URBAN TRANSITION AND PERI-URBAN LANDCOVER ECOSYSTEMS: INTERDISCIPLINARY INSIGHTS FROM CASE STUDIES IN THE PHILIPPINES AND INDIA

By

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ABSTRACT

This dissertation investigates the complex interplay between urbanization, land-cover change, and ecosystem services in peri-urban areas. It employs a three-pronged approach, combining a systematic literature review with two in-depth case studies from the Global South: Metro Manila, Philippines and Delhi National Capital Region (NCR), India. The first chapter presents a comprehensive review of the global literature published between 2000 and 2022, examining environmental and land-use changes in peri-urban regions. Using bibliometric analysis techniques like Latent Dirichlet Allocation (LDA) and co-citation network analysis, the review identifies dominant research themes, influential publications, and key research clusters. This analysis highlights the growing scholarly interest in peri-urban ecosystems and emphasizes the need for integrated approaches to manage the environmental impacts of urbanization. The second chapter focuses on Metro Manila, Philippines, analyzing the impact of urbanization-induced changes in land cover on ecosystem conditions and services. Using autocorrelation analysis and focusing on the period 2001 to 2020, the study reveals a strong spatial correlation between urbanization and the decline in ecosystem conditions and services. The expansion of urban areas, mainly at the expense of forests and savannas, has led to a decline in ecosystem health and service provision, particularly in areas closer to Metro Manila. The third chapter examines Delhi NCR, India, exploring the dynamics of land-cover change and its impact on ecosystem services between 2001 and 2020. The study reveals significant urban expansion, particularly in Gurgaon and Faridabad, leading to a decline in vital ecosystem services. Spatial analysis techniques, including spatial autocorrelation and linear regression models, reveal a clustered pattern of ecosystem services and highlight the influence of spatial factors on land-cover changes.

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Chapter 1

INTRODUCTION

Urbanization and the accompanying changes in land cover are transformative processes that significantly influence the environmental, social, and economic fabric of a region. As natural landscapes are converted into built environments, the services they once provided to humans are disrupted. These disruptions have dire consequences, particularly in light of the escalating occurrence of untimely and severe floods, extreme heat waves, and water scarcity faced by urban areas around the world (Guneralp et al., 2020). The rapid pace of urbanization is driven by various factors, including population growth, economic development, and the pursuit of better living standards.

As more people migrate to urban areas in search of better opportunities, cities expand both horizontally and vertically, leading to significant alterations in land use and land cover. These changes not only affect the local environment, but also have far-reaching implications for regional and global ecosystems. The loss of green spaces and natural habitats, increased levels of pollution, and the strain on water resources are just a few of the challenges that arise from urbanization. In addition, the built environment often lacks the resilience of natural landscapes, making urban areas more vulnerable to the impacts of climate change. As cities continue to grow, it becomes increasingly important to understand and mitigate the negative effects of urbanization on the environment and society. Urbanization occurs in two forms: horizontal expansion (urban sprawl) and vertical densification (vertical urban growth) (Zambon et al., 2019). Urban sprawl spreads cities into rural areas, converting agricultural land and natural habitats into built environments (Dupras et al., 2016). This expansion increases commuting distances, strains infrastructure, and fragments landscapes, disrupting ecosystems and increasing carbon footprints. Vertical densification intensifies development within existing urban areas by constructing taller buildings to maximize land use and accommodate growing populations. It aims to reduce outward expansion and preserve undeveloped land but increases impervious surfaces, contributing to higher urban temperatures. Vertical growth also demands more infrastructure and energy, and can lead to overcrowding and reduced green spaces (Mahtta et al., 2019). Both forms transform natural landscapes into built environments, impacting urban planning and sustainability. A balanced approach considering environmental, social, and economic factors is essential.

This dissertation examines the complex interplay between urban expansion and ecosystem functionality in two strategically chosen megacities: Metro Manila, Philippines, and India's National Capital Region (Delhi NCR). These densely populated administrative capitals, crucial to their respective national and regional economies, present contrasting yet interconnected case studies due to their unique urbanization patterns and the resulting challenges in land cover changes and ecosystem services. Metro Manila, constrained by its coastal boundaries and early urbanization, exemplifies the consequences of limited space with vertical and horizontal growth leading to green space depletion, heightened pollution, and infrastructure strain. In contrast, Delhi NCR's outward sprawl has driven significant land cover transformations and a decline in vital ecosystem services. By investigating these cases, this research aims to understand urbanization's impact on ecosystem services and propose sustainable planning strategies applicable to other rapidly urbanizing areas seeking to enhance livability and ecological resilience.

Urbanization significantly impacts ecosystem services, such as air and water purification, temperature regulation, and recreation. Studies show adverse effects of urbanization on these services. Pataki et al. (2011) note how green space loss affects thermal comfort and public health. Suarez et al. (2020) stress the economic and social importance of these services in urban planning. Integrating green areas into urban development can mitigate urban heating and improve city resilience to extreme heat (Gill et al., 2007). The COVID-19 pandemic highlighted the importance of urban ecosystem services for well-being during lockdowns (Venter et al., 2020) and exposed inequalities. Low-income communities had limited access to green areas, thus being more affected by urban heating compared to those with better access (Hoffman et al., 2020). The following chapters explore how urban growth affects ecosystem services and proposes sustainable urban planning to improve livability and resilience in fast-growing cities. The research is timely as cities face climate change challenges and increasing extreme weather events.

By understanding the complex dynamics of urban growth and its impacts on ecosystem services, we can develop evidence-based policies and interventions that promote sustainable urbanization and improve the well-being of urban residents. This dissertation delves into this multifaceted relationship between urban expansion and ecosystem functionality, highlighting the necessity of integrating ecological considerations into urban planning frameworks. The research highlights the importance of conserving green spaces, boosting biodiversity, and sustaining ecosystem services such as air and water purification, climate regulation, and recreational opportunities. With the continuous expansion of urban areas, the strain on natural ecosystems increases, resulting in habitat fragmentation, biodiversity loss, and the deterioration of ecosystem services. Through two case studies and empirical analyses, this dissertation clarifies the ways in which urbanization impacts ecological health and outlines best practices to mitigate negative effects. By deepening the understanding of these interactions, the research aims to aid in the creation of urban environments that are both economically dynamic and ecologically sustainable, capable of withstanding environmental shocks. Ultimately, the dissertation's findings aim to guide policymakers, urban planners, and stakeholders towards a balanced urban development approach that aligns human activities with the natural environment.

The dissertation is structured as follows. Chapter 2 provides a systematic review of the global literature on peri-urban development and its environmental and land use changes between 2000 and 2022. This chapter sets the stage for subsequent case studies by identifying key research themes, trends, and gaps in the existing literature. It delves into the multifaceted nature of peri-urban areas, examining how their unique characteristics influence environmental outcomes and land use patterns. By synthesizing findings from various regions and contexts, Chapter 2 offers a comprehensive overview of the current state of knowledge and highlights areas where further research is needed. Chapter 3 focuses on the Metro Manila, Philippines, case study, assessing the impacts of changes in land cover on ecosystem services and developing an indicator of ecosystem health. This chapter employs a combination of remote sensing data and field observations to paint a detailed picture of how urban expansion is reshaping the natural landscape and affecting ecological functions. Chapter 4 presents a similar analysis for the Indian National Capital Region, exploring the dynamics of changes in land cover and ecosystem services and their implications for urban sustainability. It juxtaposes the results from Metro Manila, shedding light on the similarities and differences in urbanization trends and their environmental impacts across various socio-economic and cultural settings. Understanding urban expansion and its effects on ecosystem services is crucial for creating evidence-based policies that promote sustainable urban growth and improve city dwellers' quality of life. This dissertation combines quantitative and qualitative data to offer insights into urban development challenges and opportunities, aiming to foster more resilient and sustainable urban areas.

Chapter 2

INTERDISCIPLINARY INSIGHTS INTO PERI-URBAN DEVELOPMENT: A SYSTEMATIC REVIEW OF GLOBAL LITERATURE ON ENVIRONMENTAL AND LAND USE CHANGES (2000-2022)

The chapter presents a comprehensive review of peer-reviewed literature published between 2000 and 2022 on environmental and land use changes in peri-urban regions. It focused on reviewing and analyzing research publications related to environmental and land use changes specifically in peri-urban areas for the period between 2000 to 2022. This increased citation and publication activity is used as a proxy for the significant interest and importance attributed to these themes. Focusing on developing regions and key areas of study such as land management and ecosystem services, the co-citation analysis reveals two primary clusters: fundamental ecological principles and the ecosystem services provided by peri-urban environments. This work employs text pre-processing techniques, Latent Dirichlet Allocation (LDA), and customized Python scripts for the bibliometric analysis. The chapter is a part of a broader dissertation that explores the impact of urbanization-induced changes in land cover on both urban and non-urban ecosystems. The study uses bibliographic data extracted from the Web of Science database, acknowledging the limitation of potentially missing relevant literature indexed in other databases.

Peri-urban areas, nestled at the juncture of urban and rural landscapes, are experiencing a perpetual transformation propelled by the relentless wave of urbanization (Brenner & Schmid, 2015). The rapid pace of urbanization has sparked very important research questions. As urban areas continue their expansion, understanding the intricate relationship between urbanization and the ecological dynamics within peri-urban regions becomes an increasingly critical endeavor. Reviews are important in meta-analysis because they provide a comprehensive synthesis of the existing research, identifying patterns, gaps, and inconsistencies in the literature. They help to establish a baseline understanding of the topic, highlight areas where further research is needed, and offer insights into methodological approaches and theoretical frameworks. In the context of studying peri-urban areas, reviews can distill complex information, making it easier to understand the broader implications of urbanization and inform future research directions.

Two of the early reviews during the study period focus on peri-urban transformation, addressing both the environmental and social effects of urbanization on peri-urban zones (Rakodi, 1998), as well as the governance issues faced (Adell, 1999). These reviews highlight the complexities and unique challenges faced by peri-urban areas in terms of governance and service delivery. Although the literature up to the year 2000 was relatively sparse as noted by both these studies, there has been considerable progress on the number of publications on the ecological impacts of peri-urban land cover change. Recent studies have focused on the dynamic interactions between urban and rural processes, emphasizing the need for integrated approaches to effectively manage these transition zones. Furthermore, the role of peri-urban agriculture and its potential in contributing to food security and sustainable urban development has gained attention, pointing to a growing recognition of the importance of these areas in broader urban planning frameworks.

The researchers initially faced insufficient literature on Peri-Urban Interface (PUI). They addressed this by reviewing related literature from both urban and rural research, applying it to PUI. Both reviews suggest that growing social inequalities and environmental degradation arise from urban-rural interactions, with peri-urban areas being more affected (Adell, 1999; Rakodi, 1998). Despite the insights, further exploration of the conceptual issues surrounding PUI is needed. The current PUI definition, while useful, could benefit from detailed analysis to improve planning and management. Peri-urban areas exhibit rural and urban characteristics and face various physical, ecological, and socio-economic strains. Originally agrarian, these regions convert to mixed land uses over time due to ecological pressures and rising land prices from urbanization, reflecting urban expansion into rural areas and resulting in changes in land cover, ecological conditions, and social structures (Adell, 1999; Lloyd-Jones & Rakodi, 2014; Shaw, 2005).

In this chapter, we conduct a comprehensive meta-analysis of studies (2000-2022) that center around the theme of peri-urban (PU) development, land cover, and ecosystem / environmental changes on a global scale. Our study seeks to explore past discussions on concepts and models of regional development through the use of bibliographic data. It examines the credibility and progression of the term peri-urban interface in light of evolving theoretical paradigms, including globalization. The goal is to assess the policy implications of these models and their adaptability in a dynamic spatial and temporal landscape. The study relies primarily on an extensive web-based research approach, examining the literature published after 2000, with exceptions made for older cross-referenced works. This method encompasses a comprehensive analysis of major scientific journals that cover both urban and rural domains. The presence or absence of specific topics within the material is interpreted as indicative of editorial bias or research interests.

We conducted a systematic review of relevant papers archived in the Web of Science database from 2000 to 2022. Our objective was to examine the main literature in PU development, the primary journals publishing such research, emerging themes, and co-citation networks. The outline of our search is illustrated in Table 2.1. We follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (PRISMA, 2022) to ensure the quality and transparency of our bibliographic research. These standardized guidelines provide a rigorous framework for document selection, search strategies, and inclusion/exclusion criteria. By adhering to these guidelines, we enhanced the replicability, reliability, and validity of our study, aligning it with best practices in the field.

Items	**Description**
Selected Database	Web of Science
Search String	**peri-urban** (Topic) and **Ecosystem OR "Ecosystem Service*"** (All Fields)
Publication Criteria	Journal articles
Language	English
Time Duration	2000-2022
Search Fields	Title, abstract, keywords
Inclusion	Peer-reviewed journal articles
Exclusion	Book chapters, unavailable full text, duplicates, non-English

Table 2.1: Details of the search in the Web of Science database

We adopted a systematic segmentation approach to easily identify and study literature addressing peri-urban development. A systematic segmentation approach in the context of this paper refers to a methodical process used to categorize and analyze literature on peri-urban development. This method effectively addresses the dimensions of peri-urban dynamics, facilitating a comprehensive understanding of the interactions at play. Integration of knowledge from diverse disciplines is important for the development of comprehensive policies and strategies tailored to the unique challenges and opportunities presented by peri-urban areas. Ultimately, this paves the way for more sustainable and informed decision-making processes (Brown et al., 2015).

Our systematic review aims to contribute to interdisciplinary research. Peri-urban areas present a unique and complex array of challenges and opportunities, making them fertile ground for interdisciplinary studies (Duncanson et al., 2022). Understanding the complex nature of peri-urban transformations provides a robust foundation for researchers across various fields to explore peri-urban sustainability. Climate change, which already affects lives globally, exacerbates the vulnerabilities of peri-urban areas. These regions often experience increased environmental stress due to their transitional nature and the rapid urbanization they face, which amplifies the climate-related challenges. Thus, focusing on sustainable development in peri-urban regions is crucial for the well-being of current and future populations and for preserving the essential ecological services these areas provide. Sustainable development ensures that peri-urban areas can effectively contribute to climate resilience and environmental sustainability. Without a thorough understanding and targeted efforts towards the sustainability of these areas, the adverse impacts of climate change and urbanization could lead to significant economic and environmental degradation.

2.1 Research Questions and Hypotheses

Our investigation is structured around three primary research questions aimed at a comprehensive analysis of existing literature, focusing specifically on the ecological impacts of urbanization in peri-urban areas. We endeavor to identify seminal contributors to the discourse on peri-urban development (Research Question 1), pinpoint significant co-citations (Research Question 2), investigate dominant research themes (Research Question 3), and analyze co-citation networks (Research Question 4). The hypotheses corresponding to each research question are formulated as follows:

Research Question 1 (RQ1): Which sources are most influential based on their citation counts? Hypothesis 1: The sources deemed most influential in peri-urban research are anticipated to be those papers and journals that receive frequent citations from subsequent studies. These pivotal sources are likely to include seminal works, comprehensive reviews, and studies that introduce significant concepts and methodologies.

Research Question 2 (RQ2): What are the major research themes? Hypothesis 2: Research themes in peri-urban studies are projected to be diverse and interdisciplinary, encapsulating the multifaceted nature of peri-urban transformations. These themes may encompass ecological and environmental factors, the impacts of urbanization on resources and ecosystems, socio-economic dimensions, peri-urban agriculture, and nature-based solutions.

Research Question 3 (RQ3): What are the co-citation networks in this field? Hypothesis 3: Co-citation networks in peri-urban research are expected to elucidate patterns of collaboration and knowledge exchange among researchers and disciplines. It is anticipated that researchers within similar fields will exhibit higher co-citation rates, indicative of collaborative relationships and convergent research interests.

2.2 Methodology

2.2.1 Determining the Most Influential Sources Based on Citation Frequency (RQ1)

Influential sources are those that have a considerable impact on a field of study, typically gauged by the number of citations they receive. These sources are regarded as seminal since they significantly contribute to the advancement of knowledge in a specific discipline. This systematic review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which are well recognized and founded on evidence for conducting systematic reviews and meta-analyses. For RQ1, which seeks to identify the most influential sources based on citation count, the PRISMA guidelines encompass four primary steps: identifying pertinent documents, screening them for relevance, evaluating their eligibility for inclusion, and finally including them in the analysis. The search was confined to peer-reviewed journal articles due to their stringent quality control, scientific validity, thematic relevance, credibility, and consistency. Peer-reviewed journals are trusted sources of knowledge dissemination and are more likely to provide accurate and well-founded insights into the peri-urban and ecosystem domain. By focusing on journal papers, we maintain a coherent and meaningful analysis while upholding research quality standards. Conversely, we excluded book chapters, documents with unavailability of full text, duplications, and publications in non-English languages to ensure the reliability and relevance of the selected literature.

These criteria helped streamline the dataset, ensuring that the included documents could be further analyzed for their bibliographic relevance. The detailed steps of the study selection are outlined in Figure 2.1

The initial search yielded a total of 757 records. After applying the inclusion criteria, the dataset was filtered to include 702 peer-reviewed journal articles, 36 conference papers, 14 book chapters, and 5 books. By focusing on these selected documents, we ensure the reliability and relevance of the dataset for further analysis. Data was meticulously extracted and categorized across several fields, including title, abstract, keywords, author, publication year, journal name, and funding information. This comprehensive data extraction facilitated a deeper understanding of the research landscape, allowing for robust thematic analysis and identification of recurring patterns and influential studies. Specifically, the extraction of fields like keywords and abstracts enabled a nuanced analysis of the thematic content, while the categorization based on publication year and journal name allowed us to track the evolution of research focus over time and across different academic platforms.

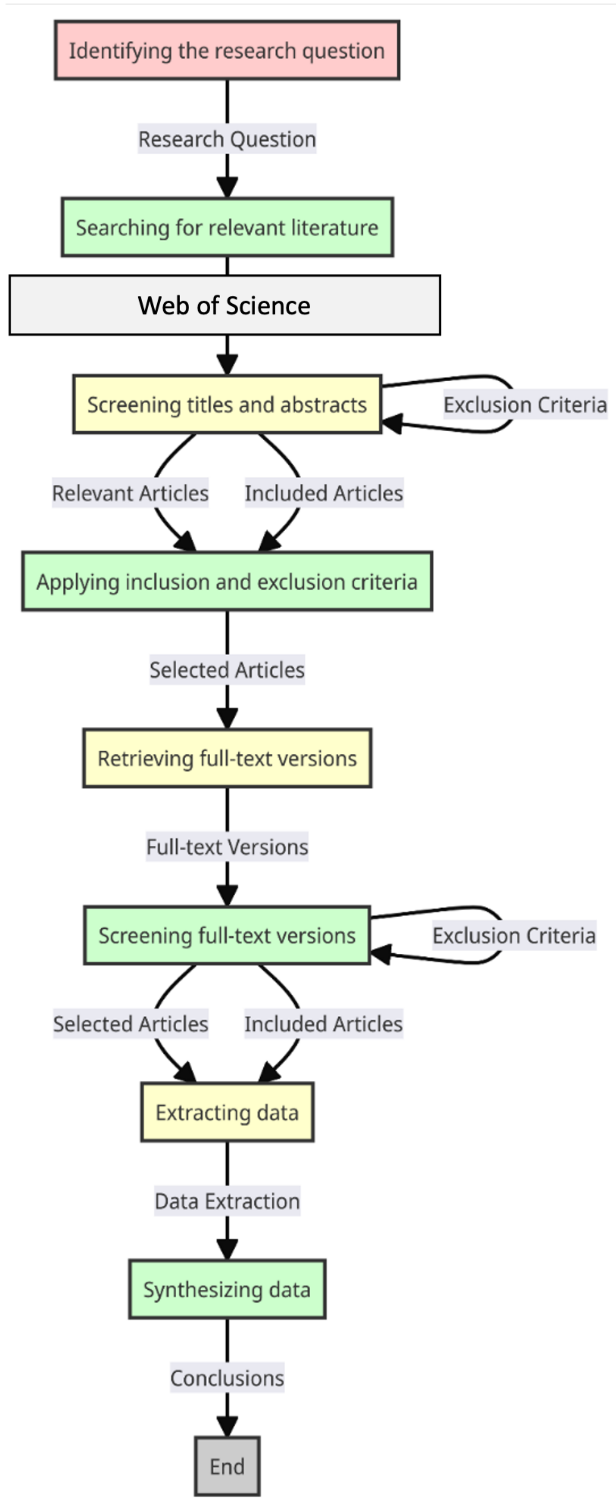

Figure 2.1: Process of Study Selection

Author information and funding sources were extracted alongside bibliographic data. Mapping co-authorship networks revealed collaborative relationships and influential researchers, pinpointing key areas and gaps. Funding data shed light on the backers of top papers, showing which institutions and agencies drive periurban ecosystem research. This analysis, including grants, sponsorships, and institutional support, identified funding patterns and their impact. Integrating author and funding data correlated financial support with research impact, enhancing our understanding beyond bibliometrics. This multi-dimensional approach identified key themes, collaboration dynamics, and funding roles, highlighting trends and opportunities for researchers, policymakers, and funding agencies, thus guiding future research and policy.

2.2.2 Text Analysis and Theme Identification (RQ2)

To address RQ2 and identify the main research themes, we performed text preprocessing to prepare the data for analysis. This involved removing common stop words, stemming words to their root forms, and tokenizing the text into distinct words or phrases. We applied the Latent Dirichlet Allocation (LDA) algorithm to the preprocessed text data, aiming to identify an optimal number of topics. The algorithm derived topic distributions per document and word distributions per topic. Parameters such as the number of iterations, and the alpha and beta hyperparameters, were fine-tuned to achieve stability and convergence of the topics. For instance, one emergent topic may feature terms like 'urbanization,' 'ecosystem services,' and 'sustainability,' suggesting a focus on the impacts of urban development on ecosystem dynamics and sustainability practices.

The resulting topics were interpreted by examining the top words associated with each topic, identifying coherent and meaningful themes from the word distributions. For example, a topic characterized by words such as "biodiversity," "conservation," and "habitat" would focus on biodiversity conservation in peri-urban areas. Another topic with terms such as "air quality," "green infrastructure", and "public health" would highlight the intersection of environmental quality and human health facilitated by green spaces. To ensure the reliability of the identified topics, we performed validation checks, including coherence scores and manual inspection. This helped refine the topics, ensuring that they accurately represented the underlying research themes. Using LDA, we systematically categorized and understood the dominant research themes within peri-urban ecosystem studies, providing valuable insights into focus areas and trends over the analyzed period. The findings are instrumental for researchers, policymakers, and practitioners aiming to address the complex challenges associated with peri-urban ecosystems.

We utilized various tools for text analysis, including the Natural Language Toolkit

(NLTK), a robust Python library for processing and analyzing human language data. NLTK was used for text preprocessing to ensure that the data extracted from research papers was high quality and consistent. The preprocessing steps involved cleaning the text by removing unnecessary characters, punctuation, and common stop words that do not add meaningful information to the analysis. Subsequently, the text was tokenized into individual words or phrases, and stemming or lemmatization was performed to reduce the words to their root forms. Part-of-speech tagging identified the grammatical roles of words within the text. These preprocessing steps were vital for preparing the data for further analyses, such as constructing the co-citation network and conducting topic modeling, thereby improving the reliability and validity of the research findings.

2.2.3 Co-Citation Network and Text Analysis (RQ3)

Co-citation analysis is a research method used to uncover trends and connections within a specific field by examining the frequency with which pairs of academic papers are cited together. This technique helps to identify relationships and patterns in the scholarly literature. In this study, co-citation analysis is applied to outline the thematic and conceptual structure of peri-urban ecosystem and landcover changes induced by urbanization. It is especially valuable for understanding the advances and changes over time in a particular research area, such as peri-urban ecosystem studies. By analyzing co-citation patterns, researchers can map out the thematic and conceptual structure of a field, identify key research areas, and discover influential papers and researchers. One of the primary promises of co-citation analysis lies in its ability to reveal the underlying research landscape and its evolution over time. For example, in the context of peri-urban ecosystem studies, co-citation analysis can help identify the foundational works that have shaped the field, as well as emerging research trends and shifts in focus.

In the context of peri-urban ecosystem studies, co-citation analysis helps identify core literature, map research clusters, and track the evolution of research themes over time. By identifying the foundational works that have significantly influenced the study of peri-urban ecosystems, researchers can understand the key concepts and theories driving the field. Mapping research clusters helps to identify the different dimensions of peri-urban ecosystem studies and how they interrelate, such as the ecological impacts of urban expansion or sustainable development practices. Tracking the evolution of research themes over time highlights emerging research priorities, such as a growing emphasis on climate change adaptation and resilience in peri-urban areas, guiding future investigations.

Analysis of co-citation networks explores the interconnections among research papers through shared citations, offering insights into the structure and dynamics of scholarly evolution in peri-urban ecosystem studies. To investigate these networks, we employed specialized software tools such as pandas, NumPy, MetaKnowledge, NetworkX, NLTK, pyLDAvis, Matplotlib, and Seaborn for analysis and visualization. The process began by screening articles based on their titles and abstracts to exclude those irrelevant to our study. Following this, we constructed two essential networks: a co-citation network, revealing the interconnections among research papers through shared citations, and a co-author network, illustrating author collaborations. These networks were visualized using the NetworkX library, which allowed us to create intuitive representations of the complex relationships within the academic literature. Analysis of this method facilitates the identification of key publications, eminent researchers, and salient research groups.

To ensure that the data were ready for rigorous analysis, we employed text pre-processing techniques using NLTK. This involved cleaning and organizing the text within the research papers to enhance the quality and consistency of subsequent analyses. The preprocessed text data were then used to construct the co-citation network. By mapping the co-citation relationships, we could identify clusters of papers that frequently cited each other, indicating cohesive research themes and influential works. The use of custom Python code for this bibliometric analysis allowed us to tailor the analysis precisely to our research questions, ensuring scalability and enhancing transparency and reproducibility. This approach promotes open sharing of methods and facilitates replication by other researchers.

2.3 Results

2.3.1 Highly cited sources from 2000 to 2022

This sub-section addresses RQ1: Which sources are most influential based on citation counts? In this chapter, we define "impactful sources" as publications, journals, and articles that have been cited most frequently in other research works, showing their considerable influence in the domain of peri-urban ecosystem studies. This section offers an in-depth view of the present state of research in peri-urban ecosystems, highlighting collaborative networks and funding sources, and effectively demonstrating regional differences in coauthorship networks, as shown in Table 2.2. From 2010 to 2022, publications on peri-urban ecosystems surged. Research focused on managing land in urbanizing areas and exploring ecosystem services and urban forests, with case studies examining the interplay between urban dynamics, ecosystem services, land, and forests (e.g., Brinkley, 2012; Chen et al., 2014; Clarke et al., 2014; Juntti et al., 2021; Mason & Davidson, 2014; Valente et al., 2020). This shift reflects the need to address environmental impacts of rapid urbanization, especially in developing countries. Geographically, as shown in Table 2.2, much research comes from or focuses on developing

Institution	Total Citations
Chinese Academy of Sciences	450
Universidad Nacional Autónoma de México	100
Consiglio per la Ricerca in Agricoltura e l'Analisi Dell'Economia Agraria (CREA)	100
Western Sydney University	300
Tuscia University	100
Canadian Institute for Women in Engineering and Sciences (CIWES)	100
Vrije Universiteit Amsterdam	150
University of Florence	100
State University System of Florida	100
4EU+ (European University Alliance)	100

Table 2.2: Top Ten Institutional Affiliations by Total Citations

regions, highlighting their unique peri-urban ecosystem challenges and opportunities.

