. The most prominent barrier was environmental concerns, followed closely by poor maintenance and overcrowding during peak times. Cultural or social barriers and insufficient shade or shelter also emerged as significant factors limiting UGS usage. Other notable barriers included lack of child-friendly facilities, inadequate parking, and poorly designed equipment. This comprehensive analysis of barriers reveals critical areas for improvement, particularly in infrastructure and management practices, to enhance UGS accessibility and overall user experience.

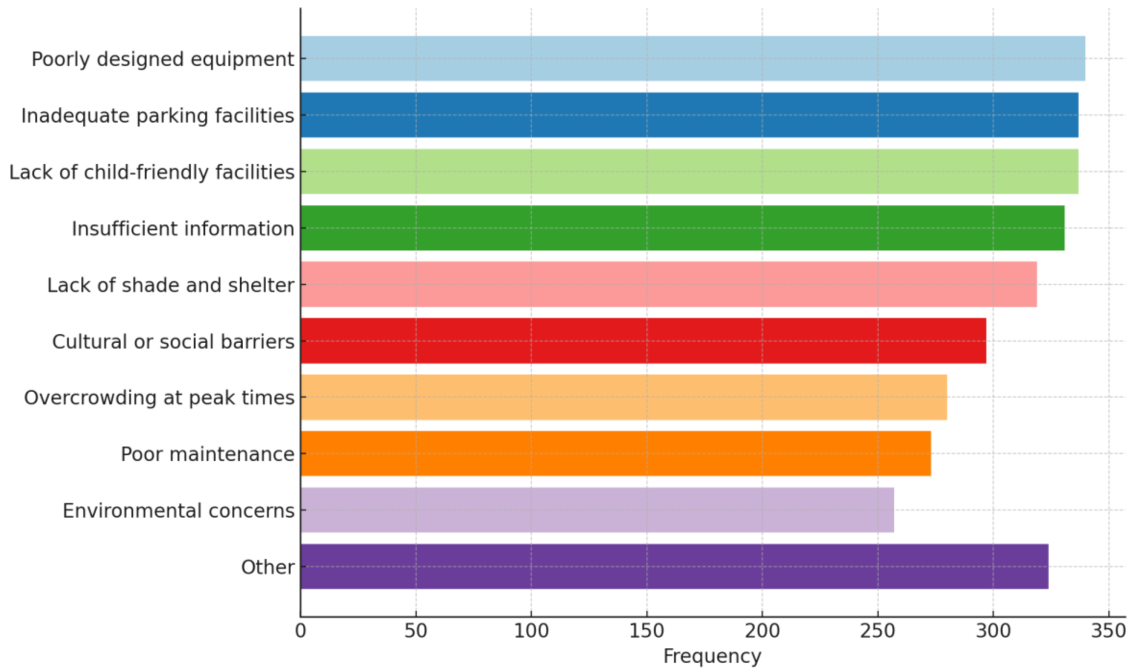

Figure 5. 5. The barriers to accessing and using urban green spaces.

5.3.3. Modelling UGS for urban sustainability perspective

The results of the factor analysis identified five distinct factors that encapsulate the diverse functionalities and challenges of urban green spaces (UGS) (Table 5.3 and 5.4). A threshold value of 0.3 was applied to the factor loadings, ensuring that only components with significant contributions were retained for factor labeling. This approach allowed for the accurate interpretation of each factor based on its prominent components.

The first factor, *"Ecological Benefits"*, was primarily defined by components such as healthcare cost savings (0.384), recreational opportunities (0.324), and improved business marketability (0.322) (Table 5.3). These components highlight the ecological and socio-economic services UGS provides, such as reducing healthcare costs, offering recreational spaces, and enhancing the attractiveness of local businesses. This factor had a significant positive influence on UGS quality and satisfaction *($\beta = 0.349$, $p < 0.01$)* (Table 5.4), indicating that these ecological benefits play a vital role in shaping positive user perceptions of UGS (Figure 5.6). However, its relationship with safety is insignificant *($p = 0.078$)*.

