ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

ASSESSING THE IMPACTS OF URBAN LAND USE/LAND COVER CHANGE ON SOIL ECOSYSTEM SERVICES

Ph.D. THESIS

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

KENTSEL ARAZİ KULLANIMI/ARAZİ ÖRTÜSÜ DEĞİŞİMİNİN TOPRAK EKOSİSTEM SERVİSLERİ ÜZERİNDEKİ ETKİLERİNİN DEĞERLENDİRİLMESİ

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Meltem DELİBAŞ, a Ph.D. student of ITU Graduate School student ID 502122807, successfully defended the thesis/dissertation entitled “ASSESSING THE IMPACTS OF URBAN LAND USE/LAND COVER CHANGE ON SOIL ECOSYSTEM SERVICES”, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 26 May 2023
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To my dearest family and Maissoun,

FOREWORD

Understanding the life beneath our feet is a long journey. Through this research, I have made a modest contribution towards this pursuit, with an aspiration of inspiring new studies aimed at better understanding and safeguarding soil in an urbanizing world.

This process would have been markedly more arduous without the invaluable support and guidance I received. Herein, I would like to express my profound gratitude to my supervisor Prof. Dr. Azime TEZER at first. She has provided me with her inspirational guidance, sincerity, and all-time patience. Since our maiden encounter in 2009, she has always illuminated my path with her insights and expertise. I also would like to thank the committee members, Prof. Dr. Remzi KARAGÜZEL and Prof. Dr. Günay ERPUL for their invaluable guidance and constructive feedback throughout the research process. Without their support and contributions, it could have been a complete mess. Furthermore, I would like to express my sincere gratitude to the esteemed jury members, Prof. Dr. Şevkiye Şence TÜRK and Prof. Dr. Osman UZUN, for their valuable contributions. Their insightful comments significantly enhanced the quality of the work, enriching its content and depth.

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I find it challenging to express my gratitude to my beloved family using my limited vocabulary. Their unwavering love and support have been indispensable in completing this research. Thank you, Mom and Dad, you are the the pillars of my strength. Another heartfelt appreciation extends to my beloved sister and aunts for their endless support and love. My dearest grandmother, you used to wonder why this academic journey never seemed to conclude; finally, it has. Unfortunately, you couldn't witness the completion of this work, but I know your support and love have always been with me. Thank you.

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October 2023
Meltem DELİBAŞ
(Landscape Architect,
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TABLE OF CONTENTS

Page

ABBREVIATIONS

CICES : Common International Classification of Ecosystem Services
CLC : Corine Land Cover
CN : Curve Number
ES : Ecosystem Services
DSI : General Directorate of State Hydraulic Works
FAO : Food and Agriculture Organization of the United Nations
GHG : Greenhouse Gases
GIS : Geographic Information System
HSG : Hydrologic Soil Groups
In-SoES : Integrated Soil Ecosystem Services
InVEST : Integrated Tool to Value Ecosystem Services
IPBES : Intergovernmental Panel on Biodiversity and Ecosystem Services
IPCC : Intergovernmental Panel on Climate Change
ISKI : Istanbul Water and Sewerage Administration
LULC : Land use and Land Cover
MEA : Millennium Ecosystem Assessment
NDVI : Normalized Difference Vegetation Index
NPK : Nitrogen (N), Phosphorus (P), and Potassium (K)
NPP : Net Primary Production
SDGs : Sustainable Development Goals
SOC : Soil Organic Carbon
SoES : Soil Ecosystem Services
SOM : Soil Organic Matter
TEEB : Economics of Ecosystems and Biodiversity
UNCCD : United Nations Convention to Combat Desertification
UNEP : United Nations Environment Programme
USDA-SCS : United States Department of Agriculture, Soil Conservation Service (currently known as the United States Department of Agriculture, Natural Resources Conservation Service, USDA-NRCS)
USGS : United States Geological Survey

LIST OF TABLES

LIST OF FIGURES

ASSESSING THE IMPACTS OF URBAN LAND USE/LAND COVER CHANGE ON SOIL ECOSYSTEM SERVICES

SUMMARY

Soil represents a dynamic living ecosystem and stands as a fundamental resource for sustaining life on Earth. However, recent years have witnessed a concerning escalation in the detrimental impacts of human activities on the terrestrial environment, particularly evident during the Anthropocene Epoch. Soil, the foundation of terrestrial ecosystems, is surely not exempt from the adverse consequences of anthropogenic interventions, which have exacerbated the problems associated with soil quality and functionality, giving rise to a global emphasis on land and soil degradation.

In response to the increasing pressures on soil, the United Nations officially designated the year 2015 as the "International Year of Soils” to raise awareness and emphasize the imperative of preventing the escalating pressures and threats to soil. Accordingly, it was affirmed by several studies that as a result of human activities (e.g., unsustainable agricultural practices, industrial activities, and urbanization) soil's biophysical and chemical characteristics are subject to varying degrees of impact, contingent upon the nature, pace, and extent of the intervention. In particular, the alterations in land use and land cover (LULC) pose significant threats to soil functions and the provision of ecosystem services provided by soil (SoES). The expansion of urban areas and the concurrent rise in impermeable surfaces accelerate detrimental alterations in SoES within urban settings. Instances of soil sealing, where impermeable materials overlay soil, or land take, involving the conversion of land for construction purposes. This transition in LULC pattern and increase of built-up areas cause long-term alterations in soil structure and result in diminished infiltration capacity for surface water, impeded vertical percolation, altered subterranean thermal dynamics, weakened soil microbial activity, and ultimately indirect or direct detrimental impacts on soil functions and services.