Research during this period shows a growing recognition of the role of urban green spaces and infrastructure in enhancing ecosystem services. Papers like Berglihn & Gomez-Baggethun (2021) highlight the importance of these green areas in improving the quality of urban life. There is also a trend toward investigating spatial literacy's influence on recognizing and mapping peri-urban and urban ecosystem services (Escobedo et al., 2020). This highlights efforts to engage stakeholders in urban planning with respect to ecosystem services. Recent developments indicate an emphasis on involving the community and improving the well-being of residents in urban research (refer to Juntti et al., 2021 for example).

Figure 2.2 ranks funding agencies by the number of total citations, highlighting financial contributors predominantly from developed countries. This reveals a research gap, emphasizing the need for a more international perspective, especially in regions like South and Southeast Asia, which face significant climate challenges. Expanding global research and funding in these areas is essential to address short term regional vulnerabilities and promote long term sustainability. International funding bodies must work towards a more equitable distribution of research funds to foster a more globally well-distributed and diverse group.

This section addresses Research Question 2 (RQ2): What are the most prominent research themes?

During the past two decades, trends in publications related to peri-urban ecosystem change have evolved significantly. Initially, the focus was largely on localized ecological aspects, characterized by terms such as "aquatic" and "limitations" (Braimoh & Vlek, 2004; Carlson et al., 2004; De Castro et al., 2004). However, as shown in Figure 2.3, the thematic focus of these publications broadened over time. A noticeable shift occurred towards a

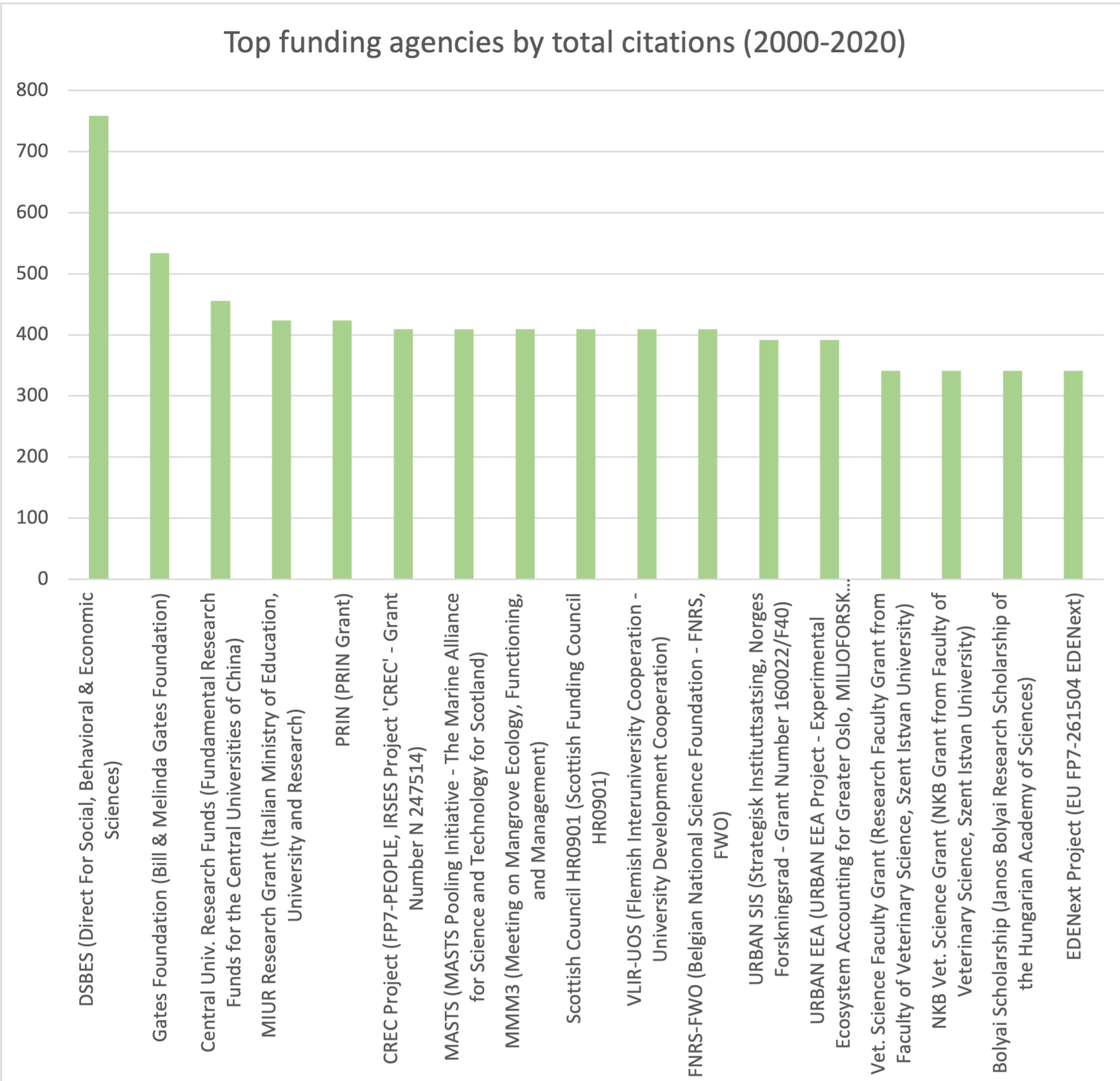

Figure 2.2: Prominent Institutional Affiliations

broader understanding of peri-urban ecosystems, evident in the prevalence of terms like "ecosystem," "environmental," and "mangrove" (Dimitriou et al., 2008; Mdegela et al., 2009; Mohamed et al., 2009; Penha-Lopes et al., 2009; Tzoulas et al., 2007). This shift signified a growing interest in understanding the environmental impacts of urbanization on diverse ecosystems.

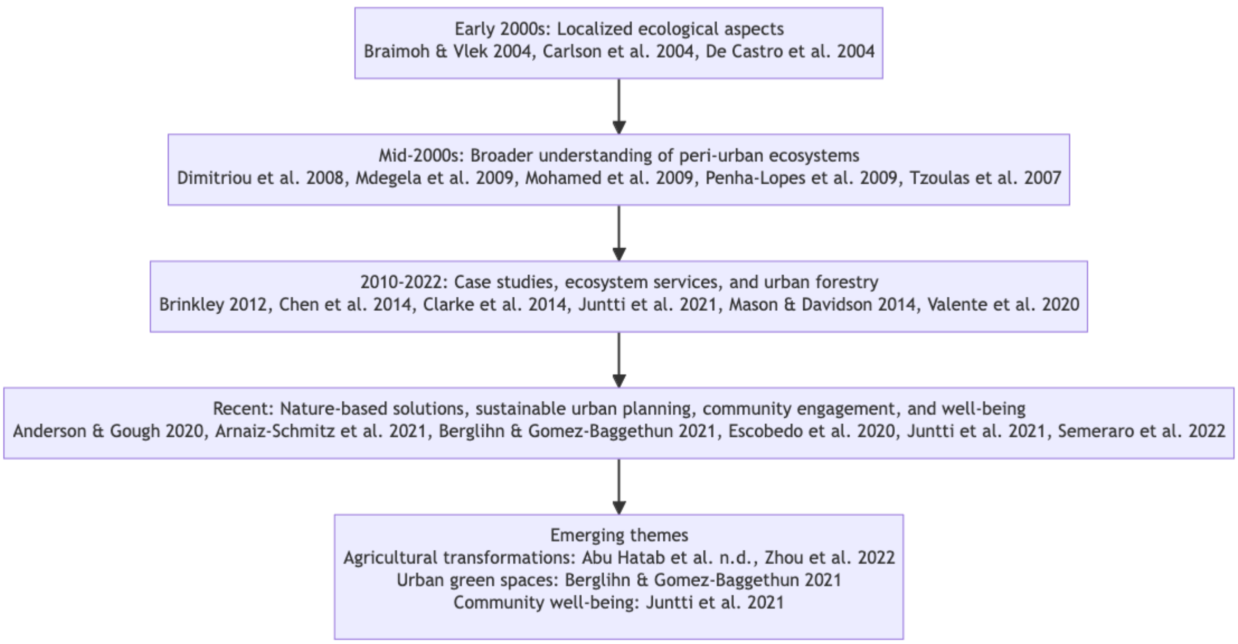

Figure 2.3: The most prominent research themes identified in the study

2.3.2 Research Themes

The latter half of the analyzed period, spanning from 2010 to 2022, witnessed a substantial surge in publications, reflecting a growing recognition of the importance of peri-urban ecosystems. This period saw a greater emphasis on land management in urbanizing areas, coupled with an exploration of ecosystem services and urban forests. Research delved into specific case studies, examining the interplay between "urban" dynamics, "ecosystem services," "land," and "forest," as evidenced by works such as Brinkley (2012), Chen et al. (2014), Clarke et al. (2014), Juntti et al. (2021), Mason & Davidson (2014), and Valente et al. (2020). This shift towards a more applied and interdisciplinary approach is likely driven by the increasing urgency to address the environmental consequences of rapid urbanization, particularly in developing nations.

This shift in research focus is not only thematic but also geographic. In the realm of urbanization, counter-urbanization processes have been observed for decades in industrialized economies, resulting in urban expansion in rural areas (Champion & Hugo, 2017). Terms like "peri-urban" and "urban fringe" initially emerged to describe such phenomena (Browder et al., 1995). Although these concepts retain relevance in certain regions, industrialized nations also fund research into concepts such as "edge cities" and "post-suburban landscapes" (Jain et al., 2013). In contrast, in developing nations, urban-rural disparities have often limited discussions to more traditional terminology (Browder et al., 1995). Recent research in cities such as Bangkok, Jakarta, and Santiago de Chile challenges these traditional notions, revealing socially homogeneous peri-urban areas characterized by middle- to lower-middle-income populations and reverse migration dynamics (Sarker, 2018; Tammaru et al., 2004).

Within the context of globalization, some scholars advocate for the universal application of similar conceptual frameworks, blurring not only the lines between rural and urban areas but also between the First and Third World regions (Ginsburg et al., 1991). In contrast, others argue that while physical distinctions between rural and urban landscapes may persist in certain areas, functional integration is on the rise. It is acknowledged that globalization tends to diminish the significance of place, but its most pronounced impacts are evident in the largest mega-urban regions of the developing world (McGee, 1997). This shift in research focus marks a paradigmatic departure from the historical separation of urban and rural development issues (Epstein & Jezeph, 2001). It underscores a growing recognition of the importance of urban-rural interactions and a move away from centralized development models that predominantly prioritize urban areas.

2.3.3 Author Co-citation Networks

This section addresses Research Question 3 (RQ3): What are the co-citation networks in this field?

Co-citation is a bibliometric measure that quantifies the relationship between two research papers based on the number of times they are both cited together by other papers. When two articles are co-cited frequently, it indicates that they are related and/or influential within a particular research field or topic. The titles clustered in cluster 1 shown in red suggest a research focus on foundational aspects of peri-urban ecology. The complete reference of the papers in each cluster is given in Appendix 1.

In cluster 1, Alston et al. (2004), Allen et al. (2003), Batinni et al. (2006), and Alam et al. (2011) are prominent references. These papers delve into core ecological principles and frameworks that underpin the understanding of peri-urban ecosystems. The recurring co-citation of these papers highlights their significance in establishing a foundational understanding of the ecological processes and dynamics specific to peri-urban areas. On the other hand, cluster 2 (green) presents a distinct thematic focus. Papers such as Carison et al. (2004), Daily et al. (2004), Zhang et al. (2010), and Ma et al. (2004) emphasize the ecosystem services provided by peri-urban landscapes. These services encompass a wide range of benefits, including regulating climate, maintaining water quality, and supporting biodiversity. The frequent co-citation of these papers suggests that they collectively form a critical body of knowledge that informs the assessment and valuation of ecosystem services in peri-urban areas.

Clusters 1 and 2 represent two essential and interrelated dimensions of peri-urban ecology research: the foundational ecological principles and the ecosystem services provided by these landscapes. The complete reference list of papers in each cluster is provided in Appendix.

Building on the analysis in Chapter 2, it is clear that while there is a growing body of literature addressing the ecosystem services and dynamics of peri-urban areas, significant knowledge gaps persist, particularly regarding long-term ecological impacts. Juntti et al. (2021) emphasize the need for more extensive longitudinal studies to understand the evolution of peri-urban ecosystems over time, especially amid rapid urbanization and climate change. Besides, the socio-economic dimensions of peri-urban ecosystems remain underresearched, including the role of local communities in managing and sustaining these landscapes.

As illustrated in Figure 2.4, many research initiatives are heavily concentrated in specific regions, resulting in the underrepresentation of other areas. To bridge these gaps, future research must integrate ecological, social, and economic perspectives, fostering a holistic understanding of peri-urban ecosystems. Collaborative efforts across regions and disciplines are crucial for developing effective strategies to manage and protect these vital landscapes.

The study of peri-urban ecosystems has evolved significantly over the last two decades, reflecting broader developments in environmental science and urban studies. Despite progress in understanding the ecological dynamics and ecosystem services of peri-urban regions, there remains a critical need for more comprehensive and inclusive research initiatives. By addressing the identified knowledge gaps and promoting greater collaboration, researchers can provide better guidance for policy and practice, ensuring the sustainability and resilience of peri-urban ecosystems in the face of ongoing urbanization and environmental changes.

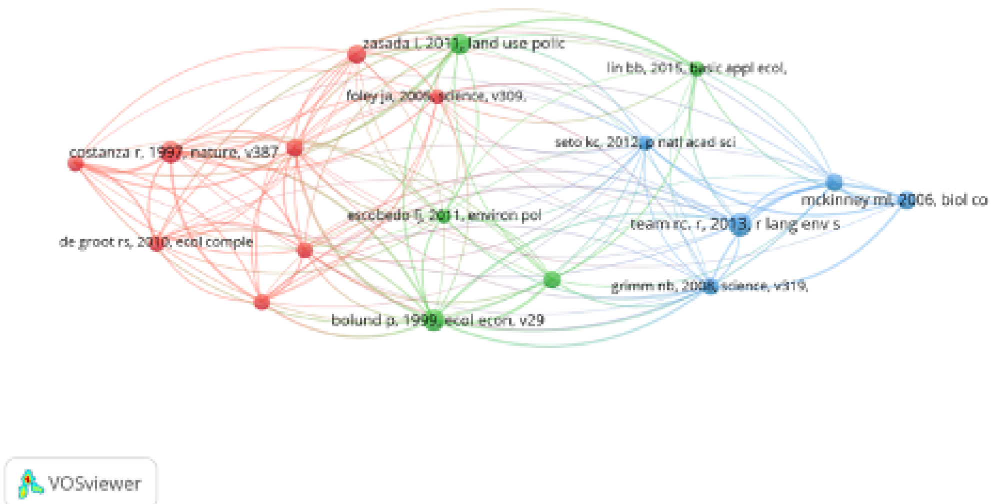

Figure 2.4: Diagram of the network illustrating international collaborations via co-author connections

2.4 Discussion

2.4.1 Evolving Landscape of Peri-Urban Development Research

This meta-analysis provides important information on research on peri-urban development between 2000 to 2022. During this time frame, we identified a significant change in research emphasis and themes. In the early 2000s, the literature predominantly centered around localized ecological aspects of peri-urban ecosystems. This focus on the "aquatic" and "limitations" aspects indicated a more narrow and specific approach to studying peri-urban areas. Possible explanations for this initial trend include a limited conceptualization of peri-urbanism and a nascent understanding of the broader ecological and social dynamics at play in these regions.

However, as time progressed, there was a noticeable shift towards a more comprehensive understanding of peri-urban ecosystems. The increased use of terms such as "ecosystem," "environmental," and "mangrove" reflected a growing interest in understanding the broader environmental impacts of urbanization on diverse ecosystems. This shift could be attributed to the maturation of the field, the increased recognition of the importance of peri-urban areas, and the pressing need to address environmental challenges associated with urban expansion. The period from 2010 to 2022 marked a substantial increase in publications, indicating a heightened importance of addressing peri-urban ecosystem changes in the context of urbanization and sustainability. Researchers began delving into intricate case studies, examining the interplay between "urban" dynamics, "ecosystem services," "land," and "forest." This shift towards more detailed case studies and a focus on ecosystem services and urban forestry can be seen as a response to the increasing complexity of peri-urban challenges and the need for practical solutions to manage these areas sustainably.

2.4.2 Practical Implications and Applications of the Study

This study is crucial as it highlights the shift in peri-urban development research from a purely ecological focus to a holistic view of peri-urban ecosystems. This broader perspective recognizes the complex interplay of factors shaping these areas. Policymakers and practitioners can use this comprehensive understanding to create strategies better suited to peri-urban realities. The traditional ecological focus now includes social, economic, and infrastructural aspects. This shift is vital as urbanization accelerates, bringing complex challenges like environmental degradation, social inequities, and land-use conflicts.

Secondly, the identification of influential sources and countries in the field provides valuable guidance to researchers seeking to engage with the existing body of knowledge. Countries experiencing rapid peri-urbanization, as highlighted in this study, can benefit immensely from collaboration and knowledge exchange with other regions that have faced similar challenges. Such global academic collaboration can foster the creation of best practices and innovative solutions rooted in diverse experiences. Furthermore, identifying key sources enables researchers to locate seminal works and fundamental concepts that have influenced the field. This focused interaction with foundational literature provides a more detailed understanding and critique of existing theories and methodologies, thus advancing the field. Thirdly, identifying key research themes highlights the complex nature of peri-urban development. This is not just an academic exercise; it has practical implications for shaping future research priorities. By stressing the need for interdisciplinary approaches that include ecological, social, economic, and agricultural aspects, the study underscores the multifaceted challenges that peri-urban areas face. This kind of holistic research agenda is essential for developing solutions that are not only effective but also sustainable in the long term. Moreover, the study highlights the necessity of investigating nature-based solutions and sustainable urban planning in peri-urban contexts. These areas often serve as the transitional zones between urban and rural environments, making them uniquely positioned to benefit from integrated planning approaches that balance development with ecological conservation.

The co-citation networks uncovered in this research shed light on collaborative links among researchers and fields. This information can enhance cooperation and information exchange, potentially leading to innovative answers for peri-urban issues. Understanding who is working with whom, and on what themes, allows for the identification of potential collaborators and the forging of new partnerships. Such networks are not only academic but also extend to policymakers and practitioners, creating a shared pool of knowledge and expertise that can be mobilized to tackle peri-urban challenges more effectively. The findings of the study have far-reaching implications for the future of research and practice in peri-urban development. Examines the term 'peri-urban interface, delving into its semantic progression and the ways its conceptualization has evolved with globalization in nearly two decades between 2000 and 2022. Such an assessment is key to understanding transitions in land cover and ecosystems, and in helping understand the urban-rural interplay in a globalized world.

The chapter highlights the importance of integrating knowledge from various disciplines. The complexities of periurban areas require a comprehensive approach to policy making and strategy development. This aligns with the dissertation's focus on urbanization's impact on quality of life from an interdisciplinary perspective. The chapter uses text pre-processing and a topic modeling technique—Latent Dirichlet Allocation (LDA), along with custom Python code for bibliometric analysis. These methods tailor the analysis to specific research questions, manage large datasets, and enhance research transparency and reproducibility.

2.5 Study Limitations

The study has some limitations that future research should consider to overcome. One major limitation is the sole reliance on the Web of Science database, which may not encompass all relevant literature in the field. Future research could consider incorporating additional databases and sources to ensure a more comprehensive review. Another limitation is the focus on the period from 2000 to 2022. While this timeframe allows for an analysis of recent trends, it may miss earlier influential works that have shaped the field. Researchers interested in the historical evolution of peri-urban development discourse may need to extend the analysis to earlier years.

While this study primarily focuses on the quantity of publications and citation counts, future research could delve deeper into the qualitative aspects of the literature, such as the methodologies employed and the impact of research on policy and practice in peri-urban areas. In terms of future research on this topic, it is essential to continue monitoring the evolving discourse on peri-urban development, especially given the dynamic nature of urbanization and its impacts on peri-urban ecosystems. Longitudinal studies that track changes in research themes and trends over time can provide valuable insights into the field's development.

An interdisciplinary approach that integrates ecological, social, and economic perspectives remains crucial. Future studies can investigate the practical implementation of nature-based solutions and sustainable peri-urban planning, considering the specific challenges and opportunities facing different regions.

Chapter 3

ASSESSING THE IMPACTS OF LAND-COVER CHANGES ON ECOSYSTEM SERVICES IN THE PHILIPPINES

This study explores the relationship between urbanization and its impact on ecosystem condition (EC) and ecosystem services (ES) in and around Metro Manila, a major city in the Philippines. The study focuses on urbanization in relation to land cover change. Using an autocorrelation analysis, we uncover spatial patterns and relationships among neighboring districts, providing an understanding of the nonrandom distribution of urbanization effects across the study area. The results show that the increase in urban land cover from 2258 sq km to 2371 sq km, a percentage increase of approximately 5% has been accompanied by significant declines in the extent of forests and, to a lesser extent, savannas. In contrast to forests, croplands have shown moderate expansion, indicative of the ongoing need to support agricultural production. The decline in EC and ES has also been detected in areas closer to Metro Manila. This spatial trend points to the influence of major urban centers on the dynamics of surrounding land cover, with nearby provinces such as Batangas, Laguna and Bulacan showing considerable increases in urban area.

This paper investigates urbanization and its multifaceted impacts on urban and peri urban ecosystems. Urbanization is a complex process that significantly alters spatial and ecological dynamics, leading to substantial changes in resource availability and usage patterns. As cities expand and populations increase, the demand for essential ecosystem services such as clean air, potable water, and food production also rises. These services are crucial for maintaining food security and ensuring a high quality of life for urban residents. Furthermore, the expansion of urban areas often encroaches upon periurban regions, which are transitional zones between urban and rural landscapes. These periurban areas play a vital role in providing ecosystem services and offer additional benefits such as recreational spaces and aesthetic value. The interaction between urban growth and periurban regions highlights the need for sustainable urban planning and management strategies to balance development with the preservation of ecological integrity and human well-being.

In the Philippines, the area around Metro Manila exemplifies this. As the city expands, nearby provinces like Laguna and Batangas supply clean air and water and offer recreational activities like hiking and bird watching. Similarly, Cebu City in the Philippines has expanded into neighboring municipalities like Consolacion and Liloan, providing fisheries and agricultural products and featuring natural attractions like beaches and marine sanctuaries. In India, Bangalore's rapid tech industry growth has expanded the city, pressuring peri-urban areas like Ramanagara and Kolar, which supply water and agricultural products and host natural parks and wildlife sanctuaries. In China, the rapid expansion of Shanghai has impacted surrounding areas such as Suzhou and Kunshan, which provide agricultural products and recreational spaces like classical gardens and water towns. Similarly, Beijing's growth has extended into neighboring regions like Hebei province, which supplies clean air, water, and agricultural produce, and offers natural attractions like the Great Wall and various nature reserves.

In Japan, Tokyo's metropolitan expansion has influenced nearby prefectures such as Saitama and Chiba, which provide agricultural products, clean air, and water, and offer recreational activities like visiting historical temples and coastal parks (Nakamura & Suzuki, 2021). Osaka's growth has similarly affected surrounding areas like Nara and Wakayama, known for their agricultural produce and natural attractions such as ancient temples and hot springs (Fujimoto & Watanabe, 2020). In South Korea, Seoul's rapid urbanization has extended into Gyeonggi Province, which supplies agricultural products and recreational spaces like national parks and historical sites (Choi & Park, 2017). Busan's expansion has similarly influenced nearby areas like Gyeongsangnam-do, which provide fisheries, agricultural products, and natural attractions such as coastal parks and islands (Lee & Kim, 2019). Given the prevalence of this trend, it warrants significant academic scrutiny and should be carefully considered by policymakers. Ecosystems, comprising complex networks of biotic entities and their abiotic surroundings, provide an array of indispensable services critical to human well-being, including nutrient cycling, biodiversity preservation, and climate regulation (Harris et al., 2016). Nevertheless, these ecosystems face disruptions due to urbanization and associated changes in land cover, leading to variations in the availability and quality of these services (Zhang & Li, 2018). The transformation of natural landscapes into urban zones, along with industrialization, brings forth new challenges to sustain ecosystem services in urban settings (Brown & Taylor, 2022).

The paper uses methodologies to quantify how ecosystem changes impact human well-being by assessing the "supply" of services from ecosystems. This supply varies due to factors like location, culture, and demographics. The paper uses the Common International

Classification of Ecosystem Services (CICES) to categorize and value ecosystem services, vital for understanding their role in human life. Current techniques measure ecosystem service supply by how individuals experience environmental changes. It examines the impact of urban expansion on ecosystem health around Metro Manila, Philippines, focusing on land cover changes. Using statistical techniques, it identifies patterns between ecosystem conditions (EC) and ecosystem service supply (ESS) across districts, emphasizing spatial specificity. Urbanization in peri-urban areas like Metro Manila significantly affects ecosystem conditions and services. The study highlights the link between urbanization, habitat fragmentation, and resource degradation, such as water quality, and advocates for sustainable practices. It investigates the dependency of urban centers on regional ecosystems due to high population density and built terrain. By analyzing land changes at the district level, the study provides insights into urban expansion trends, acknowledges data limitations, and calls for further research. This analysis emphasizes the environmental impact and implications for human well-being, contributing to sustainable development dialogue.

3.1 Research Questions and Hypotheses

Urbanization significantly alters spatial and ecological dynamics, impacting resource availability and usage. With city expansion and population growth, demands for ecosystem services like clean air, potable water, and food increase. The interaction between urban and peri-urban areas necessitates sustainable urban planning to balance development and ecological integrity. This study investigates the impact of urbanization on ecosystem conditions and services in Metro Manila and surrounding regions by examining land cover changes and urbanization patterns.

Research Question 1: How does urbanization impact Ecosystem Condition (EC) in the study area?

Hypothesis: Increased urbanization leads to a decline in Ecosystem Condition (EC) in the study area. This is because urban expansion typically results in the loss of natural habitats, increased pollution, and higher levels of impervious surfaces, which negatively affect the overall health of ecosystems.

Research Question 2: What is the relationship between urbanization and Ecosystem Service Supply (ESS) in the study area?

Hypothesis:Urbanization negatively impacts the supply of ecosystem services (ESS) due to the reduction in natural land cover and increased urban activities that degrade the environment.

Research Question 3: Is there a spatial autocorrelation between urbanization and its impact on Ecosystem Condition (EC) and Ecosystem Service Supply (ESS)?

Hypothesis: The growth and development of urban areas, characterized by built-up cities and towns, are spatially autocorrelated in their effects on ecosystem condition (EC) and ecosystem service supply (ESS). Spatial autocorrelation implies that the effects of urbanization tend to cluster spatially. This hypothesis suggests that regions close to urban centers will undergo similar changes in EC and ESS as a result of the clustering effects of urbanization.