The second factor, *"Barriers/Challenges"*, comprised components like air quality improvement (0.369), biodiversity support (0.343), and flood prevention (-0.382) (Table 5.3). This factor reflects the ecological services UGS provides alongside the challenges it faces in maintaining them. While these environmental services positively impacted UGS quality and satisfaction *($\beta = 0.143$, $p = 0.003$)*, they were associated with concerns about safety, as shown by the negative impact on UGS safety *($\beta = -0.306$, $p < 0.01$)* (Table 5.4) . This suggests that barriers in managing these services may lead to reduced perceptions of safety (Figure 5.6).

"Social Interaction/Recreation", the third factor, was marked by components such as enhanced community identity (*0.315*) and increased property values (0.334) (Table 5.3). These components emphasize the social and recreational functions of UGS, reflecting how green spaces contribute to social cohesion and economic upliftment in communities. This factor positively influenced all three outcomes—UGS quality, satisfaction ($\beta = 0.703$, $p < 0.01$), and a moderate positive effect on safety *($\beta = 0.147$, $p = 0.009$)* (Table 5.4)—showing that social and recreational opportunities are central to how the public views UGS (Figure 5.6).

The fourth factor, *"Economic Trade-offs"*, incorporated components such as stormwater cost savings (0.489) and urban heat reduction (0.349) (Table 5.3). These elements represent the infrastructure cost-saving mechanisms provided by UGS. While this factor positively influenced UGS quality and satisfaction *($\beta = 0.199$, $p < 0.01$)*, but significantly reduces perceptions of safety and it had a negative effect on UGS safety *($\beta = -0.539$, $p < 0.01$)* (Table 5.4), suggesting a trade-off between the cost-saving services offered by UGS and the public's perception of safety in these spaces (Figure 5.6).

Finally, the fifth factor, "Safety/Restrictions", included components such as social exclusion reduction (0.523) and flood prevention (0.310) (Table 5.3). This factor positively influenced UGS safety *($\beta = 0.181$, $p = 0.002$)* but negatively impacted UGS quality and satisfaction *($\beta = -0.113$, $p = 0.027$)*(Table 5.4). It suggests that while safety-related services and restrictions improve perceptions of safety, they may also introduce limitations that reduce overall satisfaction and perceived quality of UGS (Figure 5.6).

Table 5. 3. Components and factor leading

Components	Factor1	Factor2	Factor3	Factor4	Factor5
UGS_Reduce_Urban_Heat	0.177440764	-0.23338	0.263264155	0.349397085	0.036607301
UGS_Flood_Prevention	-0.381763558	-0.01215	0.303249443	-0.013945634	0.309785141
UGS_Air_Quality_Improvement	-0.202552081	0.368841	0.253981698	-0.238288417	-0.190112122
UGS_Support_Biodiversity	-0.210571078	0.342703	-0.182448155	0.203707576	-0.260628909
UGS_Water_Management	-0.252717802	0.388889	-0.099621839	0.089664053	0.251843199
UGS_Soil_Health	-0.045234541	0.067414	0.236817928	0.265356187	0.198770713
UGS_Facilitate_Social_Interaction	0.257241949	0.22702	-0.006920155	0.113545355	0.121519385
UGS_Recreational_Opportunities	0.324489745	0.023911	0.231258345	0.047378623	-0.2431145
UGS_Mental_Health_Benefits	0.140790712	0.107773	-0.280257993	-0.103619049	0.018797504
UGS_Physical_Health_Benefits	-0.058634158	-0.21129	-0.092794909	-0.013634199	-0.231768007
UGS_Enhance_Community_Identity	-0.137840253	-0.19371	0.314805801	-0.255108093	0.046331212
UGS_Reduce_Social_Exclusion	0.067644506	-0.14171	-0.097703262	-0.101457717	0.523174048
UGS_Increase_Property_Values	-0.026623815	0.173553	0.333802141	-0.120933002	-0.190325199
UGS_Attract_Tourists	0.061724111	-0.27418	-0.119766992	-0.287342999	-0.102494107
UGS_Stormwater_Cost_Savings	-0.085949478	-0.13227	-0.076119898	0.489283148	0.087445208
UGS_Healthcare_Cost_Savings	0.384468913	-0.00828	0.115834677	-0.006047466	0.238295436
UGS_Local_Employment	0.211438241	0.385915	0.034451005	-0.306263	0.214882179
UGS_Improve_Business_Marketability	0.322018793	0.030555	-0.124944778	-0.082712462	-0.23649313
UGS_Quality_Satisfaction	0.242153153	0.098913	0.488046817	0.137979879	-0.078136821
UGS_Safety_Perception	-0.063220528	-0.21462	0.103260257	-0.37821865	0.126740076
UGS_Cultural_Relevance	0.28710468	0.203908	-0.122342795	-0.014494251	0.237607506