Indeed, soil is vital in enabling and ensuring the feasibility and resilience of terrestrial ecosystems through its multifaceted functions and services. Its strategic location at the intersection of the Earth's lithosphere, atmosphere, and hydrosphere empowers it to play a central role in regulating biogeochemical cycles critical to life. Moreover, soil regulates the intricate flow of essential plant nutrients. This regulation by soil supports numerous ecosystem services (ES) indispensable to human well-being, including food, fiber, and raw material production, water regulation, temperature moderation, provision of clean water, carbon sequestration, and preservation of cultural heritage. Furthermore, soil accommodates a vast array of microorganisms, that are nearly one-fourth of the global biodiversity. In addition to its biodiversity-related significance, soil functions as a key agent in global hydrological processes, acting as a vast reservoir for water filtration and storage. Besides, soil serves as a terrestrial carbon sink, promoting equilibrium in atmospheric greenhouse gas emissions, and contributing to the ongoing struggle against climate change.

Nevertheless, recent studies emphasize that despite the significant ES provided by soil and its critical role in climate change, soil, and SoES have been partly incorporated into the global ES frameworks and have received limited attention. Furthermore, they have been largely overlooked in urban spatial planning and decision-making processes. Yet, given the multidisciplinary nature of soil science, urban planners, in collaboration with other related disciplines, can play a central role in understanding and managing the intricate functions and services of soil by considering its indispensability for the continuity of life. Herein, the holistic study of soil requires a multidisciplinary approach to integrate the fragmented policy frameworks and practices on sustainable soil management.

From this perspective, the study assesses the intricate network involving SoES, climate change, and spatial planning, considering their interdependencies. It underscores the key role of LULC dynamics in optimizing the multifaceted benefits associated with each pillar of this network. The overarching objective of this research is to contribute to the limited understanding and recognition of SoES in urban spatial planning. To achieve this, it addresses the global challenges posed by urbanization and LULC alterations concerning SoES, in connection with climate change. In this context, the study introduces a nexus framework that highlights the interconnectedness of the selected pillars and presents a conceptual framework for assessing the interactions between LULC changes and SoES, focusing on the case of the Buyukcekmece Watershed in Istanbul. The central argument of this research posits that safeguarding and improving the essential functions and services of soil requires the incorporation of soil-related knowledge into urban spatial planning processes.

In this context, the thesis comprises six chapters, the first of which presents a comprehensive overview of the research structure and content, encompassing the scope, objectives, findings, and research questions. Furthermore, the chapter provides a summary of the research organization through a thesis flowchart. The second chapter undertakes an exhaustive literature review, delving into the theoretical underpinnings of the study, exploring the significance of SoES, the increasing pressures and threats it faces, and its intricate relationship with climate change and spatial planning. This chapter also incorporates research findings about the distinctive characteristics and challenges associated with urban soil. Chapter 3 elucidates the design of the research methodology and the organization of data, while Chapter 4 serves as the implementation section, examining the research questions and methodology in a selected case study area. In this chapter, the research design is formulated, delimitations of the study are outlined, and the chosen methodology is determined. Furthermore, an exhaustive assessment of relevant literature is conducted to discern the geographical location, demographic and physical characteristics, and potentials of the case study area, as well as the pressures and threats it faces. Subsequently, data acquisition and preprocessing preparations are carried out. Within the predefined methodological framework, the study focuses on analyzing the spatio-temporal changes in the selected SoES supply, as well as the alteration in LULC patterns. Chapter 5 critically examines the findings derived from the analysis, discussing the mapping of critical areas within the study area and proposing new ideas and recommendations for the possible integration of SoES into the existing spatial planning framework. Lastly, the sixth chapter, "Conclusion," offers a comprehensive evaluation of the study, addresses its limitations, and puts forward suggestions for future research.

KENTSEL ARAZİ KULLANIMI/ARAZİ ÖRTÜSÜ DEĞİŞİMİNİN TOPRAK EKOSİSTEM SERVİSLERİ ÜZERİNDEKİ ETKİLERİNİN DEĞERLENDİRİLMESİ

ÖZET

Toprak, küresel ekolojik süreç ve döngülerin işleyişinde önemli görevler üstlenen, içerisinde ve üzerinde canlıların barınıp beslendiği canlı bir ekosistem ve yaşamın kaynağıdır. İnsanın toprak ile ilişkisi insanlığın varoluşundan itibaren güçlü bir şekilde kendini göstermiş, barınma, beslenme ve hatta kültürel bağlamda mekansal aidiyet ve mülkiyet konularıyla toprak insanlık tarihinin her döneminde önemli bir varlık olmuştur.

Fakat insan aktivitelerinin yeryüzü üzerindeki olumsuz etkilerinin gün geçtikçe arttığı, Antroposen Dönem olarak yorumlanan yeni bin yılda insan ve toprak ilişkisi yön değiştirmiş ve toprak ekosisteminin sürdürülebilirliği artan insan faaliyetlerine bağlı olarak risk altına girmiştir. Özellikle sürdürülebilir olmayan tarımsal uygulamalar, endüstriyel aktiviteler ve kentleşmenin etkisiyle toprak nitelik ve işlevlerinde karşılaşılan problemler, küresel boyutta artan toprak ve arazi bozunumu (land and soil degradation) problemini gündeme getirmiş, bu duruma dikkat çekmek amacıyla Birleşmiş Milletler (BM) 2015 yılını “Toprak Yılı” olarak ilan etmiştir. Aynı şekilde BM Sürdürülebilir Kalkınma 2030 Hedefleri (SDGs) kapsamında da 7 hedef doğrudan ya da dolaylı olarak toprak ile ilişkilendirilmiştir. Yapılan bu girişim ve çalışmaların amacı, küresel ölçekte yaşanan toprak problemlerine dikkat çekmek ve oluşumu uzun yıllar alan ve yaşamın devamlılığı için önemli roller üstlenen toprağın üzerindeki baskı ve tehditlerin önlenmesine yönelik uygulama ve stratejilerin geliştirilmesini desteklemektir.