3.2 Literature Review

3.2.1 Spatial Analysis in Urban Studies

Autocorrelation analysis serves as a pivotal instrument in urban research for identifying spatial patterns among adjacent districts. It reveals nonrandom urbanization effects and provides valuable insights into impacts on neighboring regions (Anselin, 1995; Getis, 1992). By detecting clusters of similar or disparate characteristics over a geographic space, this analysis enables researchers to uncover underlying spatial patterns that are not obvious with mere visual observation (Anselin, 2003). This technique is crucial for identifying areas witnessing significant urban growth or decline, thereby aiding in more effective targeting of urban planning efforts (Haining, 2003). The insights obtained from autocorrelation analysis assist policymakers and urban planners in comprehending the broader implications of urban expansion and its effects on surrounding areas, making it indispensable for understanding urban spatial dynamics (Fotheringham, 1989).

Anselin (1995) emphasizes the importance of spatial autocorrelation in urban studies, stating that it provides a means to quantify the degree of spatial clustering or dispersion of a variable across a geographic area. Getis (2008) further highlights the role of spatial autocorrelation in detecting hot spots and cold spots of urban growth, which can inform targeted urban planning strategies. Additionally, Li et al. (2019) demonstrate the application of spatial autocorrelation analysis in identifying the spatial patterns of urbanization and its impacts on ecosystem services in the Beijing-Tianjin-Hebei region of China.

3.2.2 Remote Sensing and GIS Techniques

To model spatiotemporal urban dynamics, Estoque and Murayama's remote sensing and GIS frameworks provide robust methodologies for capturing data over time. These techniques explore urbanization patterns and ecological impacts from 2000 to 2020 by observing land cover changes and the transition of natural landscapes into urban areas. Vrebos et al. (2015) and Wangai et al. (2019) effectively use high-resolution satellite imagery and spatial analysis tools to track urban growth and its environmental impacts, even in data-scarce regions. Ajmal and Jamal (2021) and Biswas and Ghosh (2021) highlight the importance of these techniques in assessing urban expansion. By integrating satellite imagery and ground-based observations, these methodologies enable precise, large-scale monitoring of urban processes, supporting sustainable urban planning and ecological preservation. Herold et al. (2003) emphasize remote sensing's role in providing a wide view of urban areas and their surroundings, allowing analysis of spatial and temporal urban growth patterns. Bhatta (2010) discusses GIS's ability to integrate and analyze spatial data for urban planning. Taubenböck et al. (2012) show remote sensing and GIS's use in modeling urban sprawl in megacities, offering insights into rapid urbanization's spatial dynamics.

Recent study by Kuffer et al. (2020) leverage machine learning algorithms in combination with remote sensing data to improve the accuracy of urban analysis. Similarly, Schneider and Woodcock (2008) developed a framework for urban growth modeling that integrates multi-temporal Landsat data with ancillary socio-economic data for a comprehensive evaluation of urban dynamics. In addition, Liu et al. (2019) showcase the application of high resolution remote sensing imagery to detect and characterize informal settlements, providing critical insights into urban poverty and development strategies. The integration of UAV technology (unmanned aerial vehicle), as discussed by Nex and Remondino (2014), offers a novel approach to urban mapping and data collection at finer spatial resolutions. Furthermore, Weng (2012) highlights the advances in thermal remote sensing to assess urban heat islands, demonstrating the intersection of remote sensing technology with urban climatology. These studies collectively illustrate the expanding capabilities and applications of remote sensing and GIS in urban studies, reinforcing their importance in contemporary urban planning and management.

3.2.3 Case Studies for Land Cover Mapping

Ecosystem condition analysis often relies on baselines indicative of undisturbed states (Hatziiordanou et al., 2019). In the absence of historical data, alternative approaches are applied (Haase et al., 2014; Troy Wilson, 2006). High-resolution data from SPOT5, Sentinel-2, and Landsat efficiently identify land cover changes (Burkhard et al., 2015; Hattam et al., 2021; Estoque et al., 2018). Additionally, the MODIS MCD12Q1 database, with its 500m resolution annual composites, provides valuable insights into land cover dynamics (Friedl et al., 2010). While Foody (2002) highlights the classification challenges associated with remote sensing, Wulder et al. (2018) underscore the importance of the Landsat program in monitoring these changes. Notably, GlobeLand30 offers high-resolution global land cover maps that enhance our understanding of global patterns (Gong et al., 2019).

Advances in remote sensing include integrating LiDAR data with other techniques, which significantly enhances land cover and vegetation analysis (Lefsky et al., 2002; Dubayah et al., 2010). For example, combining LiDAR and Landsat data improves forest classification accuracy, providing a more nuanced understanding of forest dynamics (McRoberts et al., 2010). Furthermore, Pettorelli et al. (2014) explore the benefits of using various remote sensing data sources for biodiversity monitoring and conservation planning, thereby offering a comprehensive approach to ecological studies.

Classifying and valuing ecosystem services are fundamental to ecological assessments. De Groot et al. (2002) emphasize that these activities are crucial for understanding the roles ecosystems play in human life. By categorizing and assigning value to ecosystem services, we can adopt a structured approach to evaluate the benefits these services provide and ensure their sustainable management. Estoque et al. (2018) highlight the distinction between forest losses near urban areas and the relative stability of remote areas, offering valuable insights into the spatial dynamics of urbanization. Additionally, Acosta-Michlik and Espaldon (2008) discuss agricultural trends in regions like Isabela and Kalinga, emphasizing the role of intensification and infrastructure improvements in cropland expansion.

The Millennium Ecosystem Assessment (2005) provides a comprehensive framework for classifying and valuing ecosystem services, focusing on their contributions to human well-being. Kumar (2010) elaborates on the economic valuation of ecosystem services, offering methodological guidelines and case studies that illustrate these principles. Seto et al. (2012) discuss global trends in urban land expansion and their impacts, emphasizing the need for sustainable urban planning to mitigate adverse effects on ecosystem services.

3.2.4 Landscape Metrics and Economic Valuation

Landscape metrics are quantitative measures used to assess the spatial characteristics of land cover and their ecological effects. They help in understanding the patterns and processes associated with different land cover types, such as urbanization, by providing important data on aspects like habitat fragmentation, landscape composition, and configuration. These metrics are crucial for ecological studies and aid in the evaluation of environmental changes and their impacts. Landscape metrics play a critical role in assessing the spatial characteristics of land cover and their ecological effects. Studies by Cai et al. (2016) and Hesselbarth et al. (2019) emphasize the importance of these metrics in evaluating the ecological implications of land cover changes. These metrics provide quantitative measures that help in understanding the spatial patterns and processes associated with urbanization. Furthermore, the ability to assign monetary values to ecosystem services with economic valuation methods significantly helps to compare these metrics with other economic indicators. Castillo-Eguskitza et al. (2019) and Davidson (2013) present a comprehensive framework for these valuations, which improves the understanding of the economic impacts of ecosystem alterations. These valuation methods offer a way to integrate ecological considerations into economic decision-making, thus promoting the sustainable use of natural resources.

Uuemaa et al. (2013) provide an overview of landscape metrics and their applications in assessing landscape structure and land cover changes. They highlight the role of these metrics in quantifying the spatial patterns and processes that influence ecosystem services. De Groot et al. (2012) discuss the importance of economic valuation of ecosystem services in decision-making, emphasizing the need to integrate ecological and economic considerations for sustainable resource management. Moreover, Costanza et al. (1997) provide a seminal work on the value of the world's ecosystem services and natural capital, highlighting the economic significance of ecosystems and the need for their conservation.

3.3 Study Area

This research explores the effects of urbanization on ecosystem services in Metro Manila, which is the capital region of the Philippines located on Luzon Island. The study covers three main regions which are shown in figure 3.1: Region III, Region IV-A, and the National Capital Region (NCR). NCR is the most densely populated and was the first to urbanize, showing substantial growth after economic reforms in the late 1980s. By 2000, the developed areas of Metro Manila had spread to fill the entire administrative region, with expansion also moving into Region III to the north and Region IV-A to the south. The NCR consists of 16 highly urbanized cities and one municipality, including Manila, Quezon City, Caloocan, and Taguig, each governed locally. Region III, also known as Central Luzon, comprises seven provinces divided into cities and municipalities, with notable provinces like Bulacan, Pampanga, and Tarlac, which include major urban centers such as Angeles City and San Fernando. Region IV-A, referred to as Calabarzon, consists of five provinces: Cavite, Laguna, Batangas, Rizal, and Quezon, with cities like Cavite City, Antipolo, and Lucena. Areas within these provinces, such as Santa Rosa in Laguna and Bacoor in Cavite, are experiencing rapid growth due to the spread of Metro Manila.

Figure 3.1 displays a visual summary of the three regions included in the study: NCR, Region III, and Region IV-A. The map highlights Luzon Island in the Philippines, pinpointing these specific regions. NCR, marked in red, is centrally located with 16 highly urbanized cities and one municipality. Region III, outlined in orange to the north, consists of seven provinces that are under varying degrees of urban influence from NCR, including key areas such as Bulacan, Pampanga, and Tarlac. Region IV-A, bordered in pink to the south,

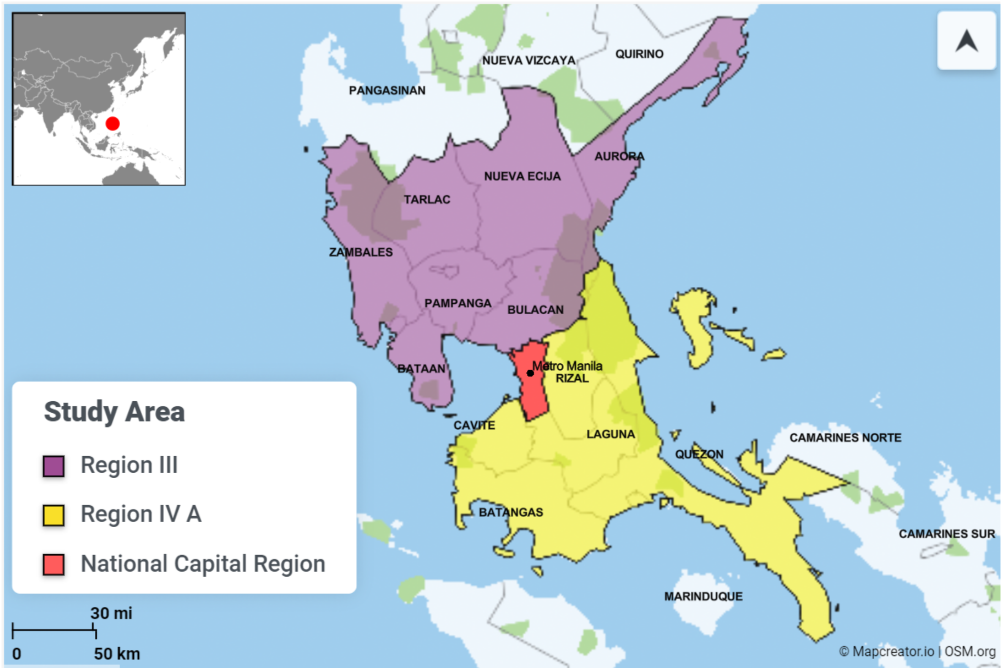

Figure 3.1: Study Area- National Capital Region, Region III and Region IV-A

contains five provinces experiencing urban growth driven by Metro Manila. The map also delineates four districts within Metro Manila: the Capital District or the 1st District, the Eastern Manila District or the 2nd District, the Northern Manila District or the 3rd District, and the Southern Manila District or the 4th District.

3.4 Methodology

3.4.1 Calculation of Ecosystem Condition Indicator

To address Research Question 1, we utilized a methodology designed to analyze land cover changes and their impacts, which proves particularly beneficial in scenarios where data is scarce, as is frequently the case in the three regions under study (Vrebos et al., 2015; Wangai et al., 2019). In a broader research context, techniques like Remote Sensing and GIS are widely used to monitor urban expansion and its environmental effects (Ajmal & Jamal, 2021; Biswas & Ghosh, 2021). Landscape metrics play a critical role in assessing the spatial characteristics of land cover and their ecological effects (Cai et al., 2016; Hesselbarth et al., 2019). Comparative analyses with other economic measures are facilitated by the capability to monetize ecosystem services using economic valuation methods (Castillo-Eguskitza et al., 2019; Davidson, 2013). Our methodology is well-suited to the scale of our study, which focuses on three regions and requires a relatively small amount of data to conduct a thorough analysis over the entire study period.

For Research Question 1, the Ecosystem Condition Indicator for a district is determined by summing the normalized scores of NDVI, NDMI, Tree Canopy Cover, Green Space Per Inhabitant, Semi-Natural area, Imperviousness per Inhabitant, and PM2.5.

To calculate the Ecosystem Condition Indicator (ECI) for a district, equations 3.1 and 3.2 are used:

Constituents of the Ecosystem Condition Indicator

$$\begin{aligned}\text{Ecosystem Condition Indicator} = &\ \text{NDVI Index} + \text{NDMI Index} \\ &+ \text{Green Space Index per capita} \\ &+ \text{Semi-Riparian Landcover Index} \\ &+ \text{Imperviousness Index per capita} \\ &+ \text{PM2.5 Index}\end{aligned} \tag{3.1}$$

Statistical Transformation of Ecosystem Condition Indicator

$$\text{ECI\_normalized} = \frac{EC - EC\_min}{EC\_max - EC\_min} \tag{3.2}$$

Where:

EC : measured/observed value of the variable,

EC_Max : high condition value for the variable (upper reference level),

EC_Min : low condition value (lower reference level).

The indicators making up the Ecosystem Condition reveal subtle environmental changes that might otherwise go unnoticed. They offer an accurate, up-to-date and easily understandable metric that facilitates both temporal and spatial comparisons. Calculating the Ecosystem Condition Indicator requires a reference point to which the current condition can be compared. Traditionally, this reference is based on a historical baseline that reflects an undisturbed ecosystem condition or the pristine state of the ecosystem (Hatziiordanou et al., 2019). However, in highly urbanized areas like the NCR, finding historical or pristine references can be difficult. In such cases, alternative methods are usually adopted to establish the reference point (Haase et al., 2014; Troy & Wilson, 2006). In our particular study, we selected 2000 as the reference year. After examining the database from this period, we identified the highest and lowest recorded values for each ecosystem condition variable in the study area. These extreme values serve as reference points for assessing the current state of the ecosystem. The percentage is a measure of the health or condition of the ecosystem, compared to a baseline or reference point. In essence, these percentages reveal the current ecosystem condition in relation to a pristine or undisturbed state, a standard that is hard to establish in extensively urbanized regions. For this research, the year 2000 was designated as the baseline year, with the highest and lowest Ecosystem Condition metrics in the area post-2000 used as reference values. Highest and lowest recorded EC values for each ecosystem condition variable from the database after that period were identified, and these values are used as baselines to assess the current ecosystem state.

3.4.2 Quantification of Ecosystem Service Provision

Addressing Research Question 2, this study uses ecosystem service mapping to evaluate the supply of ecosystem services in each area, integrating land cover data with information about ecosystem functions to gauge the impact of urbanization on ecosystem services in peri-urban Metro Manila. The approach used to detect the extent of land cover change differs from many recent studies. These studies apply the matrix method to higher resolution data from SPOT5, Sentinel-2 (Burkhard et al., 2015; Hattam et al., 2021) or Landsat (Estoque et al., 2018). Instead, this study uses the MODIS MCD12Q1 database with a resolution of 500 m. The selection of the MODIS dataset is helpful, ensuring not only consistency of data across different years but also maintaining broad, yet accurate, land cover categories. Furthermore, a significant advantage of the MODIS dataset is its ability to provide consistent resolution coverage of the entire study area for the entire duration of the study period. The study used the MODIS MCD12Q1 database with 500m resolution annual land cover composites, which were downloaded throughout the study period (Friedl et al., 2010). These composites provide preclassified land cover maps yearly using the International Geosphere-Biosphere Program (IGBP) classification system.

Ecosystem services (ES) refer to the advantages that humans obtain from the natural environment and well-functioning ecosystems, including clean air, water, and pollination of plants. This research quantifies Ecosystem Service Supply (ESS) using a matrix approach, in which services are measured based on the potential of various land use types to offer these benefits. To calculate the Ecosystem Service Supply (ESS) for different land use types, equation 3.3 is used:

$$\sum ESS_n = w_1 \cdot A_1 + w_2 \cdot A_2 + \ldots + w_n \cdot A_n \tag{3.3}$$

Where:

$$w_i = \text{Weight assigned to the } i^{th} \text{ component}$$
$$A_i = \text{Area in square kilometers for the } i^{th} \text{ component}$$

The resulting values are then normalized for comparison and spatial analysis, improving our understanding of ecosystem contributions in specific regions. The normalized Ecosystem Service Supply score is calculated using equation 3.4:

$$ESS_{\text{normalized}} = \frac{(ESS - ESS_{\text{min}})}{(ESS_{\text{max}} - ESS_{\text{min}})} \quad (3.4)$$

Where:

$$ESS_{\text{normalized}} = \text{Normalized Ecosystem Service Supply score}$$
$$ESS = \text{Original Ecosystem Service Supply score}$$
$$ESS_{\text{min}} = \text{Minimum ESS score observed in the dataset}$$
$$ESS_{\text{max}} = \text{Maximum ESS score observed in the dataset}$$

CICES classification serves as the foundation for our definition and classification of ecosystem services. Our methodology borrows heavily from the analysis by Hattam et al. (2021). While the latter does a very high-resolution classification of land cover, MODIS data, which we use for our analysis, do not provide the same detail. The land covers were classified as in Table 4A. Any attempt to quantify, map, or value ecosystem services involves classifying and describing them; this forms the foundation for doing an ecological assessment (de Groot et al., 2002). The ecosystem services identified in the previous study conducted in the same region are the ones that we also utilize. ES represents the annual Ecosystem Service Supply per hectare. In Aurora, for example, the ES for all landscapes in one hectare has shifted from 125,449 to 125,115 units per year, indicating a change from 125449 to 125115 units per hectare annually - a reduction of 0.27%.

3.4.3 Spatial Autocorrelation

To address Research Question 3, the spatial relationship between the state of the ecosystem and the supply of services was explored for each time period by calculating the Moran statistic I. Ecosystem conditions and ecosystem service supply values for different time periods, as well as spatial units (e.g., districts or provinces) to which these values correspond, were grouped in one shapefile. After collecting and cleaning the data for missing values, we created a spatial weight matrix. A spatial weight matrix (W) is created to capture the spatial structure of the data. This matrix defines the spatial relationship between all pairs of spatial units, often based on contiguity (shared borders) or distance (e.g., inverse distance weighting). This step is critical because it determines how each unit interacts spatially with all others. Another important step in the analysis is the standardization of the variables. Once standardized, Moran's I statistic was calculated using the following equation 3.5:

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{3.5}$$

$$\begin{aligned} I &= \text{Moran's I statistic} \\ n &= \text{Number of spatial units (e.g., districts)} \\ w_{ij} &= \text{Spatial weight between units } i \text{ and } j \\ x_i &= \text{Value of the variable at unit } i \\ \bar{x} &= \text{Mean value of the variable across all units} \\ \sum_{i=1}^{n} &= \text{Summation over all units} \end{aligned}$$

The number of spatial units (N) in our case is 16, representing the smallest administrative divisions (districts). Spatial weights quantify the spatial relationship between two units, with higher weights indicating stronger spatial relationships. Moran's I calculation was performed using the PySAL (Python Spatial Analysis Library) tool. A vector layer including centroids of all districts was calculated, and the matrix was developed based on the variation in distance of each district from the others. This similarity in the ecosystem values of these centroids forms the basis of our analysis for detecting spatial autocorrelation.

3.5 Results

3.5.1 Land Cover Change (RQ 1)

The study of land cover in Metro Manila, Region III, and Region IV-A from 2001 to 2020, discussed in this section combined with Ecosystem Condition calculations, helps in addressing Research Question 1: "What are the significant land cover changes in the study area over the past two decades, and what are their implications?" The region witnessed significant urbanization, with urban and built-up areas expanding from 2258 sq km in 2001 to 2371 sq km in 2020, an increase of approximately 5% (Figures 3.2 and figure 3.3).

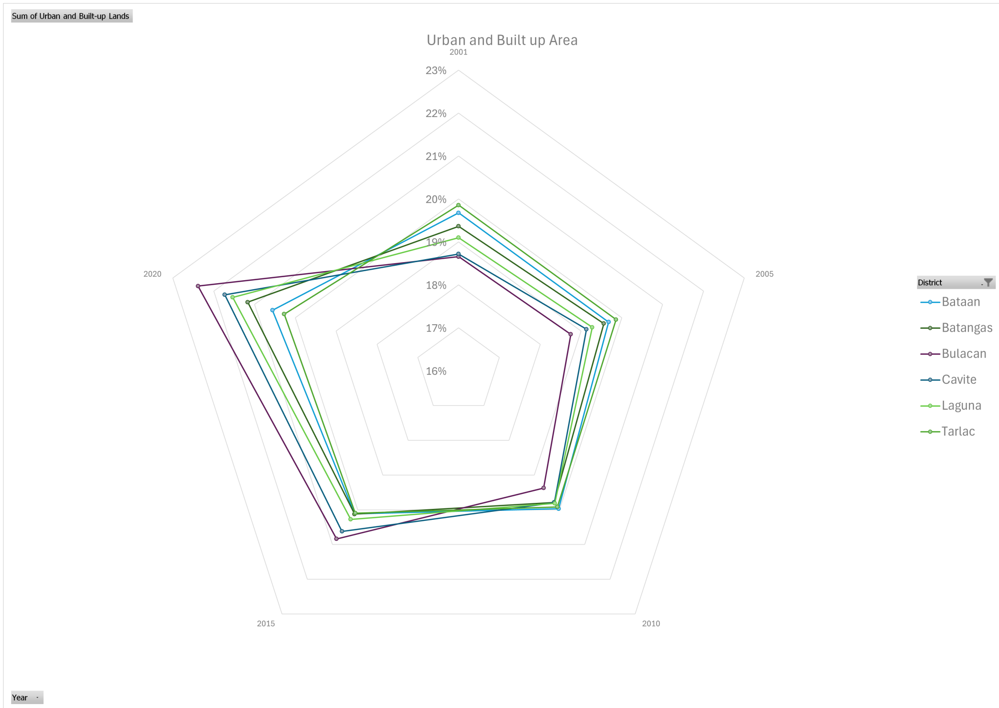

Figure 3.2: Urban land cover change relative to current built-up area

The same data presented in Table 3.5.1 indicates that Croplands increased from 13426 sq km to 14064 sq km (an absolute change of 638 sq km or 4.75%), forests decreased from 78676 sq km to 66255 sq km (an absolute change of 12421 sq km or 15.79%), grasslands rose slightly from 6913 sq km to 7085 sq km (an absolute change of 172 sq km or 2.49%), and savannas reduced from 19813 sq km to 17070 sq km (an absolute change of 2743 sq km or 13.85%). The change in Croplands over time can be observed in the radar graph in Figure 3.4.

The findings suggest that urban expansion, has been accompanied by a decrease in forest cover, which could negatively impact the ecosystem condition of the region. The general increase in croplands indicated in Figure 3.4 indicates a shift toward agricultural land use, which could be driven by factors such as intensification and improved irrigation. Additional details show that Metro Manila had a limited increase in urban and built areas, with an addition of only 3.18 sq km, since it was already significantly urbanized before 2000. Provinces such as Batangas, Laguna, Pampanga, Bulacan, and Cavite experienced high percentage increases in urban land cover close to 5% of their total land area. Minimal changes were observed in provinces such as Abra, Apayao, Ifugao, Quirino, and Mountain Province. The total urban and built-up land in all provinces increased by 112.93 sq km from 2001 to 2020.

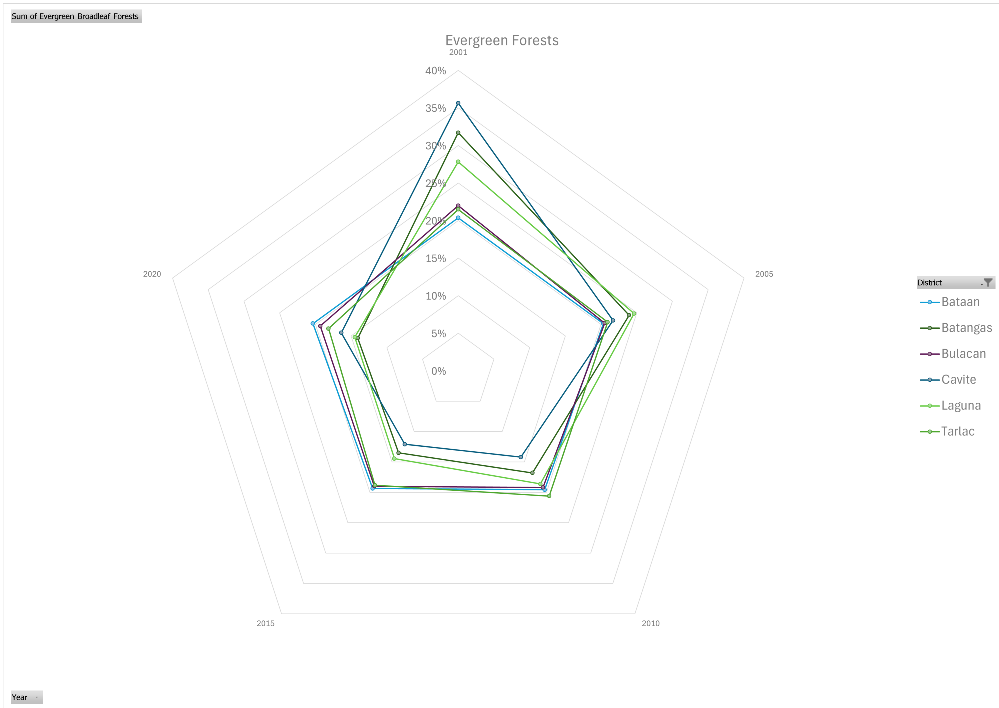

Figure 3.3: Permanent Forest Cover

Changes in the crop were also significant. Isabela maintained the highest cropland area with an increase of 462.15 sq km, while provinces like Pangasinan and Cavite saw decreases in cropland area. Metro Manila experienced a consistent decline in cropland area, losing 5.28 sq km in total.

The observed land cover transitions align with trends noted in other studies. For example, Estoque et al. (2018) highlighted the concentration of forest losses near urban areas and the relative stability of remote areas. Similarly, Acosta-Michlik & Espaldon (2008) discussed agricultural trends in Isabela and Kalinga, two other regions of the Philippines, emphasizing the role of intensification and infrastructure improvements in cropland expansion. Similarly to the results obtained in those studies, this analysis concludes that urban areas increased slightly between 2001 and 2020, while croplands expanded and forests declined. Urban expansion was concentrated near Metro Manila, with significant changes in surrounding provinces. These findings underscore the need for sustainable land use planning to balance urban growth and ecosystem conservation.