Table 5. 4. Regression results of UGS quality, satisfaction, and safety perception against identified factors

	UGS Quality		UGS Satisfaction		UGS Safety	
Variable	**Coef (β)**	**p-value**	**Coef(β)**	**p-value**	**Coef (β)**	**p-value**
Constant	2.9781***	0	2.9781***	0	3.0658***	0
Factor1	0.3489**	0	0.3489**	0	-0.09	0.078
Factor2	0.1425**	0.003	0.1425**	0.003	-0.3057***	0
Factor3	0.7032***	0	0.7032***	0	0.1471**	0.009
Factor4	0.1988***	0	0.1988***	0	-0.5387***	0
Factor5	-0.1126**	0.027	-0.1126**	0.027	0.1805***	0.002
R-squared	0.447	-	0.447	-	0.284	-
Adj. R-squared	0.439	-	0.439	-	0.274	-
F-statistic	58.07	-	58.07	-	28.5	-
Prob (F-statistic)	3.49E-44	-	3.49E-44	-	2.49E-24	-

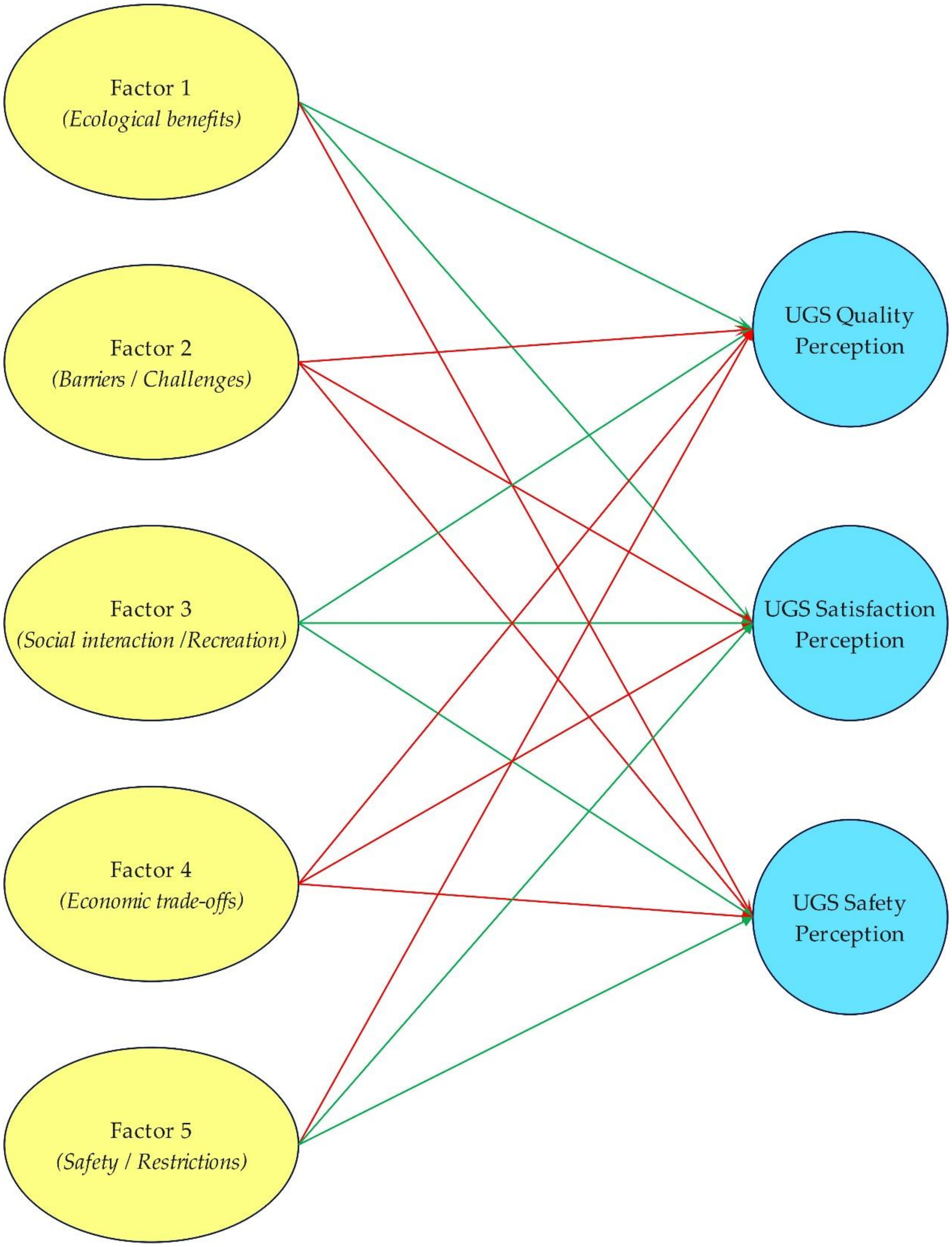

Figure 5. 6. Impact of UGS Factors on Quality, Satisfaction, and Safety Perceptions.

5.4. Discussion

Public perception is a vital element of making urban green spaces usable; it affects the usage of urban green spaces, satisfaction and support for maintenance and funding. As per the results, the people residing in Islamabad acknowledged UGS for their various advantages primarily regarded as ecological, social and economic value. This is consistent with earlier studies on sustainability and green spaces (Hartig et al., 2014; Kabisch, 2015) . The findings suggest that residents deem UGS important for bettering the environment and living conditions. This shows the local populations have a good understanding of the ecological service provided by UGS, for instance, air purification, climate regulation, and biodiversity conservation. Understanding of these core ideas is essential to getting the community involved in UGS planning and management.

Although UGS are generally perceived positively, accessibility, manageability, and safety were all recurring issues brought up by the public. Concerns about the limited access to urban green spaces (UGS) among disadvantaged groups highlight the need for more equitable urban planning practices that could boost access and maintenance of UGS for more users (Rigolon, 2016). Managing UGSs should try to do all these things to improve the satisfaction of the community so that all urban residents can benefit from the green regardless of their economic position.