Toprak, sağladığı fonksiyon ve servisleriyle yeryüzündeki yaşamı mümkün ve sürdürülebilir kılmaktadır. Bilhassa, yeryüzü, atmosfer ve su kütlelerinin ara kesitinde yer alan kritik konumu sayesinde karbon, azot, su gibi yaşamsal besin döngülerin düzenlenmesinde merkezi bir rol oynamaktadır. Ayrıca, N, P, K, Ca, Mg ve S gibi bitki besin maddeleri elementlerin taşınımını düzenlemekte ve gıda, lif ve hammadde üretimi; su rejimi ve yerel sıcaklık düzenlemesi; temiz suyun sağlanması; karbon depolama; kültürel kimlik ve miras gibi birçok ekosistem servisi (ES) sağlamaktadır. Toprak tarafından sağlanan önemli ES’lerden biri de, biyokimyasal döngüler ve bu döngülerde aktif görevler üstlenen toprak mikroorganizmalarını barındırmasıdır. Bu özelliği ile toprak, küresel biyoçeşitliliğin neredeyse dörtte birine ev sahipliği yapmaktadır. Ayrıca toprak, Dünya'daki en büyük su filtresi ve su depolama alanı görevini de üstlenmekte, karasal bir karbon havuzu olarak atmosferdeki sera gazı emisyonlarını dengelemede ve iklim değişikliğiyle mücadelede kritik bir rol üstlenmektedir.

Ancak literatür araştırmaları, insan aktivitelerinin toprağın yapı ve niteliklerinde değişime ve kirlilik seviyelerinde artışa neden olduğunu açıkça ortaya koymaktadır. Buna göre, toprağın biyo-fiziksel ve kimyasal özellikleri, bilhassa kentsel aktivitelerin türü, büyüme hızı ve etki alanına bağlı olarak ciddi etkilere maruz kalmaktadir. Bu noktada, kentleşmeye bağlı olarak gelişen arazi kullanımı ve arazi örtüsü (AKAÖ) değişiklikleri toprak tarafından sağlanan ekosistem servislerinin (SoES) temini ve sürdürülebilirliğinde en önemli tehditlerden biri olarak gösterilmektedir. Özellikle kentsel alanlarda yapılaşmış alanların artışı ve kentsel yayılmaya bağlı olarak artan geçirimsiz yüzeyler, toprak ve atmosfer arasındaki bağlantıyı keserek kentsel alanlardaki toprağın nitelik ve işlevlerine önemli zararlar vermektedir. Üzerinin geçirimsiz materyalle kapatılması sonucunda sızdırmazlaşması (soil sealing) ya da yapılaşma amacıyla kullanılması (land take) toprak sistemlerinde zaman içerisinde toprak strüktürünün değişmesine, yüzeydeki suyun infiltrasyonu ve toprak katmanlarına doğru ilerleyişinin azalmasına ya da tamamen engellenmesine, buna bağlı olarak yeraltı ısı dengesinin değişmesine, toprak mikroorganizmalarının faaliyetlerinin zayıflamasına ve söz konusu olumsuz etkilerin bağlantılı olduğu diğer toprak fonksiyon ve servislerinin dolaylı ya da doğrudan olumsuz etkilenmesine sebep olmaktadır.

Halbuki son yıllarda gerçekleştirilen araştırmalar, kentsel alanlarda yer alan, çeşitli insan müdahaleleriyle fiziksel-kimyasal-biyolojik özellikleri değiştirilmiş ve zarar görmüş toprakların doğru yönetildiği ve korunduğu takdirde doğal alanlardaki toprağın sunduğu servisleri sunabilecek potansiyele sahip olduğunu ortaya koymaktadır. Ancak kentsel alanlardaki topraklar (urban soils) mekansal planlama kapsamında bu ekolojik karakterinden uzak, genellikle tarımsal niteliği bağlamında ele alınmakta, toprağı bütüncül bir ekosistem olarak değerlendiren ve diğer kentsel ekosistemlerle bağlantılı işlevlerini dikkate alan ortak bir yaklaşım bulunmamaktadır.

Bu noktada tez çalışması, doğal denge ve süreçler açısından yaşamsal önem taşıyan SoES'nin özellikle kentsel alanlarda karşı karşıya kaldığı problemleri ortaya koyarak, toprak fonksiyon ve servislerinin korunması ve sürdürülebilirliğinin sağlanmasında mekansal planlamanın rolünü irdelemeyi amaçlamaktadır.

Araştırma AKAÖ ve SoES ilişkisinin sorgulanmasının gerekliliğini ortaya koyan 3 temel gerekçeye dayanmaktadır. Bunlardan ilki, toprak ve SoES'nin sahip olduğu yaşamsal önem nedeniyle küresel ve yerel ölçekte maruz kaldığı ciddi baskı ve tehditlere dikkat çekilmesi gerekliliğidir. Özellikle kentleşme ve insan aktivitelerinin toprak sistemi üzerindeki etkileri kapsamlı bir biçimde incelenerek, karşılıklı etkilerin ortaya koyulması ve mekansal planlama literatürüne katkı sağlaması gerekli görülmüştür. Bilimsel araştırmalar, AKAÖ değişiminin toprak ekosistemi üzerindeki etkilerine yönelik çeşitli bulgulara yer vermektedir. Ancak, kentleşme ve kentsel nüfusun artacağı öngörüsüne dayanarak, kentsel alanlardaki doğal sistemler üzerindeki baskının tanımlanmasının yanı sıra, olumsuz etkilerin durdurulması/azaltılması için gelecekte yapılması planlanan uygulamalara yönelik etkin çıktılar üretilmesi gerekmektedir. Bu kapsamda araştırma, kentleşme ve AKAÖ değişiminin SoES ile ilişkisini detaylı bir biçimde incelemekte, AKAÖ uygulamalarının doğal süreçlerin sürdürülebilirliği açısından risk oluşturmayacak şekilde planlanmasına yönelik yaklaşımlar üretmeye odaklanmaktadır. Söz konusu yaklaşımların, ileriye yönelik çalışma ve uygulamalar için yol gösterici nitelik taşıyacağı beklenmektedir.