3.5.2 Ecosystem Condition RQ 1

This section, in combination with land cover changes, discusses the methods used to investigate Research Question 1: "How does urbanization impact Ecosystem Condition (EC) in

Landcover	2001 (sq km)	2020 (sq km)
Urban Land Cover (Total Urban and Built-up Lands)	2258	2371
Non-Urban Land Covers		
Croplands	13426	14064
Forests	78676	66255
Grasslands	6913	7085
Savannas	19813	17070
Other	5834	7623
Total Non-Urban Area	138619	136097

Table 3.1: Landcover Change in the Study Area - Metro Manila, Region III, and Region IV-A

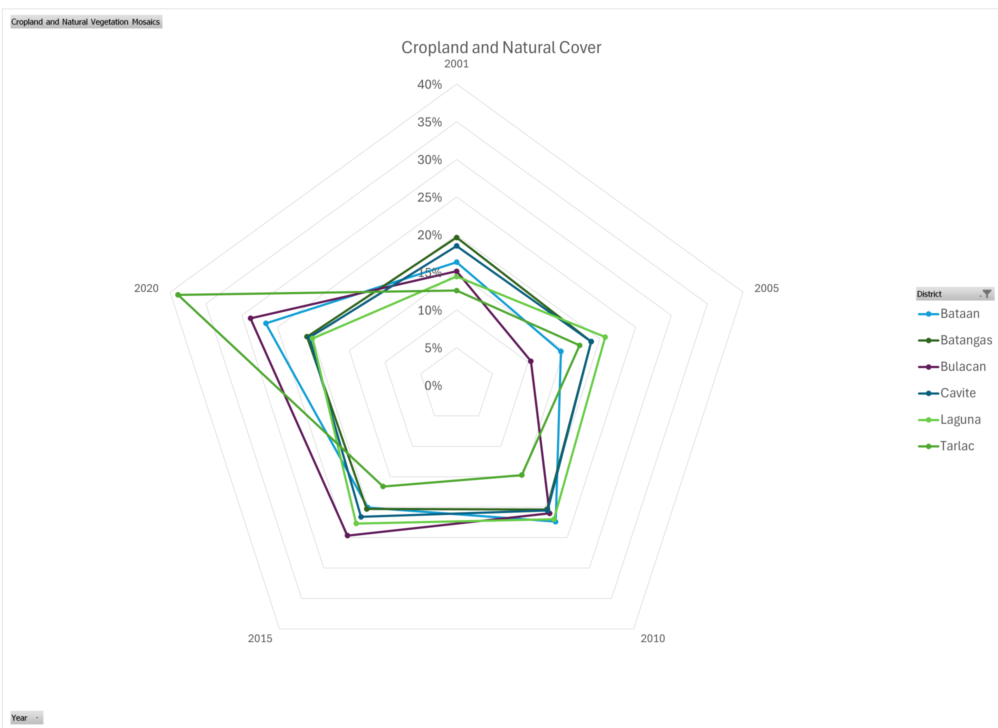

Figure 3.4: Change in Cropland and Natural Cover from 2000 to 2020 for districts in the study area

the study area?" The hypothesis states that urbanization degrades EC due to habitat loss, pollution, and impervious surfaces (Alberti, 2005; McDonnell, 1993; Grimm, 2008).

From 2001 to 2020, different regions exhibit distinct patterns in EC changes. Metro Manila saw a 3.18 sq km increase in urban area, with minimal impact on EC (Table 3.5.2). In Batangas (Region IV-A, 162 km from Metro Manila), a 7.49% urban expansion led to a decrease in the average EC from 89.9 to 74.78. Similarly, Laguna's urban area increased by 11. 87%, and the mean EC changed from 83.7 to 65. In Bulacan, a reduction of 20% in the forest area (from 835 to 661 sq km) led to a decrease in the average CE from 52. 52% of its optimal or finest ESS to 34.28% of this metric.

Region (2001-2020)	**Land Cover Change**	**Average EC Change**
Metro Manila	Urban area +3.18 sq km	44.8% to 46.65%
Batangas	Urban area +7.49%	89.9% to 74.78%
Laguna	Urban area +11.87%	83.7% to 65%
Bulacan	Forest -20% (835 to 661 sq km)	52.52% to 34.28%
Nueva Ecija	Croplands -5.51% (2633 to 2488 sq km)	56.71% to 34.83%

Table 3.2: Land cover change and EC change

Table 3.5.2 and Figure 3.5 present the summarized changes. There was a small increase in the urban area of Metro Manila, while Batangas and Laguna saw a more significant urban growth accompanied by a decline in EC. Bulacan experienced a loss of forest cover of 20%, accompanied with a drop in EC. Areas farther from Metro Manila, which have lower levels of urbanization, contribute more positively to EC. Figures 3.6 and 3.5 visually depict these patterns. The normalized values in Figure 3.6 indicate a general increase in EC, which peaks collectively between 2010 and 2015 (all EC peaks in 2005 or 2010). The EC ends up below the axis. Afterward, the EC has steadily decreased. highest points or 'peaks' around the years 2005 or 2010. This means that during those years, the EC metrics for these regions reached their maximum values before starting to decline, as referenced in Figures 3.5 and 3.6.

3.5.3 Ecosystem Service Supply (RQ 2)

This section addresses Research Question 2: What is the relationship between urbanization and Ecosystem Service Supply (ESS) in the study region? By examining the changes in percentages of various land cover types, the following analysis explains the spatial distribution and transformations of ecosystem services provided by these landscapes. Ecosystem Service Supply (ESS) refers to the benefits that humans obtain from ecosystems, such as

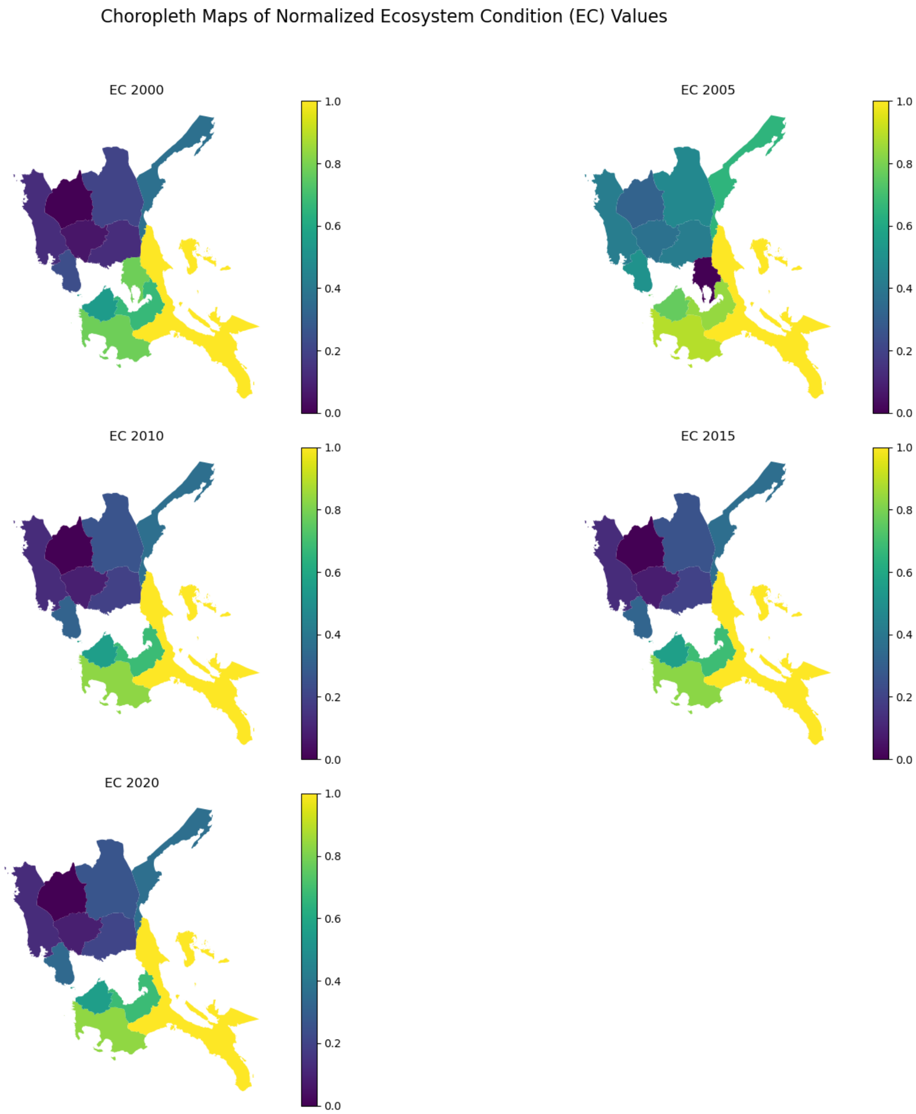

Figure 3.5: Change in Ecosystem Condition 2000-2020

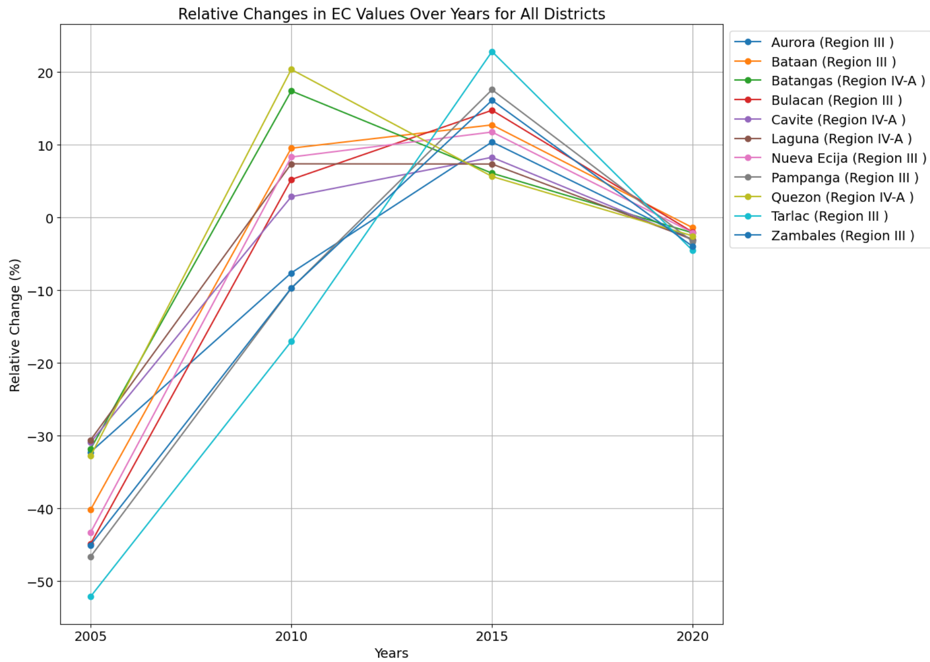

Figure 3.6: Relative Change in EC over time

water regulation, maintenance of air quality, and erosion control. Table 3.5.3 illustrates the changes in ESS over time and the shifting contributions of different regions. For example, Quezon's contribution to total ESS in the study area decreased from 27% in 2001 to 25% in 2020 despite increasing absolute values, suggesting that the presence of other regions where ESS increased at a faster pace. In contrast, Metro Manila's high urban density limits further landcover change. the ESS in the National Capital Region has remained constant.

The trajectory of change in ESS is shown in Figure 3.7 Figure 3.8, which shows proportional changes over time for all districts. Aurora in Central Luzon experienced consistent

Region	**District**	**ESS 2001**	**ESS 2005**	**ESS 2010**	**ESS 2015**	**ESS 2020**
Region III (Central Luzon)	Aurora	125,449	125,241	125,410	125,379	125,115
Region III (Central Luzon)	Bataan	47,007	47,854	48,535	48,897	49,665
Region IV-A (Calabarzon)	Batangas	103,423	104,219	104,650	110,087	108,660
Region III (Central Luzon)	Bulacan	86,262	88,127	88,522	89,180	88,574
Region IV-A (Calabarzon)	Cavite	30,086	30,413	30,263	33,529	32,788
Region IV-A (Calabarzon)	Laguna	76,948	76,777	76,706	77,828	77,294
Region III (Central Luzon)	Nueva Ecija	148,649	151,516	151,843	153,507	154,449
Region III (Central Luzon)	Pampanga	50,566	50,444	49,539	51,298	51,677
Region IV-A (Calabarzon)	Quezon	334,221	336,433	338,268	340,805	339,851
Region IV-A (Calabarzon)	Rizal	59,605	60,448	60,971	61,784	61,648
Region III (Central Luzon)	Tarlac	80,303	81,113	81,329	82,599	83,617
Region III (Central Luzon)	Zambales	145,521	147,083	145,993	145,093	146,117

Table 3.3: Ecosystem Service Supply (ESS) (per hectare per year)

Figure 3.7: Choropleth map showing change in ESS over time

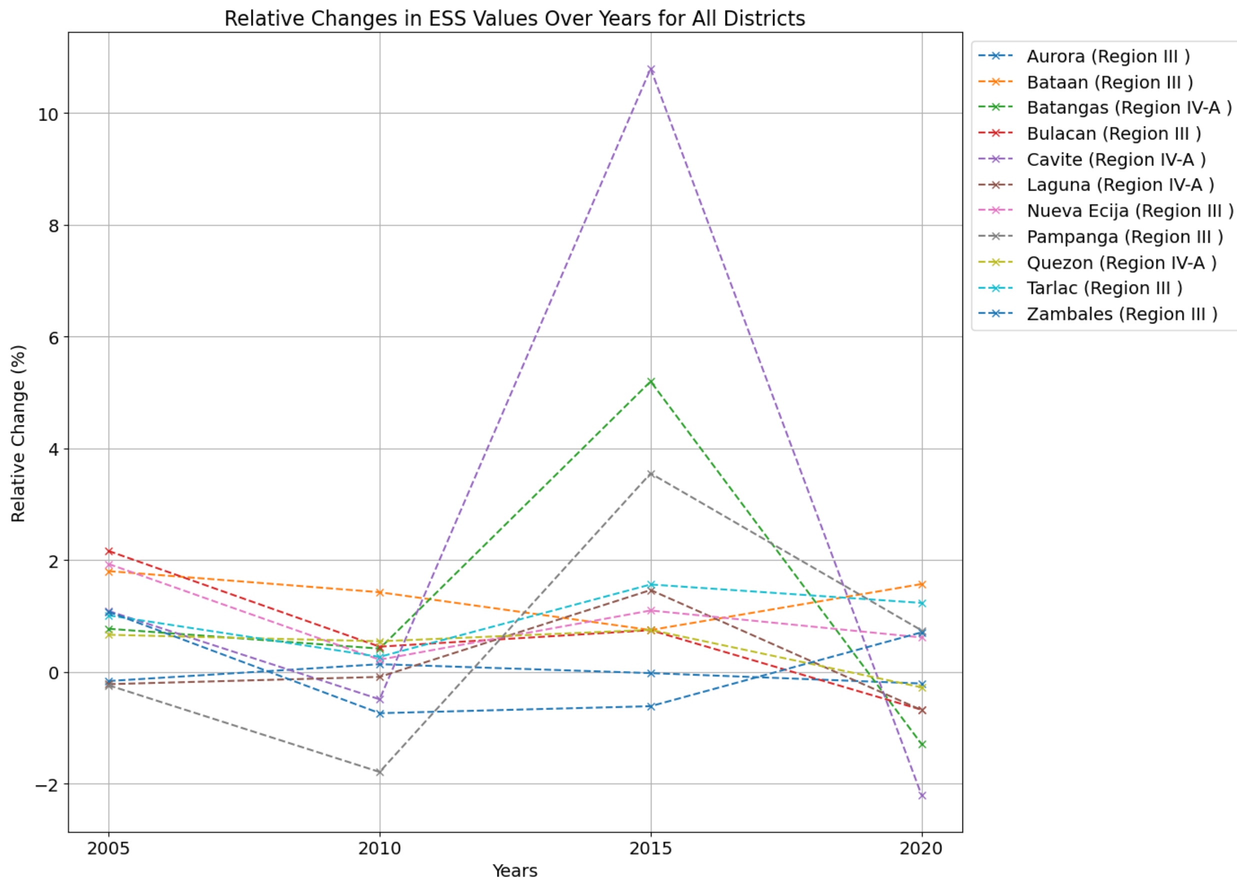

Figure 3.8: Line graph showing change in ESS over time for all districts in the study area

ESS with minimal variations, while Bataan experienced fluctuations, increasing by approximately 4.02% from 2001 to 2005, followed by a substantial rise in the subsequent period. In Region IV-A, Batangas witnessed a decrease in ESS during the period 2010-2015, coinciding with substantial urban land expansion. Similarly, Bulacan experienced a reduction in ESS and forest cover during the same period, highlighting the potential impact of urbanization on ecosystem services.

The general trend in the change of the ESS indicates a relatively low sensitivity to changes in land cover, particularly the depletion of natural vegetation. However, Quezon in Region IV-A exhibited the highest ESS value in 2020 despite significant land cover changes, including urban area expansion. This positive correlation between urban expansion and improved ESS in certain regions suggests resilience and the potential to maintain or even improve ecosystem services despite urbanization.

The analysis of the ecological condition (EC) and the supply of ecosystem services (ESS) in the regions surrounding Metro Manila reveals varying impacts of urbanization. Metro Manila itself saw minimal changes in EC despite increased urbanization, while surrounding provinces such as Batangas, Laguna, and Bulacan experienced significant declines in EC due to urban expansion and forest loss. Regions farther from Metro Manila generally maintained better EC values. In the context of ESS, while Quezon exhibited an absolute increase, its proportional contribution to the total ESS supplied by all landscapes in the area modestly declined from 2001 to 2020. This decline is likely attributable to comparatively higher ESS growth rates in Batangas, Nueva Ecija, Zambales, and Cavite. Notably, Zambales and Quezon demonstrated an increase in average ESS per hectare. Conversely, Metro Manila exhibited minimal change in ESS values, a consequence of its high urban density and relatively less landcover change. Figure 3.9 illustrates the EC and ESS scale proportions for all study areas, highlighting regions with notable EC inputs at the beginning of the research in 2001. These regions are juxtaposed against the 2020 EC heatmap. Regions with high EC are marked in red, while those with elevated ES values are also indicated in red. Areas showing minimal EC changes and low EC values are shown in blue.

The heatmap in the top right corner indicates variation in EC from 2001 to 2020 and on bottom left are corresponding values for ESS trajectories across regions. Aurora, marked in blue, maintained stable ESS, while Bataan exhibited fluctuations. Batangas and Bulacan saw reductions in ESS aligned with urban growth and forest loss. Generally, regions closer to Metro Manila experienced more substantial declines in EC and ESS, while more distant regions, such as Isabela, made more positive contributions to EC. Quezon showed an increase in ESS by 2020 despite urbanization. EC is spatially autocorrelated; poor EC in one area often means poor EC in nearby areas. In contrast, ESS values do not show the same spatial correlation because ESS can be managed. Urban green cover and biodiversity can be maintained, preventing significant declines. This management capability leads to weaker EC-ESS connections. Initial findings suggest that, unlike EC, which depends on natural processes and proximity, ESS can be managed effectively, explaining the weaker spatial association between neighboring ESS values.

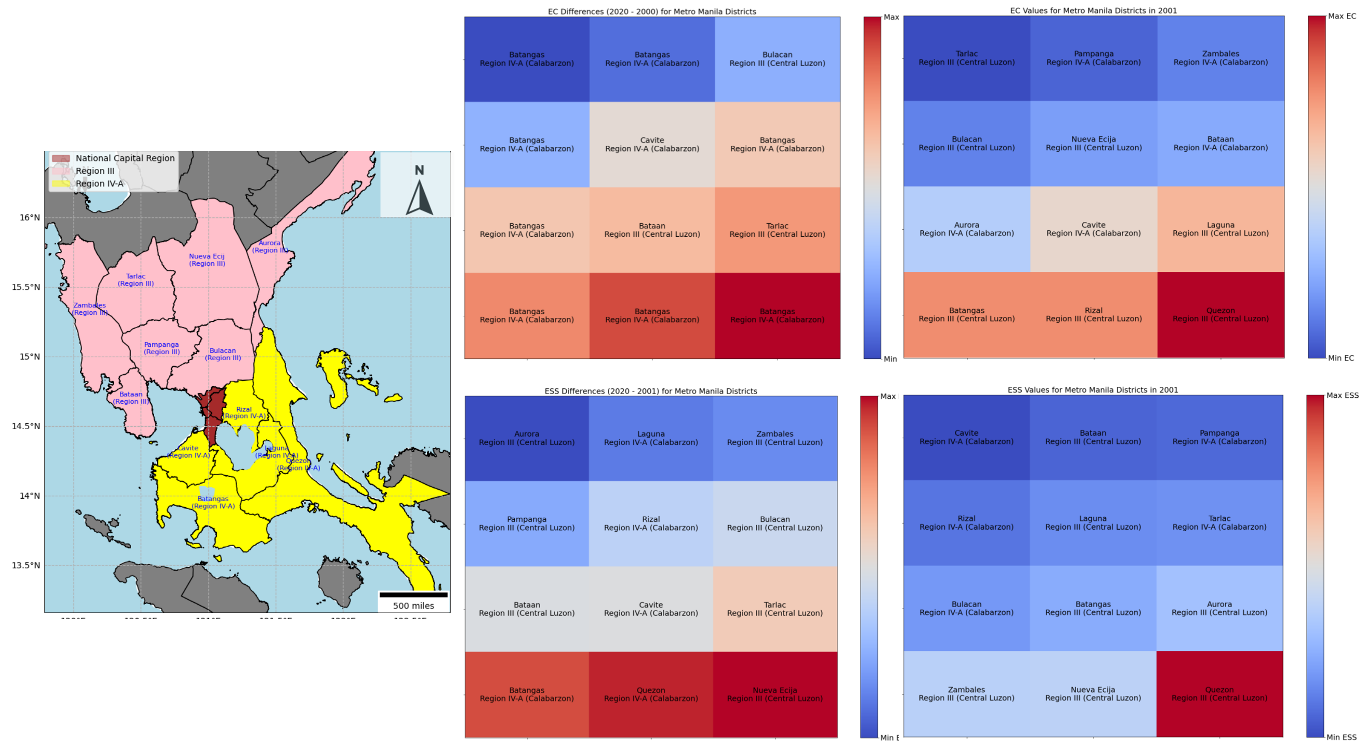

Figure 3.9: Intensity Map: Comparison of Ecosystem Condition and Service Supply in Metro Manila from 2000/2001 to 2021

3.5.4 Impact of Urbanization on Ecosystem Condition and Ecosystem Service Supply (RQ 3)

This section addresses Research Question 3: Is there a spatial autocorrelation between urbanization and its impact on Ecosystem Condition (EC) and Ecosystem Service Supply (ESS)? Autocorrelation in this study refers to the spatial similarity between neighboring geographical units in relation to the impacts of urbanization. According to Moran's I statistic, the values of Ecosystem Condition in neighboring districts are more similar than they would have been if it were just predicted by chance. With significant positive values of Moran's I statistic, adjacent districts are likely to show similar traits if one district has significant urbanization or ecological state.

The research indicates that urbanization and variations in ecosystem services and conditions are not randomly dispersed but follow a specific trend, with Metro Manila playing a significant role. This trend shows that districts closer to each other exhibit more urbanization and related ecological changes. Understanding spatial autocorrelation helps to elucidate urban expansion dynamics and its ecological impacts. Autocorrelation analysis, particularly using Moran's I, is crucial in spatial data analysis. It determines how spatial data correlate with each other. Significant autocorrelation areas can indicate where urban planning efforts are needed to preserve ecosystem services. Moran's I measures spatial autocorrelation for each variable; positive values indicate clustering of similar values, while negative values indicate dispersal. Table 3.5.4 shows the results of the autocorrelation. 'Expected I' represents the expected Moran's I for no spatial autocorrelation, close to -1/(n-1), and is constant at -0.067 for all variables. The p-value in the table indicates the probability of observing a more extreme Moran's I under the null hypothesis of no spatial autocorrelation. A low p-value (commonly ¡0.05) implies significant spatial autocorrelation.

Variable	Moran's I	Expected I	p-value
EC 2000	0.549	-0.067	0.001
EC 2005	0.293	-0.067	0.014
EC 2010	0.542	-0.067	0.001
EC 2015	0.543	-0.067	0.001
EC 2020	0.542	-0.067	0.001
ESS 2001	-0.030	-0.067	0.339
ESS 2005	-0.035	-0.067	0.359
ESS 2010	-0.033	-0.067	0.367
ESS 2015	-0.030	-0.067	0.345
ESS 2020	-0.035	-0.067	0.371

Table 3.4: Results from autocorrelation analysis

EC 2000, EC 2010, EC 2015, and EC 2020 show a high degree of autocorrelation. These variables have high Moran's I values (0.549, 0.542, 0.543, and 0.542, respectively) and very low p-values (0.001 for each), indicating that they exhibit strong positive spatial autocorrelation. The significance of spatial autocorrelation is further reinforced by the p-values, which are well below the common alpha level of 0.05, suggesting that the observed spatial patterns in these variables are highly unlikely to be due to random chance. EC 2005 has a moderate Moran's I value of 0.293 with a p-value of 0.014, which is also below the 0.05 threshold, indicating that there is a significant positive spatial autocorrelation, but it is weaker compared to the other EC variables.

The non-significant variables are ESS2001, ESS2005, ESS2010, ESS2015, and ESS2020. All these Ecosystem Service Supply indicators have negative Moran's I values very close to zero and well above the 0.05 p-value threshold. This suggests there is no significant spatial autocorrelation detected for these variables; the observed pattern could be due to random distribution. Table 3.5.4 illustrates the variability in ecosystem condition and the supply of ecosystem services across the study area for the years 2000, 2005, 2010, 2015, and 2020. The figures indicate significant positive spatial autocorrelation, implying that similar values tend to cluster. It is observed that EC is spatially autocorrelated; if a region has poor EC, neighboring regions are also likely to have poor EC. Conversely, ESS values do not show this spatial correlation. This difference can be attributed to the manageability of ESS: urban green cover and biodiversity can be maintained, preventing significant decline. This management capability may explain the weaker and distinct relationship between EC and ESS. In terms of Ecosystem Service Management, initial findings suggest that unlike EC, which is largely dependent on natural processes and proximity, ESS can be effectively managed, accounting for the weaker spatial association between neighboring ESS values.

3.6 Discussion

3.6.1 Impact of Urbanization on Ecosystem Condition

This study explores the relationship between urbanization and its impact on ecosystem condition (EC) and ecosystem services (ES) in and around Metro Manila. After calculating the values of EC and ES for all time periods, we perform an analysis to determine the spatial pattern of the change in land cover. Using an autocorrelation analysis, we unveil spatial patterns and relationships among neighboring districts, providing an understanding of the nonrandom distribution of urbanization effects in the study area. The observed spatial autocorrelation in the Ecosystem Condition values implies that the Ecosystem Condition in areas closer to Metro Manila will be similar to that of Metro Manila. Moran's I values and low p-values from autocorrelation analysis validate the significance of these spatial relationships.

Land cover in Metro Manila was already highly built up by the year 2000. This affects the provisioning services, including the production of food in the city. Clean water, food, and even air purification depend on the land cover of areas surrounding the region. Here, the land cover of the bordering peri-urban zones plays a pivotal role in shaping the direction and extent of urban sprawl. The argument stresses the importance of these periurban areas in mitigating the adverse effects of urban sprawl and suggests that the natural landscapes or permeable surfaces within these regions are crucial for ecological functions like groundwater recharge. It implies that urban expansion not only transforms the land cover, but also potentially affects the ecosystem conditions of the areas in close proximity.

The change in land cover is intrinsically related to Ecosystem Condition. The analysis shows that there is a negative association between the increase in urban land cover and ecosystem conditions. Specific areas such as Batangas, Laguna, and Bulacan have experienced significant growth in urban land cover and a simultaneous decline in their average EC scores. Metro Manila's slight increase in urban area did not significantly impact its EC, potentially due to the pre-existing high level of urbanization and the associated limited scope for further change in land cover that would impact EC. Changes in land cover composition, especially the depletion of forest areas, have far-reaching implications for ecosystem services. These include regulatory services such as climate and disease regulation, supporting services such as nutrient cycling and soil formation, and provisioning services such as food and water supply. Our analysis also found that proximity to Metro Manila appears to be a significant factor in the rate of urban expansion, with nearby provinces such as Batangas, Laguna, and Bulacan showing considerable increases in urban land cover. This spatial trend points to the influence of major urban centers on surrounding land cover dynamics.