For transformative urban change, public perceptions must align with sustainability transition principles. Favorable views of UGS can speed up their inclusion in policy frameworks, leading to their use as Nature-Based Solutions (NBS) for systemic urban problems. However, the low satisfaction with safety, accessibility, and maintenance shows gaps that present barriers to sustainability transitions. To fill these gaps, urban planning must be done in a way that includes everyone and engages the public and distributes UGS equitably. Islamabad can align community aspirations with sustainability vision. Through this alignment, multifunctional vision of UGS can be used to ensure long term ecological resilience and social equity.

Islamabad's residents are aware of the ecological benefits of UGS and view it as necessary for urban environmental health. Similar to international studies, the respondents affirmed the importance of UGS for pollution reduction, regulating heat in the city and ensuring various species biodiversity (Andersson et al., 2014; Haase, Frantzeskaki, et al., 2014). Studies show that trees and vegetation are most efficient in absorbing pollutants, and shielding cities from high temperatures, especially during the summer months (Nowak et al., 2014). Also, people think UGS is a refuge for biodiversity so diverse plants should be used in UGS design to attract and sustain the local fauna (Tzoulas et al., 2007).

However, there are constraints with Islamabad's UGS that can limit their ecological effectiveness. The problem of overcrowding and poor maintenance was another concern raised, which was also noted in other studies. They reveal that this will reduce the functioning capacities of UGS and lower their ecosystem services. In-depth approach for UGS managing will combine ecological design principles and community engagement to develop a sense of shared responsibility for maintenance.

This study corroborates the evidence found in the existing literature with respect to the social and health benefits that UGS offers. For example, UGS helps in improving mental health, reducing stress and increasing physical activity (Hartig et al., 2014; Maas et al., 2009). UGS or urban green spaces are places where people walk or exercise, relax and a space to interact with each other – all of which foster a more cohesive, and healthy community. This is also the case in urban livable spaces where citizens have limited access to green spaces. Urban green spaces are essential for social interaction and beneficial to social well-being(Peters et al., 2010). But, the research also points to safety issues regarding lights, maintenance, and other visibility issues. To tackle these issues, planners should add design features that improve safety, like lighting, visible entrances and regular patrols, so that UGS are accessible to every community member without compromising safety.