Çalışmanın dayandığı bir diğer gerekçe ise SoES'nin küresel ES sınıflandırması kapsamında bütüncül olarak ele alınmamış olmasıdır. ES yaklaşımı, doğal kaynakların öneminin anlaşılması ve sürdürülebilir olarak yönetilmesinde son yıllarda ön plana çıkan etkin bir mekansal planlama ve uygulama aracı olmuştur. Ancak, ES yaklaşımının temel taşı olarak kabul edilen Milenyum Ekosistem Değerlendirme (MEA) raporunda toprak ekosistemi, sağladığı servisler ve diğer ekosistemlerle olan bütünleşik rolü çerçevesinde önemli oranda ihmal edilmiştir. Raporda toprağın yalnızca oluşumu (soil formation) yönünden incelemeler yer almış, diğer SoES'ne değinilmemiş ve toprak küresel düzeyde yapılan bu sınıflandırmanın önemli ölçüde dışında bırakılmıştır. Raporun kapsamı yer üstündeki ekosistemleri (orman, deniz, kıyı vb.) değerlendirirken, onunla bağlantılı biçimde işleyen yer altındaki ES'leri kapsamına almamıştır. Bu bağlamda tez çalışması, toprak sistemlerinin yeryüzündeki hayatın ve biyolojik çeşitliliğin sürekliliğinin sağlanmasında su ve hava kalitesi kadar önemli bir rolü olduğuna vurgu yaparak, sağladığı servisleri bütüncül bir yaklaşımla ele alan mekansal plan kararlarının geliştirilebilmesine katkı sağlaması açısından önem taşımaktadır.

Ayrıca, toprak biliminin çok disiplinli yapısı, parçacıl yasal çerçevesi ve SoES'ni dikkate alan kapsamlı bir mekansal planlama yaklaşımının henüz geliştirilememiş olması toprağın üzerinde artan baskıların anlaşılmasını, SoES'nin bütüncül bir sistem yaklaşımıyla değerlendirilmesini ve korunmasını zorlaştırmaktadır. İlgili disiplinlerin toprağı yalnızca kendi çalışma alanları kapsamında incelemeleri (toprak ekolojisi, kimyası, ekonomisi vs.), araştırmacılar, karar vericiler ve uygulayıcılar arasında multidisipliner bir çalışma yaklaşımı oluşmasını çoğu zaman güçleştirmektedir. Ayrıca, SoES ve toprağın önemi ve kentsel alanlarda maruz kaldığı tehditler, arazi ve toprak yönetimiyle doğrudan ilişkili bir disiplin olan mekansal planlama kapsamında dikkate alınmamaktadır. Çalışmanın dayandığı üçüncü gerekçeyi ortaya koyan bu durum, AKAÖ değişikliklerinin SoES üzerindeki mevcut olumsuz etkilerinin ilerleyen yıllarda da artarak devam etmesine zemin hazırlamaktadır. Bu sebeple toprağın, özellikle de en ciddi baskının yaşandığı kentsel alanlardaki toprağın önemi, sunduğu servislerin anlaşılması ve sürdürülebilirliğinin sağlanması için SoES'in mekansal planlama kapsamında bir karar destek aracı olarak kullanılması ve geliştirilecek bu yaklaşımın tüm ilgili disiplinleri kapsayacak şekilde etkinleştirilmesi gerekmektedir.

Bu kapsamsa tez çalışması, kentsel alanlardaki toprağın sürdürülebilir bir yaklaşımla ele alınması ve buna uygun AKAÖ plan kararlarının geliştirilmesinde farklı disiplinleri ortak bir paydada ve terminolojide buluşturmayı hedeflemektedir. Söz konusu ortak paydanın oluşturulmasında, özellikle son yıllarda kentsel ekosistemlerin mekansal planlama ve karar verme süreçlerine entegre edilmesi yönünden etkin bir araç olarak kullanılan ES yaklaşımından yararlanılmıştır. Böylelikle, ekosistem niteliklerinin ve hassasiyetlerinin mekansal planlama kapsamında dikkate alındığı, SoES'ye dayalı multidisipliner bir yaklaşım geliştirilmesi amaçlanmıştır.

Çalışmanın temelini oluşturan bu yaklaşım kapsamında öncelikli olarak SoES tanımlanmış, küresel ES çerçeveleriyle entegre edilmesine yönelik detaylı literatür analizlerine dayanan kapsamlı bir SoES sınıflandırma tablosu geliştirilmiştir. Tabloda, toprak tarafından sağlanan servisler MEA raporu kapsamında sunulan dört farklı ES kategorisinde sınıflandırılmış ve böylelikle SoES'nin mekansal planlamaya entegrasyonu kapsamında ihtiyaç duyulan küresel SoES sınıflandırmasına yönelik bir katkı sağlanabileceği düşünülmüştür.

SoES'in sınıflandırmasının ardından, toprak ekosistemi üzerindeki küresel tehditlerin ortaya konulması, toprağın iklim değişikliğiyle olan ilişkisi ve mevcut mekansal planlama pratikleri içerisindeki yeri incelenmiş ve böylelikle SoES, iklim değişikliği, mekansal planlama ve AKAÖ arasındaki ilişkiselliği ortaya koyan kavramsal bir çerçeve (Nexus Framework) geliştirilmiştir. Bu çerçeve, araştırmanın yöntemi ve uygulanacak yaklaşımın temel kurgusunu oluşturmuş, çalışmanın bütüncül bir yaklaşım içerisinde ele alınmasını sağlamıştır.

Araştırmanın kavramsal çerçevesinin oluşturulmasının ardından, seçilen bir örnek alan üzerinde analiz çalışmaları gerçekleştirilmiş, belirlenen zaman periyodu içerisinde öncelikle alandaki AKAÖ değişimi incelenmiş, daha sonra, AKAÖ'de gözlemlenen bu değişikliklerin, çalışma kapsamında seçilen 3 adet SoES (yüzey suyu akışının düzenlenmesi, karbon depolama ve biomass üretimi) üzerindeki etkileri analiz edilmiştir. Analiz çalışmaları İstanbul'un Avrupa Yakası'nda yer alan ve kentin önemli içme suyu kaynaklarından biri olan Büyükçekmece Havzası'nda gerçekleştirilmiştir. Kent çeperindeki havzanın, yoğun nüfus ve kentleşme baskısı altında olduğu ve buna bağlı olarak kirlilik, erozyon, heyelan gibi çeşitli problemlere maruz kaldığı bilinmektedir. Bunun yanısıra, alanda kentleşmeye bağlı olarak değişen AKAÖ, endüstriyel ve tarımsal faaliyetler ile konut alanlarının gelişiminin havzanın ekolojik bütünlüğünü tehdit ettiği ve dolayısıyla alandaki SoES üzerinde olumsuz etkileri olduğu gözlemlenmiştir. Ayrıca, kent genelinde yapılan büyük ölçekli projelerin (Istanbul Havalimanı, Kuzey Marmara Otoyolu, Yavuz Sultan Selim Köprüsü) ve İstanbul'un mevcut kentleşme dinamiklerinin ilerleyen dönemlerde havzanın ekolojik bütünlüğü, su kalitesi ve miktarı ile, AKAÖ ve SoES'leri üzerinde ciddi baskılar yaratacağı düsünülmektedir.