Urban expansion was particularly concentrated near Metro Manila and was significant in provinces like Batangas, Laguna, Pampanga, Bulacan, and Cavite. Minimal changes were observed in provinces such as Abra, Apayao, Ifugao, Quirino, and Mountain Province. The aggregate urban and built up land across all provinces expanded by 5% or 112.93 square kilometers between 2001 and 2020 from 2258 square kilometers. analysis shows that urbanization negatively impacts the EC of an area, with Metro Manila's urbanization having minimal EC effects, while Batangas, Laguna, and Bulacan experienced EC declines due to changes in the urban and forest areas. Regions further from Manila with higher EC are closer to their pristine or best EC. Elevated normalized EC values signify the optimal environmental condition. Areas farther from Manila with high EC are nearer to this ideal EC. Low normalized EC, indicating the most deteriorated condition seen in the area, was found in provinces such as Batangas, Laguna, and Bulacan as a consequence of urbanization. Urban expansion occurred primarily near Metro Manila and significantly in Batangas, Laguna, Pampanga, Bulacan, and Cavite, with minimal changes in Abra, Apayao, Ifugao, Quirino, and Mountain Province. Urban and built-up land expanded by 5% or 112.93 square kilometers from 2258 square kilometers between 2001 and 2020. The process negatively impacts EC, with Metro Manila showing minimal EC effects, while Batangas, Laguna, and Bulacan experienced declines in EC due to changes in urban and forest areas.

3.6.2 Effects of Urbanization on Ecosystem Service Supply

To explore this link, we conducted an autocorrelation analysis of EC and ESS values within the study area over the twenty years leading up to 2020, with data divided by administrative boundaries. The findings indicate that the Ecosystem Condition in one region significantly affects the Ecosystem Condition in adjacent regions. Given that the Ecosystem Service Supply in one area operates independently of changes in ESS values in other regions, there is, therefore, no spatial correlation among Ecosystem Service Supply. Ecosystem Services are delivered to designated regions irrespective of their ecosystem conditions. Enlargement of croplands and the persistence of grasslands in certain districts indicate agricultural intensification. This connection has also been acknowledged by studies on Southeast Asian Agriculture (Alauddin & Quiggin, 2008; Malaque & Yokohari, 2007). The observed declines in forest cover and increases in built-up areas that accompanied increasing urbanization levels are considered a well-established cause of habitat fragmentation and habitat loss. Studies such as those by Beninde et al. (2015) and Lafortezza et al. (2013) explore this relationship in detail. The weakening of ecosystem condition was detected in highly urbanized districts such as Batangas and Laguna. This aligns with the findings of MacDonald et al. (2008) regarding the decline in water resource quality due to urbanization impacts. Our analysis of regions such as Zambales and Quezon reveals that these areas contribute a higher amount of ecosystem services per hectare per year on average. This finding highlights the importance of extensive forest cover and highlights the importance of peri-urban habitats as discussed in studies by Zasada et al. (2011) and Lasco et al. (2014).

However, on a larger scale, the dependence of Metro Manila on surrounding areas for essential provisioning services, due to its dense population, and heavily built up land revealed by our analysis reflects the resource transitions described by Richards and VanWey (2015). Their paper argues that cities, as they expand, have evolved from net exporters to importers reliant on connected regional ecosystems.

By examining land-use changes and their impacts at a more granular district level, our study sheds new light on Metro Manila's expansion trends documented by Estoque and Murayama in Estoque, & Murayama (2013). Landscape pattern and ecosystem service value changes: Implications for environmental sustainability planning for the rapidly urbanizing summer capital of the Philippines. The theory suggested therein postulates that urban growth happens in cycles, with phases of outward expansion (diffusion) followed by phases of consolidation and merging (coalescence). We build on Estoque and Murayama's work by incorporating updated data and applying a finer spatial analysis to understand the effects of urbanization on ecosystem services and conditions. While Estoque and Murayama looked at broader spatial patterns of urban growth using remote sensing and GIS, we focus more deeply on the district-level changes and their ecological impacts from 2000 to 2020. This detailed analysis offers a more nuanced perception of how urban centers like Metro Manila influence their peri-urban and rural surroundings.

Specifically, our findings support Estoque and Murayama's diffusion-coalescence urban growth theory, which describes the expansion and merging of urban areas. By analyzing changes in land cover and ecosystem characteristics (EC) in detail, the study shows that urban growth has widespread impacts beyond the immediate urban boundaries. The approach used in this research employs spatial autocorrelation techniques to understand the similarities and continuity between different land covers. This highlights how interconnected urban and rural ecosystems are and emphasizes the importance of regional planning to mitigate negative environmental effects. The results highlight the critical role of peri-urban areas in maintaining ecological balance and providing essential ecosystem services to cities that are expanding rapidly. The study stresses the importance of sustainable land management and conservation practices to ensure that urban growth does not undermine ecological integrity and the well-being of communities both inside and outside of urban centers. Building on Estoque and Murayama's work, this study not only supports their conclusions but also provides a more detailed view of the spatial dynamics involved. Using recent data and rigorous spatial analysis techniques, we can better understand the complex impacts of urbanization. This approach enriches current knowledge and offers practical insight for policymakers and urban planners who aim to balance development with ecological preservation.

This study focuses on urbanization in relation to land cover change. The increase in urban land cover from 2258 sq km to 2371 sq km, while seemingly modest, has been accompanied by significant declines in the extent of forests and, to a lesser extent, savannas. These changes reflect broader regional development trends and highlight the pressure exerted on natural landscapes by expanding urban centers (Cheng, 2013; Naikoo et al., 2022, 2023). In contrast to forests, croplands have shown moderate expansion, indicative of the ongoing need to support agricultural production. However, on the ground, this expansion could look different, with regions like Isabela seeing marked increases, while areas such as Pangasinan and Cavite have witnessed declines, pointing to the complex interplay between urbanization, infrastructure development, and agricultural intensification.

3.6.3 Dependency on External Ecosystem Services

By calculating ESS, the study examines whether urbanization is linked to changes in ecosystem services. ESS was evaluated using air pollution levels, vegetation, urban bird species, and structural indicators such as tree canopy and green spaces. Studies state that urbanized areas, particularly Metro Manila, heavily rely on ecosystem services sourced from less urbanized regions (Smith et al., 2015; Brown and Fisher, 2016). This finding supports the theory that urbanization negatively impacts ecosystem services by reducing natural land cover and increasing environmentally harmful human activities (Johnson, 2017; Harris et al., 2018). However, despite the spatial correlation observed, the Moran's I values indicate that the relationship is not significant.

The analysis reveals a significant positive spatial autocorrelation for Ecosystem Condition (EC) variables, as demonstrated by Moran's I statistic, indicating that areas near urban centers like Metro Manila tend to have similar EC values. This suggests a clustering effect for ecological conditions closer to urbanized areas. In contrast, no significant spatial autocorrelation is observed for the Ecosystem Service Supply (ESS) variables, implying that the ESS values are not influenced by proximity to urban centers in the same way as the EC values. These findings suggest that, while urban centers exhibit similar ecological conditions, driven by urbanization patterns, the distribution of ecosystem services is more random and does not correlate strongly with urbanization. This highlights different spatial influences on ecological conditions and ecosystem services in relation to urbanization processes. One foreseeable reason for this trend could be the difference in scale and distribution of ecological conditions versus ecosystem services. Ecosystem Conditions are often directly impacted by urban development, leading to similar patterns in nearby areas. However, ecosystem services can be influenced by a wider range of factors beyond just urbanization, such as natural landscape features, agricultural practices, or conservation efforts. This could result in a more dispersed and less spatially correlated distribution of ecosystem services compared to ecological conditions.

Chapter 4

URBAN EXPANSION AND ECOSYSTEM HEALTH: EXPLORING THE DYNAMICS OF LAND-COVER CHANGES AND ECOSYSTEM SERVICES IN THE NATIONAL CAPITAL REGION OF INDIA

The Delhi National Capital Region (NCR) is one of the largest urban areas in the world. This study aims to analyze the impacts of landcover change on ecosystem conditions and service supply patterns in the Delhi NCR region from 2001 to 2020. Over two decades, the analysis demonstrated substantial expansion in urban land cover, particularly in Gurgaon and Faridabad. The spatial assessment conducted in this study reveals a concentration of ecosystem services, suggesting that these services are concentrated in specific areas rather than being uniformly dispersed. The spatial analysis performed in this research indicates an aggregation of ecosystem services, implying that these services are localized in specific regions independent of the mere presence of respective ecosystems that provide them. This suggests a potential interrelation of various ecosystems and emphasizes the importance of targeted conservation initiatives. The results also indicate a strong spatial dependence in the regions where the Ordinary Least Squares (OLS) spatial regression model was applied, suggesting that changes in landcover are not randomly distributed but are influenced by spatial factors. This study presents a valuable first analysis that employs standardized methods to quantify the effects of urbanization on ecosystem conditions and ecosystem service delivery patterns. By providing a comprehensive assessment of the spatial and temporal dynamics of landcover change, this research contributes to a better understanding of the environmental impacts of urban growth and offers insights for future urban planning and conservation strategies in the Delhi NCR region. Although urban areas occupy less than 1% of the Earth's total land surface (Schneider et al., 2018), they have a significant ecological footprint, disproportionately affecting both their local and surrounding ecosystems (Alberti et al., 2003; Angel et al., 2011). They leave a disproportionate ecological footprint, which has long lasting impacts (Alberti et al., 2003; Angel et al., 2011). The process of urbanization acts as a pivotal force driving land use and land cover transformations that have enduring consequences on Earth's ecosystems (Turner et al., 1994; Daily, 1997; Lambin et al., 2001; Alberti & Marzluff, 2004; MEA, 2005). The wide extent and long-lasting nature of these changes have altered the crucial ecosystem services provided by natural landscapes. The fragmentation of natural landscapes beyond certain limits can increase pollution and decrease ecosystem resilience over time. Consequently, this has altered the structure and function of both terrestrial and aquatic ecosystems globally (MEA, 2005; Grimm et al., 2008; TEEB, 2011). Effective management of these longstanding environmental issues necessitates a thorough strategy. This approach could combine various methods to assess and value ecosystem services, ensuring the consideration of the effects of urbanization in multiple domains. Combining insights from various disciplines enables an in-depth analysis of urbanization's ecological impacts (MEA, 2005; Grimm et al., 2008; TEEB, 2011).

Various methods, including biophysical quantification (Balvanera et al., 2005), socio-cultural approaches (Sodhi et al., 2010), and economic valuation (Castro et al., 2011; Martín-López et al., 2012), are used to support environmental policy decisions. Economic and monetizable valuation of ecosystem services can improve the understanding of problems and trade-offs, facilitate decision making, illustrate the distribution of benefits, and enable cost-sharing for management initiatives. This, in turn, can spur the development of innovative institutional and market instruments that promote sustainable ecosystem management (Chee, 2004; Daily, 1997). Valuation of ecosystem services, which encompasses aspects beyond monetary considerations, can raise awareness and promote the protection and enhancement of ecosystems globally (de Groot et al., 2010, 2012). However, in resource management decisions, the marketed benefits of ecosystem services are often prioritized over nonmarketed benefits, even though the latter are frequently substantial and sometimes more valuable than the marketed ones (MEA, 2005). Although monetary valuation helps compare resource allocation between competing uses, qualitative assessment also has merit for resources with little economic value, yet great potential for provisioning ecosystem services (de Groot et al., 2012).

Recognizing the impact of urbanization on ecosystems in the NCR region of India is crucial. Major disasters such as floods and environmental changes can severely affect large populations. The destruction of wetlands and natural features vital for water purification worsens urban flooding, as evidenced by Delhi's severe floods in 2023 (Down to Earth, 2023). This highlights the essential role these natural features play in maintaining ecological balance and resilience. This lack of resilience, manifested in the inability of ecosystems to absorb and mitigate the effects of extreme weather events, increases the vulnerability of urban areas to natural disasters. However, in summer 2024, just ten months after the flood, Delhi faced a severe water shortage. The depletion of groundwater reserves, coupled with erratic rainfall patterns, has strained the city's water supply. This situation calls for immediate and comprehensive measures to restore and protect natural ecosystems, such as wetlands, which play a crucial role in water management. Urbanization also leads to habitat loss and declining pollinator populations, which pose serious threats to food security. The failure of ecosystems to remain resilient after substantial changes caused by rapid urbanization is a growing concern. Addressing the deficit in ecosystem services is essential for ensuring long-term sustainability and resilience of both urban and peri-urban regions, considering their vital role in economic progress and human well-being. The Delhi NCR must prioritize ecological safety and sustainability, as the region is home to a large population and serves as an economic hub for the country. The protection of ecosystems in and around the NCR will not only protect the well-being of its residents but will also contribute to the overall resilience and stability of the region in the face of increasing environmental challenges.

Urbanization and its ecological impacts are critical areas of study in rapidly developing regions. This study examines the Delhi NCR and surrounding areas to understand urbanization dynamics and ecological impacts. The NCR of Delhi and its satellite cities (Noida, Gurgaon, Faridabad, Ghaziabad) serve as a case study for land conversion and environmental change in India shown in Figure 4.1 These areas show a variety of development trajectories, from residential and commercial growth in Noida to the IT and finance sectors of Gurgaon, illustrating the diversity of urban sprawl and their respective impact on surrounding ecosystems.

The study also includes an analysis of regions like Bhiwani, which are transitioning from industrial to residential land use, shedding light on the ecological consequences of such transformations. The concept of an Ecosystem Service deficit, where the demand for services in urban areas surpasses their capacity to supply them, is a central theme of this research. The main goal is to determine the characteristics and consequences of these changes on the sustainability and resilience of both urban and peri-urban zones, considering the vital role cities have in economic growth and the substantial amount of resources they consume.Addressing the Ecosystem Service Deficit requires a multifaceted approach that involves the integration of biophysical quantification, sociocultural analysis, and economic valuation methods. By raising awareness of the value of ecosystem services and their significance beyond monetary considerations, decision makers can be encouraged to prioritize the protection and enhancement of ecosystems in urban planning and development processes. The study employs an approach that integrates all relevant aspects of local ecosystems to assess the relative im-

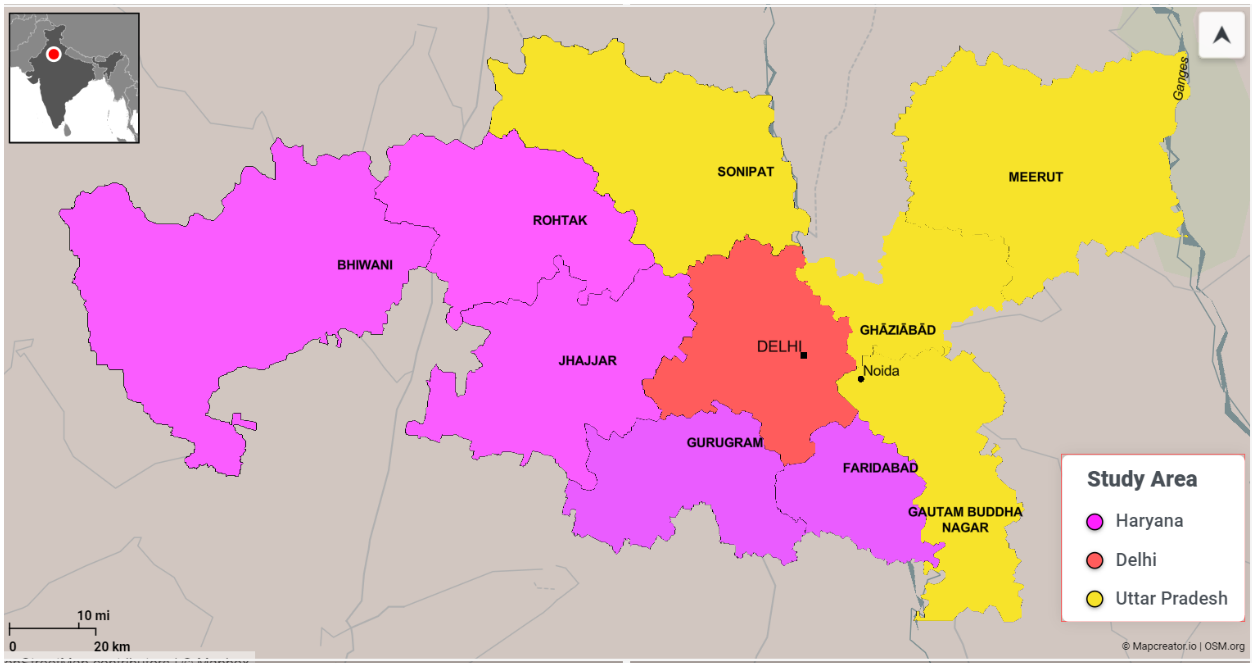

Figure 4.1: Delhi and adjoining districts of the National Capital Region

portance of different landscapes in the NCR with respect to the ecosystem services they provide. To achieve this, the research uses coefficients specifically developed for the Delhi NCR through previous studies(Maurya and Punia, 2019). Coefficients are fundamentally numerical figures created through thorough research aimed at evaluating particular facets of ecosystems. These coefficients function as instruments to measure and contrast the value of ecosystem services among different land uses and landscapes within the area. By incorporating these locally derived coefficients, the study aims to provide a more accurate and context-specific assessment of the ecosystem services provided by different areas within the NCR. This deficit coefficient is used to measure the gap between the demand for ecosystem services and the ecosystem's ability to provide them, highlighting areas where urban growth may be unsustainable.

The Common International Classification of Ecosystem Services (CICES) is a standardized framework for categorizing and describing ecosystem services, which facilitates the comparison and integration of different valuation approaches (Haines-Young & Potschin, 2018). In this study, the CICES methodology is used to systematically assess and classify ecosystem services provided by the NCR and its surrounding areas. This research uses the CICES framework to identify and quantify provisioning, regulation, and cultural services impacted by urbanization. This approach allows for a comprehensive understanding of the trade-offs and synergies between different ecosystem services, as well as the potential impacts of land-use changes on human well-being. The use of CICES also enables the integration of biophysical, socio-cultural, and economic valuation methods, providing a holistic perspective on the value of ecosystem services in the context of urban development. By adopting this standardized methodology, the study contributes to the growing body of research on ecosystem services and supports the development of evidence-based policies for sustainable urban planning and management in the NCR and beyond.

4.1 Literature Review

Rapid urbanization of Delhi's NCR is transforming its landscape, drawing scholars interested in its environmental and social impacts. This transformation brings significant shifts in social and economic structures. Interdisciplinary research in economics, public health, environmental science, and urban planning/governance reveals how urban growth affects ecosystem services and human well-being. Economic studies show urbanization fosters economic development but increases income inequality. Public health research highlights better access to healthcare and higher exposure to pollution and lifestyle diseases. Environmental science examines habitat degradation and biodiversity loss, while urban planning/governance research addresses sustainable urban growth challenges and opportunities. This section identifies patterns linking land cover changes to sociological, economic, and governance transformations that drive urban development. These patterns emphasize the complex interactions between human activities and natural systems, stressing the need for integrated urban planning. Figure 4.2 presents a flow chart of the main literary themes and supporting literature, offering a comprehensive overview of the various impacts of urbanization in the Delhi NCR.

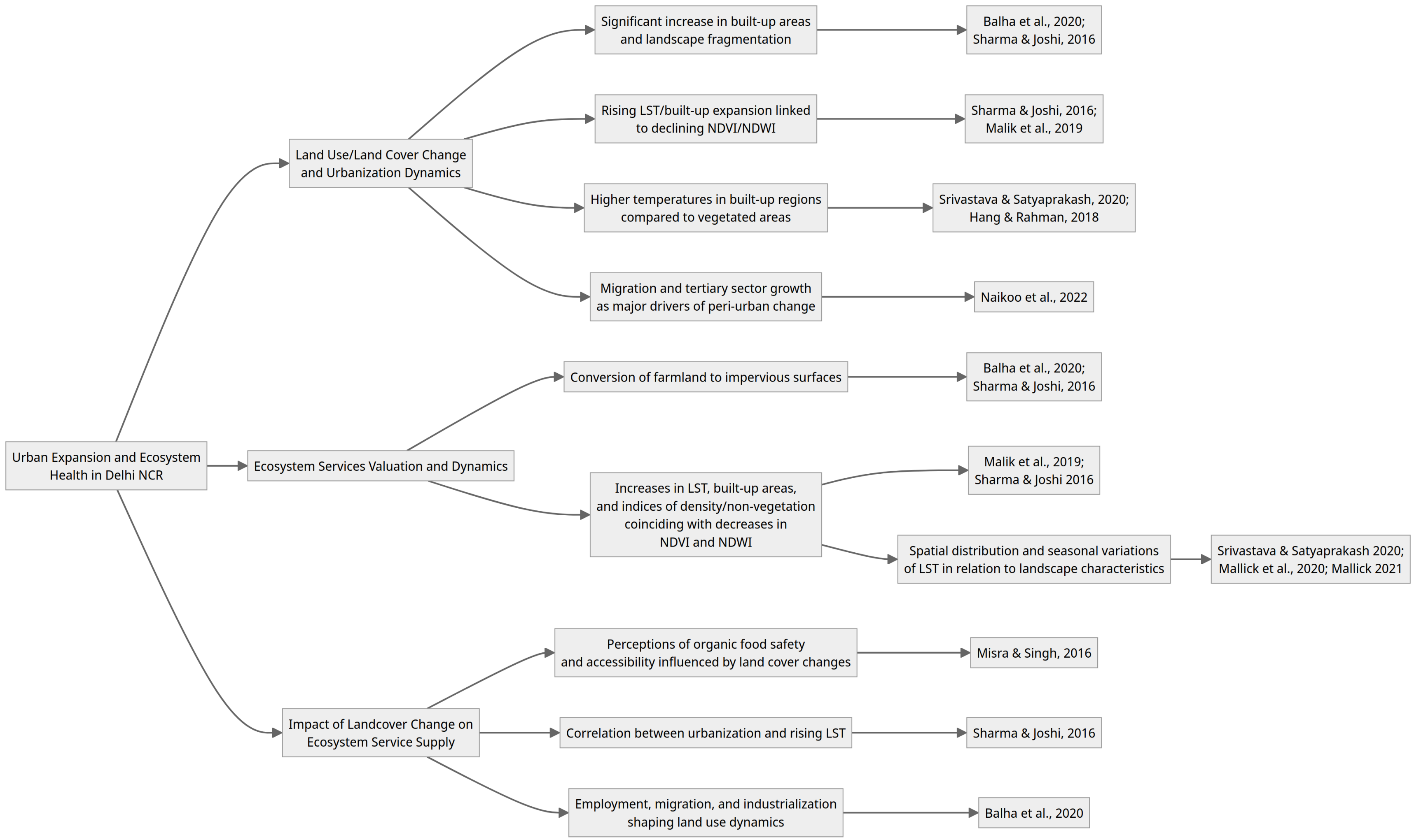

Figure 4.2: Figure showing key themes concerning studies on urbanization impacts in Delhi, NCR

4.1.1 Land Use/Land Cover Change and Urbanization Dynamics in Delhi NCR

Several studies have used remote sensing techniques to analyze spatial-temporal patterns of urbanization in Delhi NCR (Balha et al., 2020; Sharma & Joshi, 2016; Malik et al., 2019; Naikoo et al., 2022; Kumar & Sharma, 2023; Singh et al., 2022; Naikoo et al., 2023). These studies have provided insight into the dynamics of urban growth and contributed to the development of secondary data sets. The literature using land cover analysis indicates a significant increase in built-up areas and landscape fragmentation from 1990-2016 (Balha et al., 2020). Sharma & Joshi (2016) and Malik et al. (2019) linked the increase in built-up expansion to the decline in NDVI / NDWI during 2002-2011 and 1998-2011, respectively. Migration and tertiary sector growth were recognized as the main drivers of periurban change from 1990-2018 through regression analyzes (Naikoo et al., 2022). Additional key findings include the rapid expansion of the built-up area along National Highway-48 (Kumar & Sharma, 2023), significant increases in urbanization-driven temperature from 2000 to 2020 (Singh et al., 2022) and the modeling of future growth hotspots (Naikoo et al., 2023). The peri-urban landscape of the Delhi NCR has also received attention. Naikoo et al. (2022) explored the drivers of peri-urban LULC changes, focusing on migration and tertiary employment, while Naikoo et al. (2023) used modeling techniques to forecast probabilities of built-up expansion. Social aspects and impacts on human well-being, such as perceptions that affect healthy food consumption and the effects of increased temperatures and pollution on quality of life, have been considered (Sadoulet & De Janvry, 2000; Willett et al., 2019). Drivers of land use change, including migration, employment, and industrialization, have been identified (Misra & Singh, 2016; Sharma et al., 2020; Naikoo et al., 2020, 2022, 2023; Kumar & Sharma, 2023).

Remote sensing and geospatial methods have been utilized to analyze landscape patterns and urbanization trends, with a particular focus on built-up area fragmentation (Johnson & Haneberg, 2016). Previous studies have also investigated the impacts of urban growth on environmental parameters such as land surface temperature, vegetation cover, and water content (Wu & Zhang, 2017). This body of research has significantly improved our understanding of the interactions between urban expansion and environmental aspects in various regions (Li, Gong, & Li, 2018). Furthermore, advances in modeling techniques and physical parameterization schemes have improved our understanding of environmental dynamics, specifically in the Delhi NCR (Huang & Huang, 2018). Studies have also concentrated on periurban terrains, characterized by a unique blend of urban and rural characteristics, exploring the factors driving changes in periurban land use and land cover (Zhou, Huang, & Cadenasso, 2011). The insights gained from these investigations into the evolving socioenvironmental dynamics within periurban regions have been instrumental in developing a comprehensive understanding of changes in land cover and their impacts on ecosystem services in the Delhi NCR (Liu, Li, & Peng, 2019). Building on this existing knowledge base, the present study aims to contribute to the development of sustainable urban planning strategies that consider the complex interaction between urbanization, land cover dynamics, and ecosystem services.

4.1.2 Impact of Landcover Change on Ecosystem Service Supply

The transformation of land cover within urban areas significantly influences ecosystem services (ESS) and their benefits to human well-being. Research on land cover change and its impact on ESS in urban areas has yielded insights into the complex dynamics between human activities and environmental sustainability. Studies have shed light on various aspects of this relationship, such as how changes in land cover influence perceptions of organic food safety and accessibility (Misra & Singh, 2016), the correlation between urbanization and rising land surface temperatures (LST) (Sharma & Joshi, 2016), and the significant role of employment, migration, and industrialization in shaping urban growth patterns (Balha et al., 2020).