On top of ecological and social dimensions, UGS creates an economic value thanks to increased property values, tourism, and local businesses. Evidence suggests that residents will pay higher rates for real estate next to green space, which helps raise property values and ultimately increases the value of the urban economy(Chiesura, 2004; Crompton, 2001). Moreover, green places can save money on hospitals because healthier people don't need doctors as much. Urban planners and policy-makers who care about sustainable development are interested in this (Donovan et al., 2010).

But residents often perceive a more immediate value of urban green spaces (UGS) in terms of recreation and aesthetics than in economics. Knowledge of what the public thinks about these economic benefits can help inform awareness-raising campaigns that highlight the wider community benefits of UGS and encourage public investment in their care. Moreover, various funding mechanisms could likewise be heightened through Public-Private partnerships and community funding among others, to help deal with the maintenance issue (Jim et al., 2006).

Barriers were the ones identified as the biggest concern among respondents that affect accessibility and usage of UGS, such as distance from house, overcrowded, and lack of amenities. These barriers are consistent with earlier research indications that proximity and quality of amenities are the primary determinants of UGS usage(Lundy et al., 2011). It is vital to deal with these challenges so that UGS can function as desired and be accessible to all people regardless of the social matrix. Besides, the importance of fair UGS distribution in different neighborhoods, so people may not have disparity in access. People living in lower income areas may lack access to quality greenspaces (Rigolon, 2016). This can produce social inequalities, as people in these areas may not enjoy the same recreational and environmental benefits of people who live in wealthier areas. Policymakers should look at solutions for UGS planning that prioritizes underserved neighborhoods so that differences in access to green can reduced.

According to the results of this study, there are several policy implications for sustainable UGS development in Islamabad. The design of urban planning policies must ensure UGS contributes to maximum ecological, social and economic benefits and is reflection priority towards maintaining and improving UGS comprehensively in both low-and high-density neighbourhoods. This means reserving money, general maintenance, and developing structures for different uses without affecting the ecosystem (Gill et al., 2007).

Another advantage of including community input in UGS planning and management is that it can improve public satisfaction and gain ownership. When UGS (urban green spaces) become overcrowded, or maintenance is poor, would-be visitors are less likely to visit. Participatory planning and maintenance are ways that community involvement in UGS decision making could help. Making the public aware of the environmental and economic advantages of UGS can help gain community support. This is especially useful in areas where economic benefits are less visible to the people. Policymakers should involve UGS (urban green spaces) in policies related to sustainability, which will resolve urban issues like climate change, pollution, social issues, and more. Cities can create more resilient communities by positioning UGS as essential assets for urban resilience, thus ensuring their integration and safeguard as public goods.

Chapter-6

CONCLUSIONS

6.1. Overview of findings

This study examines Urban Green Spaces (UGS) in Islamabad, assessing their distribution, usefulness and value as per the ecosystem services they offer. The study highlights the importance of UGS as invaluable resources in cities for environmental, social and economic well-being. Using GIS and remote sensing technologies, the research mapped the UGS (Urban Green Spaces) of Islamabad and found significant spatial patterns. Also, the researchers found large disparity of accessibility and quality of UGS between different urban zones (Chapter 3 and 4). The UGS in Islamabad provides a good number of ecosystem services. These services include air purification, climate regulation, and recreation. According to Kabisch et al. (2015), global research has shown that UGS plays a crucial role in urban resilience. But the unequal distribution and less area of UGS in heavily populated sectors pose major challenges for urban sustainability. In the face of rising urbanization, it is critical that Islamabad's green areas are not just maintained but expanded to continue benefiting the ecosystem and society.

6.2. Key Contributions to Urban Green Space Knowledge

Combining GIS mapping with economic valuation helps city planners to take a data-driven approach for urban planning. One can visualize the present distribution of UGS as well as quantify their economic contributions. This would help policymakers to formulate policies to conserve and/or increase the UGS. A benefit transfer method valuation of ecosystem services is a powerful tool in estimating the economic value of UGS in Islamabad that can assist in justifying budget allocation towards UGS development in urban policies.