Çalışma kapsamında elde edilen analiz bulguları kentsel bir havza olan Buyukcekmece Havzası'nın kentleşme ve buna bağlı AKAÖ değişikliklerinden doğrudan etkilendiğini ortaya koymaktadır. Bu bağlamda, alandaki SoES temininde de AKAÖ değişimine bağlı etkiler gözlemlenmiştir. Havza genelinde gerçekleştirilen AKAÖ değişimleri ile SoES teminindeki değişiklikler mekansal verilerin haritalanmasıyla ortaya koyulmuştur. Bu çalışamalar, yapılaşmış alanlara dönüşen doğal alanlarda SoES sağlama kapasitesinin azaldığını; buna karşılık, orman ve mera alanlarına dönüşen tarım arazilerinde ise, SoES sağlama potansitelinin arttığını ortaya koymuştur. Söz konusu değişimler bir içme suyu havzası için oldukça önemli görevler üstlenen SoES'nin havza bütününde dikkatle ele alınması ve yönetilmesi gerektiğini ortaya koymaktadır. Çalışmanın sonuç bölümünde bu konuya yönelik öneriler geliştirilmiş ve SoES'nin ilgili mevzuata ve mekansal planlamaya entegrasyonun sürdürülebilir kentsel planlama açısından taşıdığı öneme değinilmiştir.

Ekolojik bir planlama birimi olan havzaların, özellikle kentsel alanlarda karşı karşıya kaldığı risk ve tehditlerin ortaya konulması, küresel ölçekte son yıllarda önem kazanan arazi ve toprak bozunumunun öncelikle kentsel ölçekten yola çıkılarak anlaşılması ve yönetilmesinin gerekliliği bu çalışmanın öne çıkan sonuçları arasındadır. İnsan yaşamıyla karşılaştırıldığında yenilenemez bir kaynak olarak değerlendirilen, ve fakat yeryüzündeki canlı yaşamının devamlılığının sağlanmasında kritik roller üstlenen toprağın fonksiyon ve servislerinin kaybedilmeden önce dikkate ele alınması ve sürdürülebilir bir biçimde yönetilmesi gerekmektedir. Bilhassa, kentlesme ve AKAÖ değişikliklerinin olumsuz etkilerine en fazla maruz kalan; ancak buna rağmen ilgili yasal çerçeve ile mekansal planlama ve karar alma süreçlerinde göz ardı edilen "kentsel topraklar" hem sağladıkları SoES hem de iklim değişikliğiyle mücadeledeki önemli rolleri açısından bu noktada önem kazanmaktadır.

Çok sayıda uluslararası kurum ve akademisyen tarafından da belirtildiği gibi, toprak fonksiyonları ve servislerinin sürdürülebilir olarak korunması ve geliştirilmesi disiplinlerarası yaklaşım ve kapsamlı bir çerçeve gerektirmektedir. Bu bağlamda, SoES'ne dayalı bilginin mekansal planlama süreçlerine entegre edilmesi, özellikle kentsel alanlarda AKAÖ'nün toprak üzerindeki olumsuz etkilerini yönetmek ve en aza indirmek açısından büyük önem taşımaktadır. Bu noktada araştırma kapsamında geliştirilen "In-SoES modeli", SoES'nin analizi, diğer değişkenlerle (AKAÖ, iklimsel özellkler vb.) ilişkisinin ve buna bağlı olarak değişiminin incelenmesi ve sonuçların haritalanmasına yönelik genel bir çerçeve ve altlık sunmaktadır. Model, bilhassa kentsel havzalarda halihazırda kullanılan mesafeye dayalı koruma kuşakları kapsamının, SoES'e dayalı ekolojik hassasiyetleri dikkate alan koruma yaklaşımı ile genişletilmesini ve bunun da hazırlanacak havza koruma planlarıyla mevcut planlama hiyerarşisine entegre edilmesini önermektedir.

Tüm bu değerlendirmeler ışığında; toprak bilimi ve toprağın multidisipliner yapısı gözönünde bulundurulduğunda toprağın özellikleri, çalışma sistemi ve yeryüzündeki yaşamın devamlılığı için taşıdığı önem mekan ve arazi kullanım kararlarına yön veren plancılar tarafından iyi anlaşılmalı, mutlak suretle ilgili disiplinlerle işbirliği içerisinde olunmalıdır. Ayrıca, yenilenemez nitelikteki bu kaynağın korunması, fonksiyon ve servislerinin sürdürülebilirliğinin sağlanmasinda,

(i) Kentsel alanlarin toprak ve SoES üzerindeki etkilerinin anlaşılması;

(ii) SoES açısından yüksek potansiyel taşıyan hassas bölgelerin belirlenmesi ve

(iii) Mekansal planlama araçları ve gerekli yasal düzenlemeler ile de desteklenerek SoES açısından hassas alanların korunması ve sürdürülebilirliği sağlanmalıdır.