Revolutionary technological advancements in recent years have significantly transformed the investigation of the environmental impacts of urbanization, allowing for an in-depth investigation into previously unexplored dimensions of land cover transformation. Availability of more extensive and detailed datasets has enabled studies conducted after 2000 to explore a broader range of topics, gradually providing a more refined comprehension of urban environmental dynamics over time. In particular, research areas such as future urban expansion modeling, urban heat island effects, water conservation management, and the interplay between vegetation cover and temperature variations have emerged (Sharma & Joshi, 2016; Li, Gong, & Li, 2018; Huang & Huang, 2018). These studies employ sophisticated modeling methodologies and remote sensing technology to investigate the links between land cover changes and the provision of ecosystem services, allowing for a more comprehensive analysis of urban environmental issues and their impact on human well-being (Bai, Dawson, Ürge-Vorsatz, & Delgado, 2018; Zhou, Huang, & Cadenasso, 2011). As urbanization accelerates globally, prioritizing research into the multifaceted impacts of land cover change on ecosystem services and human well-being becomes increasingly vital. By integrating quantitative analyses with qualitative insights, leveraging innovative technologies, and adopting interdisciplinary methodologies, researchers can generate actionable insights that inform sustainable urban planning and governance strategies (Marshall et al., 2024; Waldman et al., 2017). Addressing challenges posed by urban environmental degradation calls for a collaborative and interdisciplinary approach. Researchers, policymakers, and stakeholders need to cooperate in developing effective solutions that safeguard the environment and enhance urban residents' quality of life (Lambin et al., 2001; Alberti Marzluff, 2004; MEA, 2005).

4.1.3 Integrating Spatial and Temporal Patterns

In addition to understanding how urbanization affects ecosystem services and conditions, it is crucial to develop methods that allow for the prompt, systematic, and replicable measurement of landscape changes and their impacts on ecosystem functions (Smith et al., 2020). While current studies recognize the importance of examining land cover changes and their effects on ecosystem services, there is a shortage of standardized methods to evaluate these impacts across different spatial and temporal scales (Jones & Brown, 2018). There remains a significant gap in the literature regarding methodologies that can quantitatively assess the relationship between land cover changes and ecosystem services (ES) and conditions (EC), while minimizing resource use and ensuring reproducibility.

To address this gap, it is necessary to design and implement methodologies that take advantage of quasi-real-time data sources, such as satellite data, to measure changes in ES and EC resulting from land cover modifications (Punya & Maurya, 2022). These methodologies must demonstrate transparency, replicability, and adaptability on different spatial and temporal scales, facilitating the comparison of ES values across diverse landscapes. By developing such methodologies, researchers can create datasets at various scales to better understand the functions of ecosystems in changing landscapes. This understanding is crucial for managing the future impacts of changes in land cover on ecosystem services and conditions (Punya & Maurya, 2022).

The study by Punya and Maurya (2022) addresses this gap by calculating coefficients that can be used to model and quantify ES changes under different land cover scenarios in other areas of the National Capital Region (NCR). Their study period spans from 1992 to 2010, providing a valuable foundation for understanding the long-term impacts of changes in land cover on ecosystem services and conditions. Using these coefficients, researchers can develop data sets on various scales to analyze the relationship between changes in land cover and ecosystem functions. This analysis will enable better management of the future impacts of changing land cover on ecosystem services and conditions in the NCR and beyond. The focus should be on developing comprehensive datasets and understanding the complex interactions between land cover, ecosystem services, and ecosystem conditions, rather than on policy analysis. By doing so, researchers can provide the necessary foundation for informed decision-making and the development of strategies to promote sustainable landscape management and ecosystem conservation.

Delhi, the core urban area of the National Capital Region (NCR) and the administrative capital of India, is a vibrant metropolis enriched by a blend of historical, cultural, and economic elements. Its high population density and varied land use patterns showcase centuries of development and change, from the ancient relics of Old Delhi to the contemporary high-rises of New Delhi. As the political and economic hub of India, Delhi faces significant pressure on its land resources due to ongoing urban sprawl. This growth extends beyond the city boundaries, incorporating adjacent areas such as Gurgaon, Noida, Faridabad, and Ghaziabad, each playing a distinct role in the region's urban landscape and challenges. The study area depicted in Figure 4.1 offers a visualization of these regions.

Gurgaon, colloquially termed the "Millennium City," symbolizes India's rapid economic growth and urbanization. Originally a peripheral satellite town, Gurgaon has quickly evolved into a global hub for IT, finance, and real estate. However, this development has not been without drawbacks, as the city contends with issues such as traffic congestion, air pollution, and declining green spaces. Similarly, Noida, located east of Uttar Pradesh, initially established as an industrial township, has transformed into a thriving urban center with a diverse industrial base, including the IT, manufacturing, and education sectors. Its planned layout, modern infrastructure, and expansive green belts have made it an attractive destination for both residents and businesses, despite facing challenges such as land degradation and water scarcity.

Faridabad, located south of Delhi, has a significant industrial heritage dating back to the post-1947 era. Its diverse manufacturing industries, including the automobile, electronics, and engineering sectors, have flourished due to strategic location advantages and robust transportation access. However, this rapid industrialization has taken its toll on the environment, leading to air and water pollution, as well as the loss of natural habitats. Similarly, Ghaziabad which is located on the eastern fringes of the NCR, has experienced rapid suburbanization, characterized by a blend of urban and rural landscapes. Its growth is fueled by proximity to Delhi, supported by robust infrastructure and affordable housing options. However, similar to other areas of the region, Ghaziabad faces challenges related to urbanization, including loss of biodiversity and the need for sustainable land use planning (Marshall et al., 2024; Waldman et al., 2017).

Although Ghaziabad thrives as an economic hub with industrial clusters and commercial centers, its rapid urbanization has also led to environmental challenges such as pollution and deforestation, demonstrating the need to understand suburban dynamics and their impact on ecosystem services. Meanwhile, Bhiwani, in the western part of the NCR, has experienced significant urban growth from its agrarian roots, driven by improved transportation infrastructure and residential and commercial developments. This transition poses implications for ecosystem services, emphasizing the need to understand the intricate relationships between urbanization, change in land use, and ecosystem health for sustainable peri-urban development.

4.2 Methodology

4.2.1 Spatiotemporal Analysis of Land Cover Change

This subsection delves into the techniques employed to evaluate the spatial and temporal dynamics of land cover changes in the Delhi NCR area, focusing particularly on urban growth and the decline of natural ecosystems (Research Question 1). To address RQ1 and comprehend the impact of urbanization on ecosystem services in peri-urban Delhi NCR, this research uses a diverse approach that combines Ecosystem Service Mapping (Vrebos et al., 2015; Wangai et al., 2019) with remote sensing, GIS analysis, and economic valuation. The goal is to quantify the supply and demand of ecosystem services and determine how they have been influenced by urban growth.

While earlier studies have used high-resolution data from SPOT5 and Sentinel-2 to estimate changes in ecosystem services through the matrix method (Burkhard et al., 2015; Hattam et al., 2015), this study adopts a more comprehensive methodology. It integrates remote sensing and GIS data analysis (Ajmal Jamal, 2021; Biswas Ghosh, 2021) to assess urban expansion and its impact on peri-urban ecosystems. Additionally, it employs landscape metrics to analyze the spatial attributes of land cover patterns (Cai et al., 2016; Hesselbarth et al., 2019) and utilizes economic valuation techniques (Castillo-Eguskitza et al., 2019; Davidson, 2013) to ascribe economic values to ecosystem services. This integrative approach sets this research apart from preceding studies by combining various data sources and analytical methodologies, thereby providing a detailed evaluation of land cover change impacts that encompasses both the spatial and economic dimensions of ecosystem services.

This allows for a deeper understanding of urbanization's effects on peri-urban ecosystems in the intricate and evolving environment of Delhi NCR. The multi-faceted perspective provided by this approach is particularly effective for addressing RQ1 and offering valuable insights into the link between urbanization and ecosystem services in the study region.

To complement the remote sensing and GIS analysis, an on-site visit was carried out in June, 2023 to directly observe the region's changing ecology and understand the land cover transformations by interacting with local stakeholders. The field visit included the following activities: Ground-truthing of land cover classifications: The land cover maps produced from satellite images were verified through direct observations, ensuring the classification's accuracy. Interviews with local residents and experts: Conversations were conducted with local residents, farmers, and environmental experts to gather their perspectives on the historical

Data	Details
MODIS land cover data	Classified into 5 land cover types from 2001-2020 at 500m resolution
Landsat imagery	Used to derive NDMI to assess landscape condition
Air quality statistics	Included PM2.5, NO2, O3 concentrations to evaluate ecosystem chemical state
Spatial land cover datasets	Used to calculate metrics like green space/impervious surface per capita
Population data	Provided demographic information for normalizing indicators

Table 4.1: Data sources used in the landcover change and ecosystem services assessment

land cover changes, the factors driving these changes, and the impacts on the local ecosystem. Documentation of key ecological features: Photographs and field notes were taken to record important ecological features, such as the remaining natural habitats, areas with significant land cover changes, and visible signs of ecosystem degradation or restoration. The insights from the field visit were used to refine the interpretation of the remote sensing and GIS analysis results, providing a more detailed understanding of the land cover change processes and their ecological implications. Local knowledge and observations collected during the field visit also informed the selection of relevant ecosystem services for the study area and the development of the ecosystem capacity matrix.

This research maps ecosystem services to evaluate spatial variations in service supply and ecosystem condition in peri-urban New Delhi over time. Land cover data connect biophysical land change patterns to service impacts. Methods for assessing land cover change differ. Some studies use the matrix method with high-resolution data from SPOT5, Sentinel-2 (Burkhard et al., 2015; Hattam et al., 2021), or Landsat (Estoque et al., 2018). This research utilizes the MODIS MCD12Q1 database with a 500m resolution. The MODIS dataset ensures consistent data across years and broad, accurate land cover categories. Its consistent resolution covers the entire study area over the study period. Table 4.1 lists key data sources. MODIS land cover data and Landsat imagery facilitated the analysis of landscape changes and conditions over two decades. Air quality statistics and spatial data on land cover and population were also used to evaluate the ecosystem and services in relation to urban development. The approach for ecosystem service valuation is suitable for our study's scale, focusing on three administrative regions, and requires modest data for comprehensive analysis over the study period. These composites provide yearly preclassified land cover maps using the International Geosphere-Biosphere Program (IGBP) classification system as outlined in Table 4.2.1.

Habitat Classification (Hattam et al.(2021))	**MODIS MCD12Q1 IGBP Land Cover Classification**
Overall mangrove	Mangroves
Overall coral	Barren or sparsely vegetated (Note: there is no specific class for coral; they might be classified as water)
Overall seagrass	Permanent wetlands or water bodies (Note: seagrass detection might be difficult with MODIS resolution)
Overall sand (Intertidal)	Barren or sparsely vegetated
Overall sand (Subtidal)	Water bodies
Overall mud (Intertidal)	Permanent wetlands
Overall mud (Subtidal)	Water bodies
Overall rock	Barren or sparsely vegetated
Overall coarse substrata	Barren or sparsely vegetated
Overall pelagic	Water bodies
Seaweed farms	Croplands (Note: if the area is large enough to be detected and differentiated from natural water bodies)
Fish cages	Artificial surfaces (Note: might not be detectable due to size/resolution constraints)
Invertebrate aquaculture	Artificial surfaces (Note: might not be detectable due to size/resolution constraints)
Artificial substrate	Urban and built-up
Artificial beaches	Barren or sparsely vegetated

Table 4.2: Land Cover Classes for Sentinel 2 and corresponding MODIS Land Cover Classes

The IGBP framework classifies land into 17 main categories, which are further grouped into broader biomes such as forests, savannas, shrublands, and grasslands. Developed areas (labeled as Developed in the IGBP) include densely populated urban areas and infrastructure like roads and buildings; croplands (Cropland category) refer to agricultural zones on the urban periphery; grasslands (Grassland category) encompass peri-urban grazing areas; forested regions (IGBP Forest categories) include patches of Evergreen Needleleaf forests; and shrublands (Shrubland category) represent areas with secondary succession or disturbed vegetation types. Table 4.2.1 lists the land cover categories identified by previous studies and explains how our research interprets these categories based on their spectral characteristics.

The study followed the approach proposed by Costanza et al. (1997) to identify and monetarily value ecosystem services based on the functioning of ecosystems in the study area. The findings of this study revealed the effectiveness of using generalized ecosystem services value coefficients to estimate the value of ecosystem services in the Delhi NCR. This study is interesting because it applied the approach proposed by Costanza et al. (1997) to assess ecosystem services in a specific urban area and provided insight into the economic value of these services. In recent years, there has been increasing research on the concept and evaluation of ecosystem services in Delhi NCR. Various methods have been proposed for the mapping and evaluation of ecosystem services in the region, including qualitative, quantitative, and monetary approaches.

4.2.2 Assessing the Impact of Land Cover Change on Ecosystem Condition

This subsection will describe the methods employed to evaluate how changes in land cover, such as the increase in urban areas and the loss of natural ecosystems, have affected the ecosystem condition (EC) in the Delhi NCR region (Research Question 2). This study examines ecosystem condition changes in the Delhi NCR from 2000 to 2020. Urban expansion modifies land cover, impacting ecosystem health. The Ecosystem Condition Indicator (ECI) is a composite measure based on NDVI, NDMI, air quality, and tree coverage. NDVI indicates green biomass, NDMI shows moisture, tree cover provides habitat, and air pollutants indicate pressure on ecosystems. A reference point is needed to evaluate current conditions, typically a historical baseline. In urbanized areas like NCR, finding pristine references is challenging, so we use the year 2000. We identify maximum and minimum values for each variable during the study period as reference points. The ECI is the sum of normalized values of NDVI, NDMI, tree canopy cover, green space per inhabitant, semi-natural area, imperviousness per inhabitant, and PM2.5 concentration. We use diverse datasets, including Landsat imagery for NDMI, air quality statistics for pollutants, and spatial land cover data for metrics like green space and semi-natural area. Population data normalize indicators like green space and imperviousness per inhabitant.

By integrating these datasets, our analysis provides a holistic understanding of peri-urban ecosystems, facilitating informed decision making and sustainable management practices. The Normalized Difference Vegetation Index (NDVI) is derived from the near-infrared (NIR) and red spectral bands of MODIS satellite imagery, which are sensitive to the health and density of vegetation, and thus helpful in quantifying vegetation coverage. Similarly, the Normalized Difference Moisture Index (NDMI) uses the short-wave infrared (SWIR) and NIR bands, sensitive to moisture content, to identify moisture-rich areas like water bodies and vegetated lands. Green Space per Inhabitant (m2 / capita) is calculated from MODIS land cover data that distinguish vegetated areas such as parks and forests, dividing the total green area by the population to determine the green space available per person. The percentage of semi-natural areas is determined from the proportion of land cover categories such as shrubs, grasslands, and natural vegetation, which are indicative of areas with minimal human alteration, as identified by MODIS land cover classifications. The imperviousness per resident (m2 / capita) is estimated using the MODIS classifications of urban and built-up areas to calculate the total impervious surface area normalized by population density. Lastly, PM2.5 concentration is inferred from satellite-derived atmospheric data, potentially including aerosol optical depth (AOD) measurements from MODIS, which are indicative of particulate matter concentrations, including PM2.5, providing a measure of air quality. To assess the change in the physical state of peri urban ecosystems, we divided the total urban land cover by population and the Normalized Difference Moisture Index (NDMI) derived from LANDSAT data. Assessment of chemical state was carried out by analyzing air pollutant concentrations obtained from annual AQ Statistics at the district level.

These subindicators offer an accurate, up-to-date, and easily understood metric that facilitates cross-temporal and cross-spatial comparison. Equation 4.1 shows the components of the Ecosystem Condition Indicator (EC):

Components of Ecosystem Condition indicator

$$
\begin{aligned}
\text{EC Indicator} = & \text{ Indicator of NDVI} \\
& + \text{ Indicator of NDMI} \\
& + \text{ Indicator of Green Space per inhabitant} \\
& + \text{ Indicator of Semi Riparian Landcover} \\
& + \text{ Indicator of Imperviousness per inhabitant} \\
& + \text{ Indicator of PM2.5}
\end{aligned}
\tag{4.1}
$$

Estimation of the Ecosystem Condition Indicator highlights the availability of green areas, tree cover, and potential for ecosystem services like temperature regulation, carbon sequestration, and recreational opportunities (de Groot et al., 2002). The analysis of woody vegetation and semi-natural riparian cover serves as a proxy for the diversity and abundance of plant and animal species, indicating the ecosystem's functional characteristics (Dittrich et al., 2017).

4.2.3 Temporal Dynamics between Ecosystem Condition and Ecosystem Service Supply

This subsection outlines the approach to investigate the temporal relationship between declining EC and altered ecosystem service (ES) supply in the Delhi NCR region, varying across different districts (Research Question 3). Ecosystem Services (ES) are benefits humans receive from the natural environment, such as clean air, water, and pollination. This study calculates Ecosystem Service Supply (ESS) using a matrix approach, where services are quantified based on the capacity of types of land cover to provide these services, as shown in Equation 4.1. Values are normalized according to Equation 4.2 for comparison and spatial analysis, helping us understand ecosystem contributions in specific areas. Evaluation involves assigning weights to land covers based on their contribution to provisioning, regulating, and cultural services. For example, forests may be weighted more for habitat and carbon sequestration, while urban areas may be prioritized for air quality regulation and cultural amenities. Quantifying ecosystem services across land covers provides insight into their spatial distribution and relative importance, aiding sustainable land use and management decisions. **Statistical Transformation of Ecosystem Condition Indicator**

$$\text{ECI\_normalized} = \frac{EC - EC\_min}{EC\_max - EC\_min} \tag{4.2}$$

Where:

EC : measured/observed value of the variable,

EC_Max : high condition value for the variable (upper reference level),

EC_Min : low condition value (lower reference level).

The CICES classification underpins our definition and classification of ecosystem services. Our methodology is based on Hattam et al. (2021). While their analysis offers high-resolution land cover classification, the MODIS data we use does not. Thus, land covers were categorized as in Table 2. Quantifying, mapping, or valuing ecosystem services involves classifying and describing them, forming the basis for ecological assessment (de Groot et al., 2002). We utilize the ecosystem services identified in a previous study in the same region, listed in

Table 4.3.

Ecosystem Services	**Functions**
Provisioning Services	Food from Plants, Energy from Plants, Other Materials from Plants, Food from Pelagic Animals, Food from Demersal Fish, Food from Other Invertebrates, Other Materials from Animals, Genetic Material from Animals
Regulating Services	Habitat, Treatment and Assimilation of Wastes or Toxic Substances, Erosion Control, Water Flow Regulation, Maintaining Nursery Habitats, Maintaining Habitats for Charismatic Species, Climate Regulation
Cultural Services	Places for Recreation, Places for Ceremonial Activities, Places for Creative Activities, Places for Knowledge-Based Activities

Table 4.3: Ecosystem Services identified for the study

Other well-known typologies include the Millennium Ecosystem Assessment (MA, 2005) and The Economics of Ecosystems and Biodiversity (TEEB, 2010). More recent iterations, such as the Common International Classification of Ecosystem Services (Haines-Young & Potschin, 2012; Santos-Martin et al., 2018) and Nature's Contributions to People (Pascual et al., 2017), have been adopted by EU initiatives and the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES). The National Ecosystem Services Classification System (NESCS) analyzes policy-induced ecosystem changes on human welfare. The USEPA's classification system for Final Ecosystem Goods and Services (FEGS-CS) (Landers and Nahlik, 2013; Landers et al., 2016) aims for universal applicability, each with unique backgrounds aligning with specific contexts and objectives (Hattam et al., 2021). National, regional, or local assessments often adapt these international systems to suit specific needs (Jiang et al., 2017; Haines-Young & Potschin, 2012). The state of each identified service is approximated using remotely sensed land cover data.

4.2.4 Trade-offs and Spatial Dependencies in Urban and Peri-Urban Ecosystem Services in Delhi NCR

This subsection describes the integration of ecosystem service coefficients for Delhi NCR from previous studies (Maurya and Punia, 2019) and connects with the next section on autocorrelation among districts, addressing Research Question 4. These coefficients quantify and compare the value of ecosystem services in different landscapes and land covers, highlighting critical areas for ecological balance and well-being. We use the 'Ecosystem capacity matrix' approach to assess changes in ecosystem service supply over time (Burkhard et al., 2015; Hattam et al., 2021). This method scores the potential of land use or habitat types to supply ecosystem services based on collected habitat data. Detailed explanation is given in Equation 4.3. The scoring method draws from various data sources and incorporates expert judgment when data is scarce (Campagne & Roche, 2018). We used an ecosystem capacity matrix by Hattam et al. (2021) tailored for Southeast Asia, with service weights adjusted for regional suitability. Morya and Punia (2023) customized a matrix for Delhi NCR landscapes, defining five land cover classes and 11 key ecosystem services based on reviews and stakeholder consultations. Evidence for each land cover-service combination was collected from various sources and supplemented with local expert insights where data was limited. The confidence weights accompanied the scores to acknowledge the uncertainties. Once validated, this matrix allows for a comprehensive spatial mapping of the service potential. Land cover maps are overlaid with matrix scores to visualize ecosystem service delivery patterns. This adaptable methodology for Delhi NCR is based on the approaches of Burkhard et al. (2015) and Hattam et al. (2021), grounded in the local context and priorities.

Ecosystem Service Supply Indicator for n units

$$\sum_{i=1}^{n} \mathrm{ESS}_n = w_1 \cdot A_1 + w_2 \cdot A_2 + \cdots + w_n \cdot A_n \tag{4.3}$$

Where:

w_i : weight assigned to the ith component.,

A_i : area in square kilometers for the ith component.

The study uses the normalization described in Equation 4.4. Statistical transformation was performed to normalize the data within a specified range (usually 0 to 1) without changing the variance of the data. This transformation allows for the comparison of values across different scales and ensures that all values fall within the normalized range of 0 and 1. In this case, the ESS scores are normalized by subtracting the minimum ESS score and dividing it by the range between the maximum and minimum ESS scores. The matrix scores for each land cover can be mapped, along with categories of high, medium, and low potential. This allows identification of areas with good ecosystem conditions. By overlaying with other data on human pressures, like the data this study uses on Ecosystem Service Supply, the relative impacts on ecosystem service provision can be estimated. The three matrices with individual scores can be seen in Appendix1. **Normalization of Ecosystem**

Service Supply (ESS)

$$\text{ESS\_normalized} = \frac{\text{ESS} - \text{ESS\_min}}{\text{ESS\_max} - \text{ESS\_min}} \tag{4.4}$$

Where:

ESS_normalized : Normalized Ecosystem Service Supply score.,

ESS : Original Ecosystem Service Supply score.,

ESS_min : The minimum ESS score observed in the dataset.,

ESS_max : The maximum ESS score observed in the dataset.

4.2.5 Evaluating Spatial Dependencies and Trade-offs in Ecosystem Services

This subsection describes methods to analyze urban ES surpluses/deficits, spatial interdependence in ecological conditions, and service provision across Delhi NCR districts, relating to changes in ES provision to peri-urban regions (Research Question 4). It includes spatial autocorrelation analysis using Moran's I and OLS regression models, discussing implications for ecological management and urban planning. The spatial relationship between Ecosystem Condition and Service Supply for each temporal interval was examined through Moran's I statistic. The ecosystem service supply values and conditions for different time periods, along with their respective spatial units (such as districts or provinces), were merged into a single shapefile. Following the collection and imputation of missing data, a spatial weight matrix was constructed. This spatial weight matrix (W) encapsulates the spatial configuration of the data, defining the spatial relationships between all pairs of spatial units, typically based on contiguity (shared borders) or distance (e.g., inverse distance weighting). This step is pivotal as it dictates the spatial interactions among units. Another critical phase in the analysis is the standardization of the variables. Upon standardization, Moran's I statistic was computed using equation 4.5:

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{4.5}$$

$$
\begin{aligned}
I &= \text{Moran's I statistic} \\
n &= \text{Number of spatial units (e.g., districts)} \\
w_{ij} &= \text{Spatial weight between units } i \text{ and } j \\
x_i &= \text{Value of the variable at unit } i \\
\bar{x} &= \text{Mean value of the variable across all units} \\
\sum_{i=1}^{n} &= \text{Summation over all units}
\end{aligned}
$$

The number of spatial units, N, in our study is 16, representing the smallest administrative divisions, which in this context are districts. The spatial weight quantifies the spatial relationship between two units, potentially based on distance (with closer units having higher weights), contiguity (sharing a common border), or other relational metrics. A higher weight signifies a stronger or more pertinent spatial relationship. In the context of Moran's I, these weights are essential as they determine the degree of spatial influence among neighboring units. The computation of Moran's I statistic was executed using PySAL (Python Spatial Analysis Library). To derive the weights, a vector layer was calculated that includes the centroids of all districts. The matrix was formulated on the basis of the distance variations between the districts. The similarity in the ecosystem values of these centroids underpins our analysis to detect autocorrelation.

4.3 Results

In this section, we present the results of our study, organized into four subsections. Each subsection addresses one research question

4.3.1 Spatial and temporal dynamics of land cover transformations (RQ1)

The analysis of landcover change in the Delhi NCR region between 2001 and 2020 reveals a significant shift towards urbanization, with growth in urban land cover in Gurgaon and Faridabad. Figure 4.3 summarizes landcover shifts from 2000 to 2020. Forested areas have reduced, indicating the expansion of built-up urban spaces at the expense of natural vegetation. The conversion of cropland to urban areas, particularly in regions like Gautam Buddha Nagar, is accompanied by a decline in ecosystem condition. Areas transitioning from forest to cropland or urban areas exhibit varying degrees of ecosystem decline, with urban expansions having a more pronounced impact. Spatial analysis shows clustering of ecosystem services, emphasizing the interconnectedness of ecosystems and the importance of localized conservation efforts.

Transitions, such as Gautam Buddha Nagar from agricultural to built-up (residential and commercial) or Bhiwani from industrial to residential, affect ecosystem service supply (ESS) and link economic activities to ecosystem health. Urban landcover transition improved ESS in Bhiwani but had the opposite effect in Gautam Buddha Nagar, which lost more green cover by the end of the study period. Both cases saw a reduction in ecosystem condition (EC). From 2001 to 2020, Delhi NCR saw significant urbanization, with Gurgaon and Faridabad showing notable growth. Gurgaon, driven by foreign direct investment (FDI), had a 21.29% increase in urban land cover, while Faridabad saw a 44.37% surge. Forested areas decreased, indicating urban expansion at the expense of natural vegetation.

Land conversion from cropland to urban areas is prevalent, especially in Gautam Buddha Nagar, showing a 20.92% decrease in cropland and a 6.87% increase in urban land. This shift leads to ecosystem decline. Meerut and Ghaziabad also show significant land use changes, with Meerut having a 26.84% increase in cropland and an 8.85% increase in urban land. The analysis indicates that landcover change affects ecosystem condition, with urban expansion causing more pronounced ecosystem decline.

4.3.2 Impact of land cover changes on ecosystem condition (RQ2)

To understand the broader implications of land cover changes on ecosystem condition (EC) in the Delhi NCR, it is essential to analyze how these transformations affect the ecological balance within the region. The transition from agricultural to urban landscapes, as well as from industrial to residential areas, underscores the dynamic nature of land use and its consequential impact on ecosystem services. This section delves into the specific changes observed in EC across various districts, highlighting the correlation between urbanization trends and the health of local ecosystems. By examining data from 2000 to 2020, we can identify patterns and draw insights into how urban expansion has altered the ecological fabric of Delhi NCR.

The study of ecosystem conditions in the Delhi NCR region from 2000 to 2020 indicated a general decline in all districts except for Bhiwani and Jhajjar. Alterations are evident across all districts throughout the study period, as shown in Table 4.4. Figure 4.4 illustrates the effectiveness of these land covers in evaluating ecosystem conditions.