6.3. Implications for Urban Planning and Sustainability

The results show how UGS helps support Islamabad to advance sustainable urban planning. This research quantifies the economic, social and environmental benefits of UGS which serves as a catalyst to incorporate green spaces in urban infrastructure of fast-growing cities. Valuation study evidence shows that UGS add resilience and ecological services to urban living and serve as spaces for recreation and social interaction which also enhance public health (Introduction). In dealing with densely populated areas with inadequate access to green spaces, policymakers may use these findings to prioritize UGS in town planning. The geographic study of UGS distribution reveals major disparities in neighborhoods with poor accessibility to quality green spaces. The unequal distribution of UGS, as reported in various cities across the globe, points to the necessity for policy intervention to enhance equity in urban UGS provision. The UGS advantage should not be a privilege, but rather a birthright, of all urban residents. Islamabad's urban strategies must focus on inclusive planning to address the existing inequalities and foster cohesion. Using sustainability transitions theory in urban planning would help to provide a structured approach to the inequality in access to green space. According to Markard et al. (2012), achieving long-term ecological and social objectives necessitates systematic alterations in urban infrastructure and governance, thereby establishing a framework for sustainability transitions. The Urban Green Spaces (UGS) that enable the transition and increasingly become “niches” for innovative planning practices towards adaptive urban systems aligned to the global sustainability goals (Frantzeskaki et al. 2017). Islamabad can address inequity in green space distribution and build resilience to future challenges through the incorporation of UGS into wider socio–technical systems. Policymakers must adopt these principles to design inclusively, so that urban green spaces can fulfil their multifunctionality by ensuring equal benefits to all.

6.4. Challenges in UGS Implementation and Maintenance

The UGSs offer the potential to improve urban resilience. However, several barriers are limiting their effective implementation and maintenance in Islamabad. Problems such as lack of funding, poor maintenance and over-crowding were identified as affecting the quality of UGS. Parks, gardens and other green spaces in cities are facing numerous challenges in terms of pollution and invasion by aliens. When UGS get overcrowded that negatively impact natural features which lose vegetation and compact the soil to lessen services that UGS provide (Jim & Chen, 2006). To deal with these problems, we need extra attention and matching efforts from the government. In Islamabad, to keep UGS well maintained, a budget will be needed. However, it can be supplemented with some innovative solutions like PPP or community-based solutions. If urban planners involve the local community in the management of UGS, a sense of shared responsibility will arise, ensuring high-quality green spaces with longevity (Shackleton et al., 2015).

6.5. Recommendations for Future Research and Policy Development

The recommendations provided by this study suggest a way to make UGS more effective with respect to sustainability in urban areas like Islamabad. The first recommendation encourages policymakers to take a systematic approach when expanding UGS, particularly in neighborhoods with limited green space. This fair way of giving out UGS can lower unequal living standards in cities, helping people in areas that have poorer quality of life. Future UGS projects should also include ecological design principles that maximize multifunctionality i.e. biodiversity corridors and climate-resilient vegetation to improve ecosystem service provision across environmental conditions. In the future, we should investigate how UGS urge and support sustainability transitions and evaluate their adaptive urban strategies. Using sustainability transitions can help cities address their immediate issues with infrastructure that combines the best possible interventions with long-term solutions for social and ecological resilience (Köhler et al., 2019). By doing so, Islamabad could serve as a leading example of UGS integration in sustainability transition pathways, with implications for other rapidly urbanizing regions.

6.6. Limitations of the Study

This study offers important insights into the value and distribution of UGS in Islamabad, it is not without limitations. The study applied the Benefit Transfer Method (BTM) which is practical but may cause various estimation errors due to differences that the context varies. BTM uses valuation information from other regions, which may not adequately reflect local ecological, social or economic dynamics, which may impact the actual valuation effort (Richardson et al., 2015). Future research may improve accuracy by using primary valuation methods, e.g., contingent valuation or choice experiments, to collect Islamabad-specific data. There isn't enough GIS and remote sensing data available for UGS mapping, which is another constraint. Even though a lot of progress has been made, the quality and resolution of the spatial data available do not reflect many UGS attributes, especially in lower/less developed areas. Moreover, the assessment looked only at public UGS and not certain private or informal green spaces that are part of the greenery. Future studies can reveal way more about the green infrastructure of Islamabad that haven't been considered yet.

6.7. Contributions to Knowledge and Practical Implications

This study will add to the urban ecology and planning literature by demonstrating the advantages of spatial analysis and ecosystem valuation. The method utilized provides decision-makers in Islamabad and comparable cities with an effective approach for assessing the multifunctionality of UGS and justifying the investments in green space by economic evaluation. This study highlights the wide range of benefits provided by urban green spaces (UGS) by quantifying their ecosystem service and social and economic contributions.