Tez çalışması yukarıda yapılan değerlendirmeler kapsaminda toplam altı bölümden oluşmaktadır. İlk bölüm araştırmanın geri planı, temel gerekçeleri ve içeriğine ilişkin genel çerçeveyi araştırmanın kapsamı, amacı, problem bulguları ve araştırma soruları başlıklarında ele almaktadır. Bölüm aynı zamanda araştırmanın organizasyonunu tez akış şeması ile özetlemektedir. İkinci bölüm ise çalışmanın geri planındaki teorik alt yapıya ilişkin detaylı literatür verilerini değerlendirerek; SoES'nin önemi, üzerindeki baskı ve tehditler ile iklim değişikliği ve mekansal planlamayla olan ilişkisini irdelemektedir. Bu bölümde ayrıca kentsel toprağın özellikleri ve problemlerine yönelik değerlendirmelere de yer verilmiştir.

Tezin 3. Bölümü araştırma kapsamında kullanılan yöntemin nasıl tasarlandığı, yöntem ve verilerin nasıl organize edildiği hakkında bilgiler sunarken, 4. Bölüm ise seçilen örnek alan üzerinden uygulama sonuçlarını ortaya koymaktadır. Buna göre, öncelikle araştırmanın yöntem/uygulama tasarımı hazırlanmış, çalışmanın sınırları tanımlanmış ve bu kapsamda uygulanacak metodoloji belirlenmiştir. Uygulama alan çalışmasında ise öncelikle alana ilişkin detaylı literatür değerlendirmesi yapılarak alanın konumu, demografik ve fiziksel özellikleri ile potansiyelleri ve üzerindeki baskı ve tehditler ortaya koyulmuştur. Detaylı alan incelemesi sonrasında, alana ilişkin veri temini ve ön işlem hazırlıkları yapılıp, belirlenen yöntem çerçevesinde alandaki 1) AKAÖ deseninin değişimi, 2) Çalışma kapsamında seçilen SoES temininin yıllara bağlı mekansal ve niceliksel değişimi ele alınmıştır. Analizler sonucu elde edilen bulgular 5. Bölüm kapsamında tartışılmış; alandaki hassas bölgelerin haritalanması ve SoES'nin mevcut plan sistemiyle ve yasal çerçeveyle entegrasyonuna yönelik değerlendirme ve öneriler paylaşılmıştır. 6. ve son bölüm olan "Sonuçlar" bölümünde ise çalışmanın genel bir değerlendirmesi yapılarak araştırmanın kısıtları ve gelecek çalışmalara yönelik önerilere yer verilmiştir.

1. INTRODUCTION

“*Land is not solely composed of soil; it represents a dynamic source of energy that circulates through interconnected systems of plants, soils, and animals.*” Aldo Leopold, 1949.

The Anthropocene epoch has expanded the scope of destructive human interventions in nature. Today, most of the environmental problems such as deforestation, pollution, habitat fragmentation, desertification, and climate change are exacerbated by the growth of urban populations and changing consumption patterns (Chester et al, 2019; Sharma et al, 2018, Petz, 2014). According to Marcotullio et al, (2008), unprecedented human pressure and the demand for natural resources rapidly increase as cities continue to grow. In this regard, urban areas as the innovative catalysts and frontrunners of development, become centers of environmental conflicts as well, where multiple natural hazard risks and environmental disruptions have intensified.

As a result, the profound effects of the Anthropocene period on urban ecosystems have become an increasingly important topic of discussion in the last decades. Several studies indicate that urbanization dynamics and transformation of land cause partial or irreversible damage to the structure and functioning of urban ecosystems (Theodorou, 2022; Jiang et al, 2015; Mohan et al, 2011; Alberti, 2005) resulting in complex environmental problems such as disrupted hydrological systems, fragmented and isolated habitats, modified nutrient cycling, environmental pollution and changes in temperature and precipitation patterns (Elmqvist et al, 2013; Alberti, 2005; Carlson and Arthur, 2000). Soil, as the fundamental basis of all terrestrial ecosystems and one of the most important and vulnerable ecosystems in the urban environment, is also experiencing growing pressure due to destructive human activities. According to FAO (2019), the deterioration of soil resources poses a serious environmental problem because of its essential role in Earth’s terrestrial ecosystems.

As it was mentioned by Delibas et al, (2021), due to its critical existence at the interface of Earth, air, and water, soil plays a central role in regulating life-sustaining cycles such as carbon, oxygen, and water circulating through the atmosphere (air), biosphere (plants and organisms), hydrosphere (water) and lithosphere (rocks) (Li et al, 2012). It regulates the flux of plant nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) and provides a burden of ecosystem services (ES) including the production of food, fiber, and raw materials; regulation of water regime and local temperature; availability of clean water; carbon storage; cultural identity and heritage (Schwilch et al, 2016; Pouyat et al, 2010; Dominati et al, 2010; Daily et al, 1997). Most critically, it hosts almost a quarter of global biodiversity (EC, 2010), functions as the biggest water filter and storage on Earth (FAO and ITPS, 2015), and serves as a terrestrial carbon pool, contributing to mitigating the release of greenhouse gases into the atmosphere and helps combat climate change (IPBES, 2018; EEA, 2012). As FAO and ITPS (2015) state, the services provided by soil sustain life on the planet and they are the key tools for understanding the characteristics, functioning, and importance of the soil system.

Although it is a limited source, due to the extensive duration of soil formation, soil can be perceived as non-renewable on the human timescale (Dominati et al, 2016; EC, 2006). Yet, similar to other ecological systems susceptible to critical human intervention, soil is exposed to profound threats and pressures many of which are caused by direct or indirect anthropogenic disturbances. Besides the threats caused by natural factors such as climate and topography, unsustainable agricultural practices, industrial activities, and urbanization processes have significant and varying impacts on the physical, chemical, and biological properties and so the functions and services of soil (Geitner et al, 2019; Ronchi et al, 2018; Marcotullio, 2008). Such unprecedented human interference causes a decline in soil quality and fertility, depletion of soil organic matter (SOM), erosion, soil pollution, and some biochemical changes in soil structure due to salinity, acidity, or alkalinity which ultimately result in serious degradation of soil at the global scale (IPBES, 2018; Schwilch et al, 2016; Stolte et al, 2015; Tóth et al, 2008). Particularly in urban areas, soil resources have been compacted, sealed, and polluted due to anthropogenic activities and land transformations, which recently led to a new type of soil termed: ‘urban soil’ (Pavao-Zuckerman, 2008; Effland and Pouyat, 1997).