Bhiwani saw increases in cropland and urban land cover from 2001 to 2020. However, cropland EC decreased from 24.13% to 21.40% and urban land EC slightly decreased from 2.25% to 2.01%. Delhi saw significant increases in urban land and decreases in cropland cover. The EC of Delhi's urban land decreased from 43.89% in 2001 to 40.80% in 2020. Faridabad

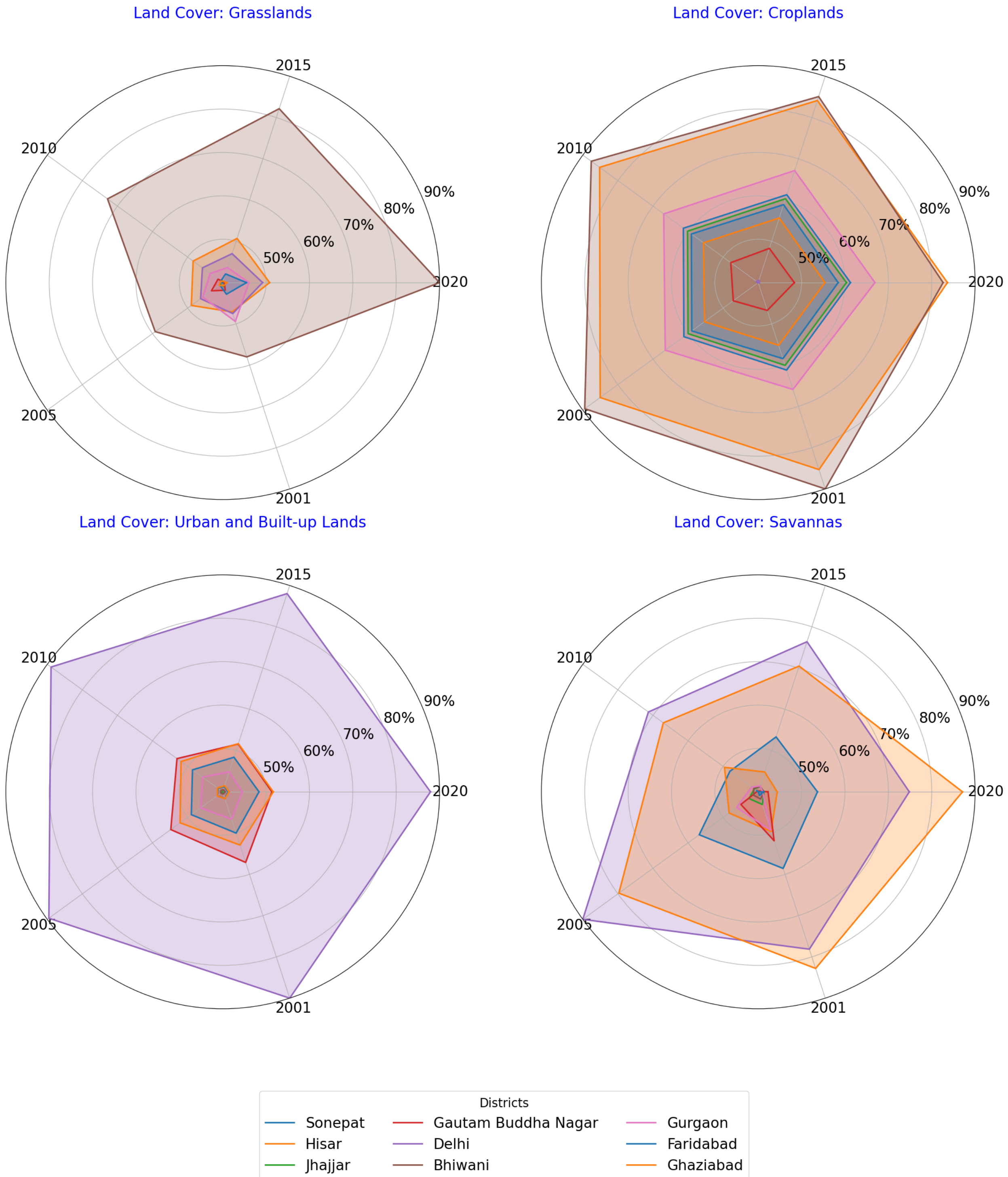

Figure 4.3: Temporal variations in land cover within the Delhi NCR from 2001 to 2020

	A	B	B-A
District	**EC 2001**	**EC 2019**	**Difference**
Bhiwani	12.4	16.0	3.6
Delhi	4.5	3.5	-1.0
Faridabad	3.1	2.5	-0.7
Gautam Buddha Nagar	7.2	4.6	-2.6
Ghaziabad	4.9	3.6	-1.4
Gurgaon	4.8	4.6	-0.2
Jhajjar	11.8	13.2	1.4
Meerut	17.3	15.8	-1.5
Sonipat	17.4	15.7	-1.7
Total	**83.5**	**79.5**	**-4.0**

Table 4.4: Change in Ecosystem Condition from 2001 to 2020

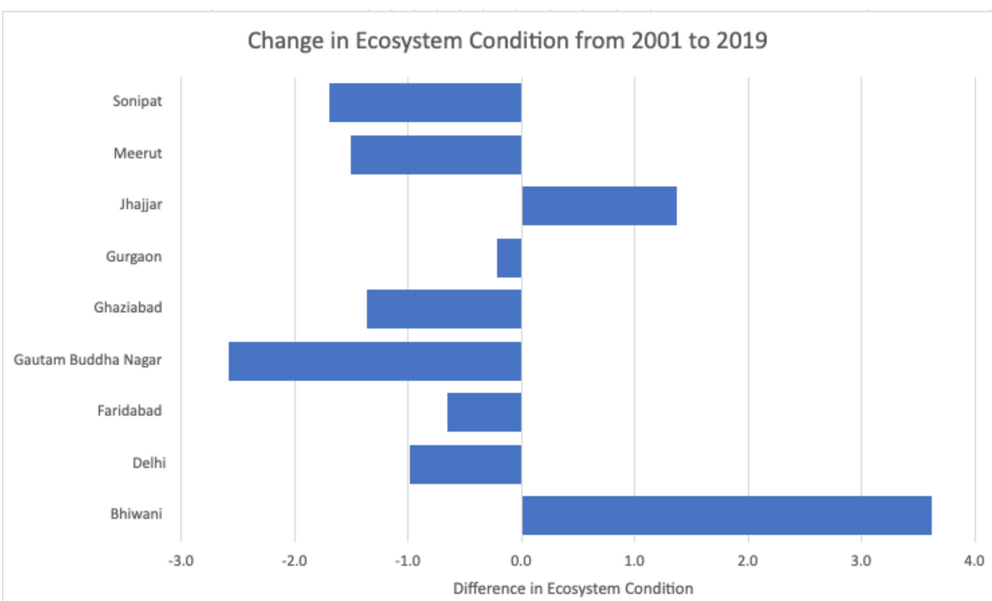

Figure 4.4: Change in Ecosystem Condition from 2001 to 2020

experienced growth in croplands and urban land, but cropland EC decreased from 10.91% to 10.70% and urban land EC increased from 9.14% to 9.44%. Gautam Buddha Nagar saw sharp declines in cropland cover and EC, while urban land and EC increased. Specifically, cropland areas fell from 6.53% to 5.73%, and EC fell from 15.01% to 11.76%. Ghaziabad showed declines in cropland EC from 12.03% to 11.71% despite marginal urban land growth. Gurgaon saw notable urban land expansion with an increase in cropland EC from 5.73% to 6.80%. Jhajjar and Sonepat reported growth in cropland and urban land cover, but cropland EC decreased in Jhajjar from 14.59% to 13.88% and in Sonepat from 12.14% to 11.88%. Meerut saw expansion in croplands and urban lands, with cropland EC declining from 9.64% to 8.85%.

The analysis revealed that urban expansion had a more pronounced negative impact on ecosystem condition (EC) compared to cropland conversions. The intensity and scale of land use changes significantly influenced this impact. Gautam Buddha Nagar experienced the largest decline in cropland area and EC, indicating that rapid urbanization in new areas has severe consequences on ecosystems. In contrast, districts like Delhi, with major urban land increases, saw less steep declines in cropland EC, suggesting that preexisting urban areas might better absorb development impacts. This finding aligns with the research question on how varying landcover conditions affect ecosystem services and valuation processes.

Interestingly, not all district patterns conformed to the expected trend where higher urban land area was associated with lower cropland EC. For instance, in Meerut, both urban and cropland areas increased, but the decline in cropland EC was less pronounced. This anomaly suggests that factors beyond land use extent, such as industrial activities and landscape fragmentation, might also have influenced EC. The study of land cover changes in Delhi NCR from 2001 to 2020 also demonstrated complex patterns of urbanization and its effects on ecosystems. Significant urbanization in districts like Gurgaon and Faridabad led to ecosystem declines, while Bhiwani and Jhajjar saw improvements despite increased cropland and urban land cover. These findings highlight that land use changes and ecosystem health are influenced by more than just the extent of land use, in line with the central aim of the research, which is to comprehend the dynamics between land cover and ecosystem service supply. By exploring these subtleties, the study provides insights to guide sustainable urban development and conservation efforts in the Delhi NCR area.

4.3.3 Temporal correlation between ecosystem condition and ecosystem service supply (RQ3)

The study investigates the temporal relationship between the degradation of ecological conditions (EC) and the modification of ecosystem service (ES) supply in the Delhi National

Capital Region (NCR) from 2001 to 2020. It highlights the impact of land use changes on ES over time and notes spatial heterogeneity in the correlation between EC and ES across different districts. Some districts show negative, negligible, or positive correlations. The research utilized an ecosystem matrix approach to quantify ES based on land cover types. Significant trends in ES supply were observed, with Bhiwani showing the largest increase in EC, while Delhi, Faridabad, and Gurgaon showed moderate declines, with Gurgaon having the smallest decline. The total ES supply for Delhi NCR increased from 1,102,811 to 2,198,392 units. Urban expansion had the most pronounced negative effect on EC and ES provision, although increases in cropland did not necessarily reduce ES supply.

The research methodology entailed allocating weighted values to different land cover types and summing these values according to the area they occupy within each district. Field observations indicated that as urban areas expanded, there was a noticeable decline in crop-based services, which are essential for food production and local agriculture, while Bhiwani's shift to residential land use improved regulating and cultural services. The results imply that the temporal disparity between EC reduction and ES alterations is heterogeneous across districts, corroborating the hypothesis that comprehending this temporal lag is imperative for enhancing urban ecosystem resilience and formulating anticipatory policy measures. These findings underscore that the temporal delay between EC reduction and ES modifications is district-specific, substantiating the hypothesis that a thorough understanding of this delay is vital for fortifying urban ecosystem resilience and devising proactive policy strategies.

The ecosystem service supply in Delhi NCR was evaluated using an ecosystem matrix approach based on land cover classes. Table 4.3.3 shows the total ecosystem service scores for each district from 2001 to 2020, with significant trends illustrated in Figure 4.5. In 2001, Bhiwani recorded the highest total ESS with 255303 units. By 2020, its ESS had risen substantially to 519515 units, a change of 264212 units or 103.5%. Delhi saw a higher marginal growth of ESS from 37789 to 73145 units, an increase of 35356 units or 93.5%. Faridabad recorded ESS gains from 1114233 to 226456 units, a reduction of 887777 units or -79.7%. Gautam Buddha Nagar grew from 66133.5 to 126671 units, an increase of 60537.5 units or 91.5%. Ghaziabad increased from 98535 to 195872 units, a change of 97337 units or 98.8%. Gurgaon demonstrated a dramatic expansion of the ESS from 151706.2 to 301573.93 units, a growth of 149867.73 units or 98.7%. Similarly, Jhajjar surged from 118552.3 to 236440.6 units, an increase of 117888.3 units or 99.4%, and Meerut jumped from 137645 to 273646.7 units, a change of 136001.7 units or 98.8%. Sonepat experienced significant growth, increasing from 122912 to 245069.4 units, a rise of 122157.4 units or 99.4%. The aggregate data showed a substantial rise in Delhi NCR's total ESS, climbing from 1102811.089 units in 2001 to 2198392.502 units in 2020, an increase of 1095581.413 units or approximately

District	2001	2005	2010	2015	2020	Total
Bhiwani	255.3	259.3	265.3	264.8	264.2	1,308.8
Delhi	37.8	37.2	36.3	35.2	35.4	181.9
Faridabad	114.2	113.7	113.2	112.9	112.2	566.3
Gautam Buddha Nagar	66.1	66.0	64.8	63.2	60.5	320.6
Ghaziabad	98.5	98.7	98.7	98.3	97.3	491.6
Gurgaon	151.7	150.9	149.9	149.6	149.9	752.1
Jhajjar	118.6	118.5	118.0	117.5	117.9	590.5
Meerut	137.6	137.3	136.6	136.8	136.0	684.4
Sonepat	122.9	122.8	122.8	122.4	122.2	613.1
Total	1,102.8	1,104.5	1,105.7	1,100.8	1,095.6	5,509.4

Table 4.5: Ecosystem Service Supply from 2001 to 2020 (in thousands)

99.3%. The analysis revealed variations in the impacts of different land cover transitions on ecosystem service supply networks.

While urban expansion had the most significant negative impact on ecosystem service provision, some cropland conversions did not necessarily lead to declines in total ecosystem service scores. For instance, Meerut experienced expansions in both cropland and urban land between 2001 and 2020. Despite this, its total ESS increased substantially during this period, from 137,645.249 units to 273,646.7313 units, as shown in Table 4.3.3. This indicates that cropland growth alone did not negatively affect the overall service supply. Similarly, Bhiwani saw developments in both cropland and urban land extent, as illustrated in Figure 4.5. Interestingly, Bhiwani's ESS increased the most significantly among all districts, rising from 255,303.4892 units to 519,515.9127 units. This indicates that certain cropland conversions, when not accompanied by urbanization, may not reduce total service scores.

The matrix methodology attributes a superior provisioning service weight to cropland as compared to urban areas. Consequently, moderate increases in cropland do not necessarily diminish the overall score when calculating the total district ESS.rban expansion must reach a certain significant level to reduce the weighted scores attributed to various types of land cover noticeably enough to affect the total ecosystem service supply (ESS) values for a district. This implies that moderate or low levels of urban growth do not have a substantial impact on the overall ESS due to the weightings and contributions assigned to different land covers, such as cropland versus urban areas. Therefore, it is only when urban area expansion is considerable that there will be a marked decrease in the ESS scores for the district, highlighting the sensitivity of the ecosystem service supply to significant urban development. This nuance around different land use impacts warrants further investigation.

Figure 4.5: Change in Ecosystem Service Supply from 2001 to 2020

The large values reported in units for the total ecosystem service supply scores are the result of the methodology used in the study. The ecosystem service supply was quantified using an ecosystem matrix approach developed by previous researchers. This assigns weighted scores to different land cover classes based on their potential contribution to provisioning, regulating, and cultural ecosystem services.

The study region spans multiple districts across three states, with land cover quantified in thousands of hectares. Aggregated scores at the district level are substantial but remain valid for trend analysis and inter-district comparisons over time due to consistent scoring methodology. The large units in Table 4.3.3 reflect the extensive spatial scope and land area analyzed for ecosystem service supply patterns in the Delhi NCR.

The scores were subsequently aggregated based on the area covered by each land cover type within each district. Given that the study area spans multiple districts across three states, with land covers quantified in thousands of hectares, the total scores aggregated at the district level are substantial in magnitude, reported in the specified units. Despite the high absolute values, the trend analysis and inter-district comparisons over time remain valid due to the consistent application of this scoring methodology throughout the study period. The large units merely reflect the extensive spatial scope and land area encompassed within the analysis of ecosystem service supply patterns in the Delhi NCR region.

Insights from the field visit to the study area provided additional context to the observed ecosystem service supply trends. Interactions with local stakeholders revealed that the expansion of urban areas, particularly in Gautam Buddha Nagar, was driven by rapid industrialization and population growth. The development of new residential complexes and industrial parks resulted in the conversion of agricultural lands, leading to a decline in crop-based provisioning services. However, in Bhiwani, the transition from industrial to residential land use was accompanied by an increase in green spaces and urban parks, contributing to improved regulating and cultural services. These observations highlight the importance of considering the specific nature of land cover changes and their associated ecosystem service trade-offs when interpreting the results of the ecosystem matrix approach .

4.3.4 Urban-peri-urban ecosystem service trade-offs and spatial dependencies (RQ4)

The diagnostic tests conducted, results of which are explained in detail in Table 4.6 reveal significant spatial autocorrelation, indicating that nearby locations influence each other's scores. Spatial autocorrelation occurs when observations close to each other exhibit similar values due to underlying processes such as environmental factors, socio-economic conditions, or infrastructural elements. This spatial dependence has important implications for urban and peri-urban ecosystem services, as changes in one area can impact adjacent areas. Understanding these dependencies is crucial for effective urban planning and policy-making, allowing for targeted interventions that consider the broader spatial context.

The findings presented in the next section demonstrate substantial spatial dependence within the analyzed regions, indicating the necessity for a spatial regression approach. The Lagrange Multiplier (LM) tests for both spatial lag and error, along with their robust versions, validate the existence of spatial autocorrelation. The significance of the SARMA test implies that a spatially lagged autoregressive model that includes both spatial lag and error processes is essential. These results underscore that the connections between Ecosystem Condition scores (ecScore) and land cover types are not adequately explained by conventional OLS regression models, necessitating the use of spatial econometric methods to account for spatial effects.

4.4 Discussion

The examination of land cover changes in Delhi NCR from 2001 to 2020 reveals key insights. Urban growth, especially in Gautam Buddha Nagar, Gurgaon, and Faridabad, decreased forested areas and cropland, reducing ecosystem conditions. Urban expansion impacted

Diagnostic Test	Value	Probability (PROB)	Indication	Interpretation of Variables
Lagrange Multiplier (lag)	162.051	¡ 0.0001	Evidence of spatial lag dependence	The ecScore might be affected by neighboring scores, indicating that the spatial distribution of croplands, urban areas, and service supply are interrelated.
Robust LM (lag)	84.328	¡ 0.0001	Indicates spatial lag effect, robust to spatial error	The importance of this test
Lagrange Multiplier (error)	131.683	¡ 0.0001	Evidence of spatial error dependence	The error patterns suggest the presence of omitted variables or unobserved spatial processes related to land cover types affecting EC.
Robust LM (error)	53.960	¡ 0.0001	Indicates spatial error autocorrelation, robust to spatial lag	This suggests a spatial structure in error terms not explained by the model, possibly related to the spatial configuration of land cover variables.
Lagrange Multiplier (SARMA)	216.012	¡ 0.0001	Indicates both spatial lag and spatial error processes	The joint significance of spatial lag and error implies that both the ecScore and the regression residuals are spatially structured, necessitating a model that accounts for spatial dependence in both the dependent variable and the error process.

Table 4.6: Diagnostic test results for determining spatial dependence of ecScore

ecosystem conditions more than cropland changes. While most districts showed a decline in ecosystem conditions, areas like Bhiwani and Jhajjar improved with more green spaces. Despite urban expansion negatively affecting service provision in some areas, most districts saw an increase in ecosystem service supply. The interactions between land cover changes and ecosystem service supply, along with spatial autocorrelation, highlight the need for spatially informed urban planning to mitigate urbanization's negative impacts and encourage conservation.

Planning should not only focus on how many green spaces there are but also on their quality and how they are distributed across the area. This means that effective policies should aim for a balanced development by integrating sustainable land use, green infrastructure, and ecosystem management. Through the application of spatial tools such as Geographic Information Systems (GIS) and remote sensing on a local level, planners can understand the regional patterns of green spaces, enabling them to develop conservation strategies that are well-suited to local needs and aligned with regional objectives. This strategy of integrating sustainable land use, green infrastructure, and ecosystem management augments ecosystem service provision and resilience, thereby ensuring sustainable development within both urban and peri-urban contexts. The application of spatial econometric analysis provides valuable insights into how these dynamics operate at a regional scale, enabling decision-makers to tailor conservation strategies that are both locally appropriate and regionally coordinated. By addressing the spatial dependencies, urban planners can enhance ecosystem services and resilience, ensuring the sustainable development of urban and peri-urban areas. Continuous monitoring and adaptive management based on spatial analysis will be crucial in responding to the evolving land cover patterns and their associated impacts on ecosystem conditions. The spatial econometric analysis underscores the critical role of spatial dependence in understanding ecosystem condition dynamics, and future research should integrate spatial econometric models with land use planning to develop more effective conservation strategies. The findings emphasize the importance of considering spatial interactions in environmental management practices to enhance ecosystem resilience.

The study revealed a general growth in urban land and a reduction in forest cover within selected districts of the Delhi NCR region. Although both changes, namely the transition from forest to cropland and from forest to built-up areas, highlight the increased urban pressure on the land and a decline in ecosystem condition, the analysis suggests that the decline in ecosystem services is more prominent in regions experiencing conversion to urban land. This emphasizes the adverse impact of urban expansion on ecosystem health. Data analysis demonstrates that areas experiencing a shift from forest to cropland or urban areas exhibit varying degrees of ecosystem decline. Gautam Buddha Nagar, in particular, witnessed the largest landcover transition from cropland (decreased 20.9%) to urban land and the most significant decline in ecosystem condition, revealing the relationship between landcover change and ecosystem health. The findings presented in this study align with existing literature on landcover change and urbanization trends in the Delhi NCR region. It confirms the rapid urban growth and ecological implications observed in the vicinity of Delhi, especially in regions such as Gurgaon that experienced development driven by foreign direct investment (Gururani, 2020). It is crucial to recognize that cities act as aggregators of resources and ecosystem services rather than producers of either. Urban areas, compared to other land covers, tend to preserve many services such as water availability and the distribution of green spaces. The decline in ecosystem services stops once the change in land cover is stopped in urban areas.

This study also found spatial clustering of ecosystem services as nearby areas display similar ecosystem conditions and provide similar ecosystem services. This spatial pattern highlights the interconnectedness of ecosystems within the Delhi NCR region and the importance of localized conservation efforts and efficient land use planning to maximize the benefits offered by ecosystems across landscapes. For example, ecosystems in regions with dense forests offer benefits such as carbon sequestration and habitat provision, whereas ecosystems in urban built-up areas may be geared toward pollution filtration and recreational opportunities. Spatial clustering of ecosystem services also provides valuable information for targeted conservation efforts. By identifying areas with abundant or lacking ecosystem services, policymakers and land managers can focus their resources on areas with the greatest need. This information allows for a more informed approach to land use planning and conservation strategies, promoting effective ecosystem management and biodiversity preservation.

A significant limitation of this research pertains to the constraints in data availability. While MODIS satellite imagery allowed for uniform land cover analysis over the vast study area and period, utilizing data with a finer spatial resolution than 500 m could have offered more detailed insights, especially on landscape fragmentation trends. Nevertheless, this study provides an initial analysis employing standardized methods to assess the impacts of land change on ecosystem conditions and service supply patterns in the Delhi NCR region over the past twenty years. Ongoing observation with higher resolution data would enhance comprehension of the long-term ecological consequences of urbanization, thus better informing sustainable development planning.

Chapter 5

DISCUSSION

5.1 Relationship between Land Cover and Ecosystem Changes

The interrelationctedness of land cover and ecosystem changes requires detailed analysis. This dissertation focuses on this examination, with a particular emphasis on the changes in Ecosystem Conditions and Ecosyst em Services. In cities, the density of green cover and the ratio of built-to-non-built vary, affecting the present quality of life and future sustainability(Lin, Philpott, & Jha, 2015; Tzoulas et al., 2007; Zasada et al., 2011). Urbanization transforms city land cover, creating different ecological conditions through increased pollution, reduced green spaces, and altered local climates (Costanza et al., 1997; de Groot et al., 2010). In cities like Delhi NCR and Metro Manila, different land covers lead to distinct ecosystem conditions. In agricultural regions, land cover changes from crop cycles and farming techniques affect soil health, water supply, and biodiversity. Coastal areas experience land cover changes due to human activities or natural events like erosion, impacting marine life and communities. Similarly, land cover conditions in urban areas vary across landscapes, playing a crucial role in ecosystem valuation. Urban Ecosystems are very diverse and recognizing this diversity is essential for effective ecosystem management and conservation.

Urbanization provides ecosystem services to a large part of the national population involved in urban activities, ensuring the continuous supply of water, safe waste disposal, and food security, while maintaining a relatively limited spatial scale. However, this dynamic of ecosystem services raises a crucial question. Are the services received by the city sourced from ecosystems within its administrative boundaries? Although ecosystem services such as air quality and green cover are largely the result of activities within the urban area, water supply and waste disposal services often depend on external regions (Escobedo et al., 2020). Metropolitan areas such as Metro Manila in the Philippines depend on surrounding regions for these essential services. As nonurban land covers, such as agricultural land, slowly transform into urban built-up areas such as highways, buildings, and parking lots, it creates a delicate balance that must be carefully considered in the valuation process.

To address the complexities of quantifying the significance of land cover and ecosystem changes and their repercussions on human well-being, particularly in the context of urbanization and its influence on ecosystem services both within and beyond urban environments, this dissertation proposes a novel methodology. The Common International Classification of Ecosystem Services (CICES) method, introduced herein, is posited as a significant advancement over traditional approaches. This method emphasizes the incorporation of ecosystem service elements into the valuation process, thereby providing a more precise understanding. It recognizes that land value encompasses not only market price but also the ecosystem services it renders (de Groot et al., 2002). The CICES method is regarded as superior to other prevalent techniques such as the Millennium Ecosystem Assessment (MEA) and The Economics of Ecosystems and Biodiversity (TEEB) for several reasons. Unlike MEA and TEEB, which delineate broad categories of ecosystem services, CICES offers a detailed and standardized classification system that enables more consistent and comparable assessments across various studies and regions (Haines-Young & Potschin, 2018). Moreover, CICES encompasses a broader spectrum of ecosystem service elements, including provisioning, regulating, and cultural services. This comprehensive approach ensures the inclusion of all pertinent ecosystem benefits in the valuation process, fostering a more complete understanding of ecosystem contributions (Maes et al., 2013). In addition, CICES is designed to be flexible and adaptable to diverse contexts and scales. It is applicable to various types of ecosystems and land covers, making it suitable for a wide range of applications in urban, peri-urban, and rural areas (Haines-Young & Potschin, 2013). The detailed classification and extensive coverage of ecosystem services in CICES make it particularly effective for informing policy decisions. Policymakers can use CICES to identify and prioritize essential ecosystem services, ensuring that land use planning and development strategies are aligned with sustainability objectives (Schröter et al., 2016). By integrating these advantages, the CICES method offers a more nuanced and accurate evaluation of land cover and ecosystem changes, supporting informed decision making for sustainable urban development (Costanza et al., 2017).

5.2 Economic Valuation of Ecosystems to Valuation of Ecosystem Services

Economic valuation relies on the opportunity cost of the ecosystem, referring to the economic loss that would arise if the ecosystem were to vanish. Various methodologies employ this approach to assess ecosystems, which is beneficial for the conservation of crucial ecosystems (Costanza et al., 1997). The value of the ecosystem can be assessed based on its value of ecosystem service rather than its value in the market. Market value attributes an economic worth to resources based on their overall demand, engaging a broader spectrum of stakeholders who establish the economic cost (Loomis, 2000). Alternatively, the ES valuation method suggested in this dissertation systematically assesses the provisioning, regulating, and cultural services provided by various land covers. This methodology effectively maps landscapes and identifies key areas. Regions crucial for ecosystem services (ES) can be included in economic assessments or prioritized in policy development. The resulting measure can be utilized to regulate land prices, given the strong correlation we have identified. This tool is valuable for balancing global and local factors that influence land prices.