The study calls for urban planning professionals to design UGS (urban green spaces) that incorporate both environmental and social objectives. The results show that the urban planners in Islamabad should focus on not just the number of UGS but also their spatial distribution and accessibility for community benefit. We can ensure that the benefits of UGS become available to all by supporting equitable access to UGS alongside their availability. This approach contributes towards a healthy and resilient urban population (Kabisch et al. 2015).

6.8. Conclusion and final thoughts

The research showed that UGS is essential for sustainable urban growth in Islamabad. Using GIS mapping and economic valuation is called a quantitative tool that enables policymakers to get information about the current distribution and accessibility and value of UGS. The above finding shows that UGS is important for environmental resilience, such as combating urban heat and improving air quality, as well as enhancing social wellbeing, through providing spaces for recreation, relaxation and social activities. The UGS offer remedies for the long-term health of the city indicating they should be essential component of urban infrastructure.

As we move forward, green space must be an essential ingredient in the development of Islamabad. Findings from the study support a balanced approach to the incorporation of greens in urban spaces in terms of quantity and fair access. UGS can provide natural solutions to enhance urban resilience and building sustainable, inclusive communities in response to continued population growth and environmental challenges.

Acknowledging UGS as part of sustainability transitions will help Islamabad incorporate green spaces in a vision for urban development that focuses on adaptive, inclusive, and resilient systems. This framework is in line with global initiatives aimed at encouraging sustainable urbanization. In this context, the Global South cities demonstrate environmental and social solutions through innovative urban planning (Frantzeskaki, 2019). As we go forward, and for a balanced and fair distribution of UGS, these will be critical in following and supporting the transitions, green infrastructure and others for present and future.

To summarize, this study lays the groundwork for future research and policies for enhancing urban green spaces development in urban areas. By understanding how important UGS are for the environment, society and economy, Islamabad will be able to take better steps towards becoming a more sustainable, resilient city. The city is committed to protecting and growing green infrastructure, which will improve the quality of life for local residents now and ensure that future generations experience enhanced green infrastructure.

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Annexture- 1. Indices calculation for Landsat 7 ETM+ and Landsat 8 OLI/TIRS in GEE to enhance the pixel of land cover for selection of training sample.

Index	Full form of index	Landsat 8 Calculation	Landsat 7 Calculation
NDBI	Normalized Difference Built-up Index	(Band 6 - Band 5) / (Band 6 + Band 5)	(Band 5 - Band 4) / (Band 5 + Band 4)
EBBI	Enhanced Built-up and Bareness Index	(Band 6 - Band 5) / (Band 6 + Band 10 / 10)	(Band 5 - Band 4) / (Band 5 + Band 6 / 10)
NDVI	Normalized Difference Vegetation Index	(Band 5 - Band 4) / (Band 5 + Band 4)	(Band 4 - Band 3) / (Band 4 + Band 3)
BAEI	Bare Soil Index	(Band 6 / Band 5) - (Band 3 / Band 4)	(Band 5 / Band 4) - (Band 2 / Band 3)
EDI	Enhanced Difference Index	(Band 6 - Band 4) / (Band 6 + Band 4)	(Band 5 - Band 3) / (Band 5 + Band 3)
EVI	Enhanced Vegetation Index	2.5 * (NIR - Red) / (NIR + 6 * Red - 7.5 * Blue + 1)	2.5 * (NIR - Red) / (NIR + 6 * Red - 7.5 * Blue + 1)
LVI	Land Surface Vegetation Index	(Band 6 / Band 5) - 1	(Band 5 / Band 4) - 1
SAVI	Soil Adjusted Vegetation Index	(1 + L) * (NIR - Red) / (NIR + Red + L), where L = 0.5	(1 + L) * (NIR - Red) / (NIR + Red + L), where L = 0.5
GNDVI	Green Normalized Difference Vegetation Index	(NIR - Green) / (NIR + Green)	(NIR - Green) / (NIR + Green)
NDWI	Normalized Difference Water Index	(Green - NIR) / (Green + NIR)	(Green - NIR) / (Green + NIR)
MNDWI	Modified Normalized Difference Water Index	(Green - SWIR1) / (Green + SWIR1)	(Green - SWIR1) / (Green + SWIR1)

Annexture- 2. Classified image accuracy and Kappa statistics.