In light of its critical role in life-sustaining processes and the measures (adaptation and mitigation) for climate change impacts due to its alarming rates of degradation, soil has gained significant prominence in the current global agenda as well (Delibas et al, 2021). To emphasize its importance and increase global public awareness, the United Nations (UN) designated 2015 as the “International Year of Soils” and dedicated some goals and targets of the Sustainable Development Goals (SDGs) to the relationship between soil health and human well-being. Specifically, “Goal 15: Life on Land” is directly linked to reducing desertification and restoring degraded land and soils (UNSD, 2015).

Meanwhile, several scholars highlight the gap in fragmented policy frameworks on land and soil management. They underline the necessity for incorporating soil-based knowledge into spatial planning processes to enhance and safeguard the capacity of soil to mitigate climate change and provide ES (Drobnik et al, 2020; Silva et al, 2018; Ronchi, 2018). According to Tezer et al, (2020), embedding the ES approach into spatial planning processes provides practical tools not only for sustaining the benefits of ES but also for mitigating natural hazards. In this case, an urban spatial planning framework considering soil ecosystem services (SoES) can also be used to converge the multidisciplinary nature of soil management, besides sustaining its vital services and mitigating the risks caused by soil degradation (e.g., flooding, erosion, landslide, and drought). However, as it has been mostly neglected by the urban spatial planning processes, SoES is not fully understood and incorporated into the global ES frameworks as well (Delibas et al, 2021; Silva et al, 2018; Adhikari and Hartemink, 2016).

By adopting a multidisciplinary approach that encompasses the fields of soil science, geological engineering, landscape architecture, and urban planning, this study primarily focuses on the vital importance and problems of the soil ecosystem and aims to clarify the ecological consequences of human-induced land use and land cover (LULC) change on the services provided by soil. The overall intent of the research is to explore the possible integration of SoES into urban spatial planning processes to enhance the provisioning of SoES, minimize anthropogenic threats to soil, and contribute to global efforts against soil degradation and climate change.

The content of the thesis is organized into six major chapters. The first chapter provides an outline of the research background and design while the second chapter is organized as the theoretical framework discussing the global threats to soil together with the position of SoES within the recent ES frameworks and urban spatial planning processes. In chapters 3 and 4, empirical site analysis and the methods used in the study were shared. Lastly, the evaluations related to research findings and case study analysis, along with recommendations for integrating SoES into the relevant legislation and spatial planning framework, are discussed in the 5th and 6th chapters.

In the context of "Chapter 1: Introduction", the scope and content of the study are presented under four sub-chapters namely: Problem statement and research objectives; Rationale of the study; Hypothesis and research questions, and; Thesis outline.

1.1 Problem Statements and Research Objectives

As FAO and ITPS (2015) indicate, currently, one-third of global soils are already degraded as a result of soil compaction, erosion, salinization, acidification, and chemical pollution. Yet, 90% of the earth's fertile topsoil could be at risk by 2050 by putting food security in jeopardy (FAO, 2022). In this regard, the main concern of the research is the destructive human intervention on soil with a particular emphasis on the adverse effects of LULC change on SoES in urbanizing landscapes.

The scope of the key research problems addressed was clarified below:

Problem 1: Soil as a vital part of the natural environment is under continuous pressure caused by various human activities and altered LULC patterns (Joss and De Tender, 2022; Delibas et al, 2021; Rumpel et al, 2019; Pereira et al, 2017; Smith et al, 2016; Jiang et al, 2015; Bajacco et al, 2012; Marcotullio et al, 2008). In the recent global agenda, soil degradation was described as "reaching its critical limits to provide SoES" (FAO and ITPS, 2015).

<u>Description:</u> Soil is where food begins. 95% of the food we consume comes directly and indirectly from soil (FAO, 2022), in which around 25% of all biodiversity on Earth lives and continuously interacts to sustain soil functions and services (EC, 2010). However, according to UN (2023), Joos and Tender (2022), Smith et al, (2016), Stolte et al, (2015) and FAO (2013) soils are subject to some degree of direct or indirect human disturbance. Although it is not always straightforward to distinguish between natural and anthropogenic threats (Smith, 2016), some human activities have a direct influence and great impact on soil. These include improper agricultural practices (e.g., intensive farming, heavy machinery, agrochemicals, tilling), industrial activities (e.g., mine extraction, waste disposal), and urbanization (FAO and ITPS, 2015; Stolte et al, 2015; Glæsner et al, 2014). In this context, the study focuses on the impacts caused by

urbanization-induced processes mostly associated with LULC change since the effects of some mismanagement practices on land greatly threaten the availability of soil and its services in urban areas (FAO, 2013).

According to Vitousek et al, (1997), between one-third and half of the earth's land surface has been altered by human activities. This long-term transformation in LULC patterns causes degradation and/or loss of key soil characteristics resulting in a decline in soil quality and fertility, altered soil drainage and water flow, increased soil temperature, restricted gas exchange, removal of fertile topsoil, loss of soil biodiversity and nutrient imbalance (Khan et al, 2022; Silva et al, 2018; Schwilch et al, 2016; FAO and ITPS, 2015; Alberti, 2005). Deteriorating effects on soil threaten its critical role in climate change measures as well. As an integral part of the global carbon cycle, soil captures and stores 80% of the total carbon found in terrestrial ecosystems (Lal, 2008). Sequestration and storage of carbon are critical for soil health and fertility (FAO, 1995), regulation of the global carbon budget (Lal, 2008), and climate change (FAO, 2019). Depending on the management of soil and land, soil can offset the greenhouse gases (GHG) as a carbon sink and contribute to mitigating climate change (FAO, 2019) or can cause carbon release to the atmosphere which further exacerbates the climate change-related problems (EEA, 2012). Although it is acknowledged by the international authorities that soil is one of the major factors in adaptation and mitigation to climate change (EEA, 2019; FAO, 2019; IPBES, 2018; IPCC, 2019; UNCCD, 2016), insufficient political attention and fragmented approach in soil management together tend to reverse the mitigation potential of soil (Delibas et al, 2021).