The concept of land valuation is pivotal to this dissertation. Transformation of land, driven by economic determinants, can precipitate the conversion of forests to agricultural land, which can subsequently be transformed into urban areas. By integrating ecosystem service elements into the valuation process, as proposed herein, a more nuanced understanding of the trade-offs and ramifications of these transformations can be achieved. The proposed valuation methodology facilitates the calculation of the value of land by incorporating components of ecosystem services and is tuned to the significance of the land cover (Cai et al., 2006). In relation to the delivery and the ecosystem services (ES) away from its source, land valuation becomes indispensable when evaluating the economic feasibility and environmental repercussions of converting land from one use to another (Costanza et al., 1997). For example, when considering the conversion of a forest into agricultural land, the valuation methodology must consider the ecosystem services rendered by the forest, such as carbon sequestration, biodiversity, and water regulation (de Groot et al., 2010). Similarly, when agricultural land is considered for urban development, the valuation should include the potential loss of agricultural productivity and ecosystem services. By doing so, stakeholders can make more informed decisions that judiciously balance economic advantages with environmental sustainability.

Balancing landcover transformations is a delicate process that requires a nuanced understanding of the slow transformation of non-urban landcovers into urban built-up areas. Peri-urban areas, which supply ecosystem services to cities, face a decline in ecosystem condition, such as forests that are replaced by agricultural land and a drop in the water table. The implications of these transitions must be carefully analyzed, and the proposed valuation method can help understand the trade-offs and impacts on ecosystem services (Setlhogile et al., 2011). By adopting a comprehensive approach that considers the context of landcover conditions, the dynamics of urbanization and ecosystem services, and the inclusion of ecosystem service elements in the valuation process, we can better understand the value of landcover and ecosystem changes and their impact on our lives (Costanza et al., 1997).

5.3 Overview of Key Arguments

The three chapters re-emphasize the need for an integrated approach to understand the valuation of land cover and ecosystem transitions. The first chapter explores the present literature through a systematic review of literature, the last two chapters present a comprehensive perspective on the effects of urbanization on ecosystem services through case studies. The discussion stresses on the importance of acknowledging the diversity of land cover conditions and questions whether the ecosystem services a city benefits from are sourced from within its administrative boundaries. The CICES method is proposed as an alternative approach to understand the value of land cover and ecosystem changes. The importance of including elements of ecosystem service is emphasized in the land valuation process. The dissertation responds to these arguments by providing an extensive analysis of the impacts of urbanization on ecosystem services in two different case studies, offering a nuanced understanding of the trade-offs and consequences of land cover transformations. The ultimate objective of the dissertation is to guide policymakers, urban planners, and stakeholders towards a balanced urban development approach that harmonizes human activities with the natural environment.

Chapter2:Interdisciplinary Insights into Peri-Urban Development: A Systematic Review of Global Literature on Environmental and Land Use Changes (2000-2022)

Practical Implications and Applications of the Study

This study is crucial as it highlights the shift in peri-urban development research from a purely ecological focus to a holistic view of peri-urban ecosystems. This broader perspective recognizes the complex interplay of factors shaping these areas. Policymakers and practitioners can use this comprehensive understanding to create strategies better suited to peri-urban realities. The traditional ecological focus now includes social, economic, and infrastructural aspects. This shift is vital as urbanization accelerates, bringing complex challenges like environmental degradation, social inequities, and land-use conflicts. Secondly, the identification of influential sources and countries in the field provides valuable guidance to researchers seeking to engage with the existing body of knowledge. Countries experiencing rapid peri-urbanization, as highlighted in this study, can benefit immensely from collaboration and knowledge exchange with other regions that have faced similar challenges. Such global academic collaboration can foster the creation of best practices and innovative solutions rooted in diverse experiences. Furthermore, identifying key sources enables researchers to locate seminal works and fundamental concepts that have influenced the field. This focused interaction with foundational literature provides a more detailed understanding and critique of existing theories and methodologies, thus advancing the field.

Thirdly, identifying key research themes highlights the complex nature of peri-urban development. This is not just an academic exercise; it has practical implications for shaping future research priorities. By stressing the need for interdisciplinary approaches that include ecological, social, economic, and agricultural aspects, the study underscores the multifaceted challenges that peri-urban areas face. This kind of holistic research agenda is essential for developing solutions that are not only effective but also sustainable in the long term. Moreover, the study highlights the necessity of investigating nature-based solutions and sustainable urban planning in peri-urban contexts. These areas often serve as the transitional zones between urban and rural environments, making them uniquely positioned to benefit from integrated planning approaches that balance development with ecological conservation.

Finally, the co-citation networks uncovered in this research shed light on collaborative links among researchers and fields. This information can enhance cooperation and information exchange, potentially leading to innovative answers for peri-urban issues. Understanding who is working with whom, and on what themes, allows for the identification of potential collaborators and the forging of new partnerships. Such networks are not only academic but also extend to policymakers and practitioners, creating a shared pool of knowledge and expertise that can be mobilized to tackle peri-urban challenges more effectively. In sum, the study's findings have far-reaching implications for the future of peri-urban development research and practice. Chapter 2 examines the term 'peri-urban interface,' delving into its semantic progression and the ways its conceptualization has evolved with globalization in nearly two decades between 2000 and 2022. This critical assessment is key to understanding transitions in land cover and ecosystems, in helping understand the urban-rural interplay in a globalized world. The chapter highlights the importance of integrating knowledge from various disciplines. The complexities of peri-urban areas necessitate a comprehensive approach to policy making and strategy development. This aligns with the dissertation's focus on urbanization's impact on quality of life from an interdisciplinary perspective. The chapter uses text pre-processing and a topic modeling technique- Latent Dirichlet Allocation (LDA), along with custom Python code for bibliometric analysis. These methods tailor the analysis to specific research questions, manage large datasets, and enhance research transparency and reproducibility.

The latter part of the period examined in this chapter, from 2010 to 2022, saw a significant increase in publications. This increase in research output indicates a growing recognition of the significance of peri-urban ecosystems. During this time, research focused mainly on land management, ecosystem services, and urban forests, often using illustrative case studies.

This emphasis on peri-urban ecosystems supports the dissertation's argument about the importance of understanding changes in land cover and ecosystems. In developing countries, the discussion has often been limited by traditional urban-rural dichotomies. However, the chapter shows that recent research in some cities challenges these established notions by revealing peri-urban areas with social homogeneity.

The chapter explores the relationship between globalization and urbanization. Although globalization can often reduce the importance of specific locations, its effects are most significant in the largest mega-urban areas of the developing world. This indicates a move away from the traditional divide between urban and rural development issues, a point also emphasized in the dissertation. In its concluding section, the chapter recognizes that despite significant progress in understanding peri-urban areas, there are still knowledge gaps, especially concerning the long-term ecological impacts of peri-urbanization. It calls for more longitudinal and interdisciplinary research to address these gaps. This supports the dissertation's call for a comprehensive understanding of the value of landcover and ecosystem changes and their impact on human life.

Chapter3: Assessing the Impacts of Land-Cover Changes on Ecosystem Services in the Philippines

This chapter explores the impacts of urbanization on ecosystem condition (EC) and ecosystem services (ES) in and around Metro Manila, Philippines, making the following arguments. The first argument is the transformation of land cover due to urbanization, with urban land cover increasing by approximately 5% from 2258 sq km to 2371 sq km between 2001 and 2020, resulting in significant reductions in forest areas and, to a lesser extent, savannas, while croplands have moderately expanded. The second argument concerns the negative effect of urban expansion on EC in periurban areas like Batangas, Laguna, and Bulacan, leading to forest fragmentation and habitat loss, although certain regions have shown resilience in maintaining or improving ES. The third argument pertains to the observed spatial autocorrelation in EC values, suggesting similar ecological conditions in areas closer to Metro Manila, while no significant spatial autocorrelation was found for ES supply values, emphasizing the need for targeted urban planning and conservation strategies. Lastly, the study advocates for a comprehensive approach to land valuation, incorporating elements of ecosystem services, resonating with the CICES framework, and supporting a holistic valuation approach that considers both the market value of land and the value of the ecosystem services it provides.

The discussion in this chapter outlines the challenge which lies in balancing the delicate equilibrium required when converting non-urban land covers into urban built-up areas, especially in peri-urban regions that provide vital ecosystem services to cities. This issue is consistent with the discussions on knowledge gaps in peri-urban ecosystem studies, particularly highlighting the need for further research on the socio-economic aspects of these ecosystems and the involvement of local communities in their valuation, management, and sustainability. A comprehensive understanding of peri-urban ecosystems can be achieved by synthesizing ecological, social, and economic perspectives, aligning with the demand for a deeper understanding of the trade-offs and ramifications associated with land cover transformations.

Chapter 4: Urban Expansion and Ecosystem Health: Exploring the Dynamics of Land-Cover Changes and Ecosystem Services in the National Capital Region of India

The impact of urbanization on ecological conditions is a key theme in environmental research. The chapter highlights significant urbanization in Delhi NCR, leading to degradation of ecosystem health in various districts. Urban expansion in Gautam Buddha Nagar, for instance, has led to a decline in cropland and a deterioration of ecosystems, as evidenced by data and corroborated by field observations. Over the last twenty years, NOIDA, a prominent city within Gautam Buddha Nagar, has experienced significant alterations in land cover and economic conditions.

This chapter also explores the dependency of urban centers on external regions for resources like water and waste management, aligning with the "Ecosystem Service deficit" concept, where urban demand exceeds supply. It highlights the essential function of peri-urban regions in delivering these services, emphasizing the mutual reliance between urban and peri-urban areas to sustain ecological equilibrium. It calls for a thorough land valuation that incorporates elements of ecosystem service to capture the benefits of different landcovers. This aligns with the theme of the rest of the dissertation- the application of the CICES framework and ecosystem matrix to measure and compare ecosystem service values across various land use types. The chapter emphasizes the necessity of balancing the conversion of non-urban landcovers to urban areas, especially in peri-urban regions that provide essential services. This issue parallels the analysis of landcover transformations in Delhi NCR, highlighting the trade-offs between urban expansion and the reduction of ecosystem services.

The study highlights significant urban land cover growth in Gurgaon and Faridabad from 2001 to 2020, leading to a decrease in forested areas and croplands, resulting in a general decline in ecosystem conditions (EC) across most districts except for Bhiwani and Jhajjar, which saw improvements; the impact of urban expansion on EC was more pronounced than cropland conversions. It emphasizes the importance of integrating various valuation methods, including biophysical quantification, socio-cultural approaches, and economic valuation, to assess the impact of urbanization on ecosystem services (ES), emphasizing that while monetary valuation of ES can aid in decision-making, qualitative assessments are crucial for resources with significant ecosystem service potential but little market value. Additionally, the chapter discusses the spatial dependence and clustering of ecosystem services within the NCR, highlighting the interconnectedness of ecosystems and indicating that changes in one area can impact adjacent areas. This highlights the necessity for urban planning and policy-making that is informed by spatial data. It also shows considerable spatial autocorrelation, requiring the application of spatial econometric techniques to address spatial influences. The research delves into the temporal correlation between the degradation of ecosystem conditions (EC) and the fluctuations in ecosystem service (ES) provision, with an emphasis on spatial heterogeneities across districts. It explains a district-specific nexus between the deterioration of EC and the variations in ES. Understanding this relationship is essential to understand the resilience of urban ecosystems and formulate anticipatory policy interventions. The chapter provides a detailed evaluation of the spatial and temporal dynamics of land cover change, its effects on ecosystem conditions and services, and the importance of interdisciplinary approaches for sustainable urban planning and conservation in the Delhi NCR region. It stresses the need to address the shortfall in ecosystem services in urban and peri-urban areas to ensure long-term sustainability and resilience. The study promotes a multifaceted approach that combines biophysical, socio-cultural, and economic perspectives to create effective strategies for managing and protecting ecosystems in the NCR.

Through a meticulous systematic literature review and the execution of two detailed case studies, this dissertation rigorously examines the intricate relationship between urbanization, land cover changes, and ecosystem services. The in-depth case studies conducted in Metro Manila and Delhi NCR underscore the imperative for a holistic approach to urban planning—one that synthesizes economic, biophysical, and socio-cultural dimensions to achieve environmental sustainability. The employment of the CICES framework is advocated as an exhaustive methodology to evaluate the worth of ecosystem services, facilitating a more sophisticated comprehension of the trade-offs inherent in land cover alterations.

The approach used in this paper proposes the use of the CICES framework to assess the value of ecosystem services in urban settings, helping policymakers make well-informed and sustainable choices. The findings emphasize balancing urban and non-urban areas to ensure ecosystem services are not compromised, advocating for integrating green infrastructure and preserving natural habitats within urban areas to enhance urban residents' quality of life. Incorporating the value of ecosystem services into urban planning enables cities to strike a sustainable equilibrium between development and environmental conservation, thus improving the environment and improving the well-being and prosperity of urban populations. The case studies demonstrate that urban centers prioritizing environmental considerations exhibit enhanced resilience to climate change, thereby endorsing policies that advocate for sustainable land use and the conservation of biodiversity within metropolitan regions.

5.4 Comparative Analysis of Case Studies

The analysis in this dissertation highlights the impact of urbanization on land cover and ecosystem services in Metro Manila and the National Capital Region of India (NCR). In Metro Manila, urban land increased from 2258 to 2371 sq km (2001–2020), a percent change of approximately 5.0%,reducing forests and savannas, with moderate expansion of cropland. In NCR, urban growth in cities like Gurgaon and Faridabad (2001–2020) decreased forests and croplands, affecting ecosystem conditions, although districts like Bhiwani and Jhajjar showed improvements. This highlights the need for a regional analysis of urbanization impacts.

The concept of 'Ecosystem Service deficit' is evident in both regions, where urban demand exceeds ecosystem services supply. In Metro Manila, peri-urban areas like Batangas, Laguna, and Bulacan faced challenges in maintaining ecological balance due to urban expansion, though some regions showed resilience. NCR's urban centers heavily relied on external regions for resources like water and waste management, stressing the importance of balanced urban-rural resource management.

Case studies revealed significant spatial autocorrelation in ecosystem conditions, highlighting spatial dependencies in urban and peri-urban landscapes. In Metro Manila, spatial autocorrelation in ecosystem conditions was observed, necessitating targeted planning and conservation strategies. In NCR, spatial econometric techniques were required to address these influences, indicating that changes in one area significantly impact adjacent areas.

The dissertation emphasizes a comprehensive land valuation approach that incorporates ecosystem services, adopting the CICES framework and the ecosystem matrix to measure and compare values between land use types. This holistic valuation considers both market value and ecosystem services, offering a nuanced understanding of land cover transformations. The findings reflect differences in urban expansion, ecosystem resilience, socio-economic focus, and temporal dynamics between regions. In Metro Manila, the study stressed further research on the socio-economic aspects of periurban ecosystems and the participation of the local community in valuation, management, and sustainability. In contrast, NCR's study explored the temporal correlation between ecosystem condition degradation and ecosystem service fluctuations, emphasizing district-specific heterogeneities. Understanding these variations is pivotal for policy interventions.

5.4.1 Policy Implications from Chapter 2

The findings of this systematic review indicate that initially, research was concentrated on specific ecological aspects. However, the scope of research has since expanded to provide a more integrated understanding of peri-urban ecosystems. This expanded scope covers land management, ecosystem services, and urban forestry, especially from 2010 onward.

A trend, illustrated by the changing significance of keywords in Figure 2.3, highlights a growing awareness of the interconnected factors affecting peri-urban regions, as highlighted by Duncanson et al. (2022), who recommend holistic strategies to tackle the diverse challenges of these areas. Although this systematic review of the literature does not provide direct policy implications, it is important to acknowledge that understanding changes in land cover and ecosystem transitions is an interdisciplinary concept that requires contributions from multiple fields for effective policymaking. By understanding the geographic scope of research, policymakers can identify empirical studies. The thematic understanding of the data facilitated by this study aids in this respect. Moreover, the methodology employed in this analysis is applicable and reproducible, ensuring that researchers from different disciplines, such as geographers or physicists, will identify the same or similar themes with great accuracy when analyzing the same data.

The availability of these data at all times allows policymakers to remain at the forefront of research without needing to gain expertise in each discipline, and this is achieved in a cost-effective manner without consuming excessive resources. Another interesting aspect of this analysis is it can be further extended to datasets comprising full papers, not just abstracts. Although it was not possible to download and include PDF files of all the articles in this study, the inclusion of full articles can significantly broaden the scope of this application, enabling a more comprehensive analysis. The prominence of institutions from developed nations (Table 2.2) and funding agencies (Figure 2.2) in peri-urban research highlights the need for greater focus and investment in developing regions, particularly in South and Southeast Asia, which experience unique challenges due to rapid urbanization and climate change. Brown et al. (2015) underscore the importance of fair distribution of research funds and global cooperation to design effective strategies tailored to the particular contexts of these regions. The co-citation analysis (Figure 2.4) further highlights the interconnected nature of research themes, focusing on clusters centered on fundamental ecological principles, ecosystem services, and the consequences of urbanization on biodiversity. The interlinkages emphasize the need for policy interventions that consider the complex interplay of ecological, social, and economic factors in peri-urban areas.

The research points out existing knowledge gaps, particularly in relation to the long-term ecological effects and socio-economic dimensions of peri-urban ecosystems, as noted by Juntti et al. (2021). This emphasizes the necessity for policy support for prolonged studies and multidisciplinary research that includes perspectives from local communities. Rakodi (1998) argues that such an all-encompassing strategy is crucial in developing effective and sustainable management plans for peri-urban regions, ensuring their crucial function in providing ecosystem services and enhancing urban resilience.

5.4.2 Policy Implications from Chapter 3

The analysis reveals that landcover changes due to urbanization significantly affect ecosystem condition (EC) and ecosystem service supply (ESS), as indicated by the ecosystem service (ES) matrix coefficients shown in the Appendix Table A.4 and Table A.5. The study highlights the significant impact of urbanization on EC and ES in Metro Manila and surrounding regions, as evidenced by the analysis of land cover changes and urbanization patterns. This necessitates sustainable urban planning policies to balance development and ecological integrity. For example, Estoque et al. (2018) note the distinction between forest losses near urban areas and the relative stability of remote areas, underlining the spatial dynamics of urbanization's impact on ecosystems. Broad-scale regional planning, which takes into account larger spatial areas, might be more effective than targeted, localized policies. Support for this preference comes from the hypothesis in Research Question 3, which examines whether urbanization impacts Ecosystem Condition (EC) and Ecosystem Service Supply (ESS) in similar ways across adjacent areas. The spatial autocorrelation analysis demonstrates that urbanization's effects on EC and ESS tend to occur in clusters. This means that areas in close proximity, especially those near urban centers, show similar ecological changes. Research Question 3 states: 'Is there a spatial autocorrelation between urbanization and its impact on Ecosystem Condition (EC) and Ecosystem Service Supply (ESS)?' The spatial autocorrelation analysis suggests that the consequences of urbanization on EC and ESS are clustered spatially, with regions near urban centers undergoing similar changes.

Advanced technologies for monitoring urban growth, such as remote sensing and GIS techniques, are crucial for analyzing urbanization patterns and ecological impacts from 2000 to 2020. These methods, discussed by Vrebos et al. (2015) and Wangai et al. (2019), are effective even in data-scarce regions. Recent advancements, like integrating machine learning algorithms (Kuffer et al., 2020) and high-resolution imagery (Liu et al., 2019), further underscore their value for urban planning and management. The economic valuation of ecosystem services is essential for understanding their contributions to human well-being. Studies by De Groot et al. (2002) and Kumar (2010) provide frameworks for the economic valuation of ES. Integrating these values into decision-making can promote sustainable resource management and mitigate the adverse effects of urban land expansion on ecosystem services (Seto et al., 2012). Targeted conservation efforts are needed to protect critical ecosystems in peri-urban regions. The study area description and land cover mapping case studies highlight the varying degrees of urban influence on different provinces and districts within the Metro Manila region. For example, Estoque et al. (2018) note the distinction between forest losses near urban areas and the relative stability of remote areas, guiding targeted conservation efforts.

The study emphasizes interdisciplinary approaches to urban planning, integrating various data sources and analytical techniques. The literature review underscores the importance of combining ecological and economic considerations for sustainable resource management. The findings highlight significant impacts of urbanization on EC and ES in Metro Manila, Philippines. Policymakers can use this understanding to create better strategies for urban and peri-urban ecosystems. Urban land cover increased by 5% from 2258 sq km to 2371 sq km between 2001 and 2020 (Figures 3.3 and 3.4), necessitating targeted urban planning and conservation. Forest areas decreased from 78676 sq km to 66255 sq km (15.8% decrease), while croplands expanded from 13426 sq km to 14064 sq km (4.8% increase), highlighting the need for policies balancing urban development and natural habitat preservation (Table 3.5.1). In peri-urban areas like Batangas, Laguna, and Bulacan, where forest fragmentation and habitat loss are prevalent, policymakers must prioritize reforestation, habitat restoration, and sustainable land use to mitigate negative effects.

Secondly, the observed spatial autocorrelation in EC values, suggesting similar ecological conditions in areas closer to Metro Manila, calls for a comprehensive approach to land valuation. Incorporating elements of ecosystem services into this process, as resonated with the CICES framework, ensures a holistic valuation approach that considers both the market value of land and the value of the ecosystem services it provides. This can guide land use planning and development strategies that align with sustainability objectives, ensuring that urban expansion does not come at the expense of vital ecosystem services. Figures 3.5 and 3.8 show the significant urbanization and its impacts on EC around Metro Manila.

The analysis also highlights the essential function of peri-urban regions in delivering ecosystem services to cities. The mutual reliance between urban and peri-urban areas to sustain ecological equilibrium must be acknowledged in policy frameworks. Policymakers should promote integrated planning approaches that balance urban development with ecological conservation, ensuring that the benefits of different land covers are captured and preserved. Regions farther from Metro Manila, with lower urbanization, contribute more positively to EC, highlighting the need for sustainable urban planning to balance development with ecological integrity and human well-being (Figure 3.9 and Table 3.5.2). A balanced approach to urban development that harmonizes human activities with the natural environment is crucial. By integrating ecosystem service elements into land valuation processes and involving local communities in ecosystem management, policymakers can make more informed decisions that support sustainable urban and peri-urban development.

5.4.3 Policy Implications from Chapter 4

The study indicates that the main change in land cover in various sections of the Indian National Capital Region is the growth of urban areas. Figure 4.3 shows that between 2001 and 2020, urban land cover in Gurgaon increased by 21. 29% and Faridabad by 44. 37%. This urban sprawl diminishes natural environments, conforming to the 'Ecosystem Service deficit' theory, where urban needs surpass the local ecosystem's supply. Cities extend into natural landscapes, leading to habitat fragmentation, a decline in biodiversity, and changes in microclimate. Changes in land cover influence EC, as evidenced by the Ecosystem Condition (EC) indicator. Figure 4.4 depicts EC changes from 2001 to 2020. Although Bhiwani and Jhajjar showed improvement, many districts, particularly Gautam Buddha Nagar, saw a decline due to the detrimental impacts of urban growth, such as increased impermeable surfaces, reduced vegetation and increased pollution, which harm ecosystem health and functionality. Alterations in land cover influence both the EC and the ESS, which are evaluated using an ecosystem matrix that considers different land cover types and their respective ecosystem service supply. Land cover transitions alter weighted scores for provisioning, regulating, and cultural services, aggregated by area. This changes the total ESS scores for each district, as shown in Table 4.3.3 and Figure 4.5. The observed results highlight the significant impact of urbanization on ESS. Although most districts experienced an increase in total ESS scores, the study reveals that urban expansion had a more pronounced negative effect on ES provision compared to cropland conversions. This finding is attributed to the lower weighted scores assigned to urban areas for certain ecosystem services, particularly those related to provisioning and regulating functions. For example, Meerut, which saw expansions in both cropland and urban land between 2001 and 2020, experienced a substantial increase in its total ESS during this period (Table 4.3.3). This indicates that cropland growth alone did not negatively affect overall service supply.

Variations in coefficients within the ES matrix, which indicate the different capacities of various land covers to deliver ecosystem services, are directly linked to the observed changes in ESS. For example, the matrix approach assigns a higher provisioning service weight to cropland than to urban areas. Therefore, slight expansions in cropland do not necessarily lower the overall ESS score. The supply of ecosystem services depends on both the type and the extent of land cover. Urban regions typically have lower ESS scores compared to other land covers such as cropland, which receive higher weights for their provisioning services. Consequently, when urbanization exceeds growth limits, as observed in Gurgaon and Faridabad, it can substantially decrease overall ESS values due to the replacement of land covers that provide greater ecological advantages.

It is essential to maintain a balance between the requirement for urban development and the conservation of ecosystem services. Strategies should be adopted to mitigate the negative impacts of urbanization on ecosystems. This involves considering the value of ecosystems in land-use planning and using frameworks such as CICES (Common International Classification of Ecosystem Services). In addition, understanding changes in land cover is vital for sustainable planning. Putting emphasis on longitudinal and interdisciplinary research is crucial to understanding socioeconomic factors and involve local communities in decision making. Taking these issues into account can create policies that support urban growth while preserving essential ecosystem services. Urban planning should emphasize green infrastructure and nature-based solutions to improve the resilience and sustainability of ecosystems, with minimal change in land cover. Regulatory frameworks should protect and restore vital ecosystems, especially in peri-urban areas. The offer of incentives for sustainable land use can motivate stakeholders to practice environmentally friendly methods. Global cooperation and knowledge sharing can help develop best practices and innovative solutions for managing urban ecosystems. Policymakers should encourage collaboration with regions facing similar challenges to implement successful strategies.

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APPENDIX

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Table A.3: Co-citation Cluster 3

Habitat	Food from plants	Energy from plants	Other materials from plants	Food from pelagic animals	Food from demersal fish	Food from other invertebrates	Other materials from animals	Genetic material from animals
Mangrove	3	3	3	1	1	3	2	3
Coral	1	-	1	1	3	3	3	3
Seagrass	1	-	2	1	1	2	2	3
Sand	1	-	-	1	1	2	3	1
Overall mud	NA	NA	NA	1	2	3	1	3
Overall rock	1	-	1	1	1	1	1	-
Overall coarse	-	-	-	1	1	1	1	-
Pelagic	-	-	-	3	1	3	2	1
Seaweed farms	3	-	3	-	2	-	-	2
Fish cages	1	-	-	1	3	1	-	-
Invertebrate aquaculture	1	-	-	-	1	3	1	-
Artificial substrate	-	-	-	1	-	1	-	-

Table A.4: Ecosystem Service Supply Score (Provisioning Services)

Habitat	Waste Treatment	Erosion Control	Water Management	Nursery Sites	Iconic Species Sites	Climate Management
Mangrove	3	3	3	3	3	3
Coral	-	2	2	3	3	2
Seagrass	3	2	2	3	3	3
Sand	1	2	2	2	2	2
Overall Mud	-	1	1	2	2	1
Overall Rock	-	1	1	-	1	-
Overall Coarse	1	1	1	-	-	-
Pelagic	1	-	-	3	3	1
Seaweed Farms	1	1	1	1	1	1
Fish Cages	3	-	1	1	2	-
Invertebrate Aquaculture	NA	1	1	1	1	1

Table A.5: Supply Score for Ecosystem Services (Regulating)