Year	Classified Image	Overall Classification Accuracy	Overall Kappa Statistics
2000	Landsat 7 ETM+	82.33%	0.7449
2005	Landsat 7 ETM+	84.51%	0.7632
2010	Landsat 7 ETM+	88.47%	0.9235
2015	Landsat 8 OLI/TIRS	95.77%	0.9144
2020	Landsat 8 OLI/TIRS	95.81%	0.9443

Annexture- 3. Questionnaire - Residents' Perception of Urban Green Spaces in Islamabad

1. Demographics

1.1. Age: _______

1.2. Gender:

- Male
- Female
- Other (please specify):

1.3. Education Level:

- No formal education
- Primary (up to 8^{th} grade)
- Secondary Education (SSC - Secondary School Certificate, up to 10th grade)
- Intermediate (HSSC - Higher Secondary School Certificate, up to 12th grade)
- Higher Education (Bachelor's degree and above)
- Other (please specify):

1.4. Occupation: _____

1.5. Residential Area in Islamabad: _____

1.6. Please specify the name(s) or location(s) of the Urban Green Space(s) you most frequently visit: _____

2. Urban Green Spaces (UGS) Usage

2.1. How frequently do you visit UGS in Islamabad?

- Daily
- Once a week
- Several times a week
- Once a month
- A few times a month
- Rarely or never

2.2. During a visit to UGS, how long do you typically spend?

- Less than 30 minutes
- 30 minutes to 1 hour
- 1-2 hours
- More than 2 hours

2.3. Do you feel your neighboring area has a sufficient amount of UGS as compared to other sectors of Islamabad?

- Yes
- No
- Unsure

2.4. The barriers to accessing and using urban green spaces

- Poor maintenance (e.g., overgrown vegetation, littered spaces, damaged walking paths)
- Environmental concerns (e.g., pollution within parks, waterlogged areas during monsoon season)
- Cultural or social barriers (e.g., spaces not seen as welcoming to certain groups, lack of privacy)

- Overcrowding at peak times (e.g., too crowded during evenings or weekends, making it less enjoyable)
- Poorly designed or unsafe equipment (e.g., playground equipment in disrepair or outdated, posing safety risks to children)
- Lack of shade and shelter (e.g., insufficient tree canopy to provide shade, lack of covered areas to protect against sun or rain)
- Inadequate parking facilities (e.g., limited or overcrowded parking areas making access difficult, especially for families with young children or elderly visitors)
- Insufficient information (e.g., lack of signage about the flora and fauna, no educational programs about the benefits of UGS)
- Lack of child-friendly facilities (e.g., absence of safe, well-equipped playgrounds; insufficient recreational options for young children)
- Other (please specify): _____

3. Assessing the Multifunctionality of Urban Green Spaces (UGS)

Each question relates to how Urban Green Spaces (UGS) benefit our city and lives. For each question, please indicate how much you satisfy the functionality UGS providing (highest rate to not applicable). This helps us understand the USG value and provision of multi functionality in Islamabad.

Category	Function	Excellent	Good	Fair	Poor	Not Applicable
Ecological Impacts	UGS are important for reduction of Urban Heat Island effect.					
	UGS help in preventing floods.					
	UGS help in improvement of the Air Quality.					
	UGS are important for provision of habitat with high biodiversity.					
	UGS are playing important role in water management (e.g., groundwater recharge, purification, etc.)					
	UGS are helpful for the maintenance of soil health.					
Socio-cultural Impacts	UGS help in provision of recreational opportunities.					
	UGS are important for the mental health and benefit.					
	UGS are important for the physical health and benefit.					

	UGS are important for the enhancement of the community identity.					
	UGS are help in reduction of the social exclusion.					
Economic Impacts	UGS are important and can enhance the property value.					
	UGS are important for the enhancement of tourism.					
	UGS are important for the cost-saving / reduction of the storm water management/storm water.					
	UGS are important for Healthcare Cost Savings.					

4. How satisfied are you with the following aspects of UGS in your area?

Aspect	Very Satisfied	Somewhat Satisfied	Neutral	Somewhat Dissatisfied	Very Dissatisfied
Accessibility					
Security Measures					
Cultural Relevance					