Taking into consideration that soil has crucial roles in vital ecological processes (e.g., primary production, energy flow, cycling of water, carbon, and nutrients) and provides ES essential to human well-being (such as improving food security, resilience to floods and droughts, storing and filtering water, combat and adapt to climate change) the threats and pressures on soil can be considered as a serious environmental problem at multiple scales.

Problem 2: SoES are neither well represented in the ES literature nor well integrated into the spatial decision-making process (Delibas et al, 2021) despite its crucial services and the critical role they play in climate change measures.

Description: Although the growing global need for soil protection was acknowledged by several authorities at different levels, and the need for integration of SoES into spatial planning was identified as a potential strategy to combat climate change, SoES has not been categorized yet under a common ES framework and was overlooked in urban spatial planning and decision-making processes (Delibas et al, 2021; Haines-Young and Potschin-Young, 2018; Adhikari and Hartemink, 2016; Jónsson and Davíðsdóttir, 2016; Dominati, 2013). In the last decades, several studies further contribute to extending the influence of ES to landscape and spatial planning (Qui et al, 2022; Longata et al, 2021; Tezer et al, 2020; Ronchi, 2018; Silva et al, 2018; Schwilch et al, 2016) and promote its integration into spatial decision-making processes. The studies reveal that integrating ES-based strategies into urban spatial planning provides several benefits one of which is contributing to the overall understanding of the ecological, social, and economic impacts of spatial planning decisions. Moreover, it serves as an effective spatial decision-making tool to support the synthesis and interpretation of various data from different disciplines and analyze their synergies and trade-offs (Longata et al, 2021). As Almenar et al, (2018) state, ES-oriented spatial planning tools also support the designation and protection of ecologically vulnerable zones in human-dominated environments. At that point, urban soils as an overlooked and highly threatened ecosystem in the urban landscape need an integrated approach embedding SoES knowledge into urban spatial planning strategies to safeguard and sustain its vital functions and services.

Problem 3: The holistic study of soil requires a multidisciplinary approach to integrate the fragmented policy frameworks and legislative structure on sustainable soil management and planning (Rodrigo-Comino et al, 2020; Brevik et al, 2015; Emadodin et al, 2009).

Description: Due to its forming at the intersection of the atmosphere, biosphere, hydrosphere, and lithosphere, soil has a dynamic, complex, and multifaceted nature (Brevik et al, 2015) which is closely linked to several disciplines including agronomists, engineers, geologists, microbiologists, physical geographers, physicist, chemists, ecologists, archaeologists and specialists in landscape architecture and urban and regional planning. This fragmented structure of soil science poses a great challenge in establishing a common scientific language and integrated approach to soil management and planning since researchers from different professional backgrounds have different definitions, terminologies, and perceptions of soil. Besides, depending on the organizational dynamics, active collaboration of all actors from related disciplines can be challenging due to institutional strains, conflicts of authority, and bureaucratic processes.

However, as it has been repeatedly emphasized by several international organizations and reports, understanding and minimizing the long-term effects of human-induced soil degradation requires an integrated, comprehensive and interdisciplinary approach (FAO, 2019; Olsson et al, 2019; Emadodin et al, 2009). In particular, analyzing, interpreting, and managing the spatiotemporal changes in urban land together with their impacts on SoES involves multidisciplinary research, in which urban and landscape planners play a central role in connecting the experts in related fields.

From this point of view, the research aims to contribute to the limited understanding and recognition of SoES in urban spatial planning and decision-making processes to converge the fragmented structure of soil management through ES-based policies and to cope with the growing challenges and negative consequences of soil threats in the long run. Given the fact that urbanization and local anthropogenic activities are the pioneer drivers contributing to the global degradation of land and soil resources, the development of urban-based solutions in soil management is of great importance. Moreover, considering the mutual interactions between soil, urbanization, LULC, and the climate crises, SoES-based urban spatial planning strategies can also be useful to optimize the multifaceted benefits and help to combat climate change.

In line with the above-mentioned primary focus and general purpose of the study, four objectives and a set of sub-objectives have been determined to emphasize the key points and themes that need to be clarified in the context of the research. These are as listed below:

Objective 1: Contributing to the classification of SoES under global ES frameworks

Sub-objective 1.1: Understanding the functions and services of soil

Sub-objective 1.2: Reviewing the status of SoES in the existing ES frameworks

Sub-objective 1.3: Classifying SoES under the MEA-ES Framework

Objective 2: Understanding the effects of LULC change on SoES in the urban context

Sub-objective 2.1: Assessing the natural and anthropogenic threats to urban soils

Sub-objective 2.2: Clarifying the impacts of urban LULC change on SoES

Sub-objective 2.3: Defining the characteristics and functionality of urban soils

Objective 3: Analyzing the changes in LULC and SoES in the Buyukcekmece Watershed case

Sub-objective 3.1: Building a conceptual framework by assessing the global response to soil threats

Sub-objective 3.2: Establishing a methodological approach that translates the conceptual knowledge into an empirical framework

Sub-objective 3.3: Implementing the empirical analysis of the study case

Objective 4: Translating the quantitative research results into planning and policy suggestions: "How can we safeguard and enhance SoES provision through urban spatial planning and related legislation?"

Sub-objective 4.1: Evaluating the findings of the case study analysis

Sub-objective 4.2: Assessing the position of SoES within the existing legislative and spatial planning framework in Turkiye

Sub-objective 4.3: Providing suggestions on integrating SoES-based knowledge into current legislation and spatial planning process

To sum up, the overall intent of the study is to highlight the global significance and problems of the soil ecosystem and make recommendations for further consideration of SoES within urban spatial planning and decision-making processes. Hereby, detecting and protecting the critical zones with high SoES potential can be possible in urbanizing landscapes where the impacts of land transformations on soil are severe and destructive.

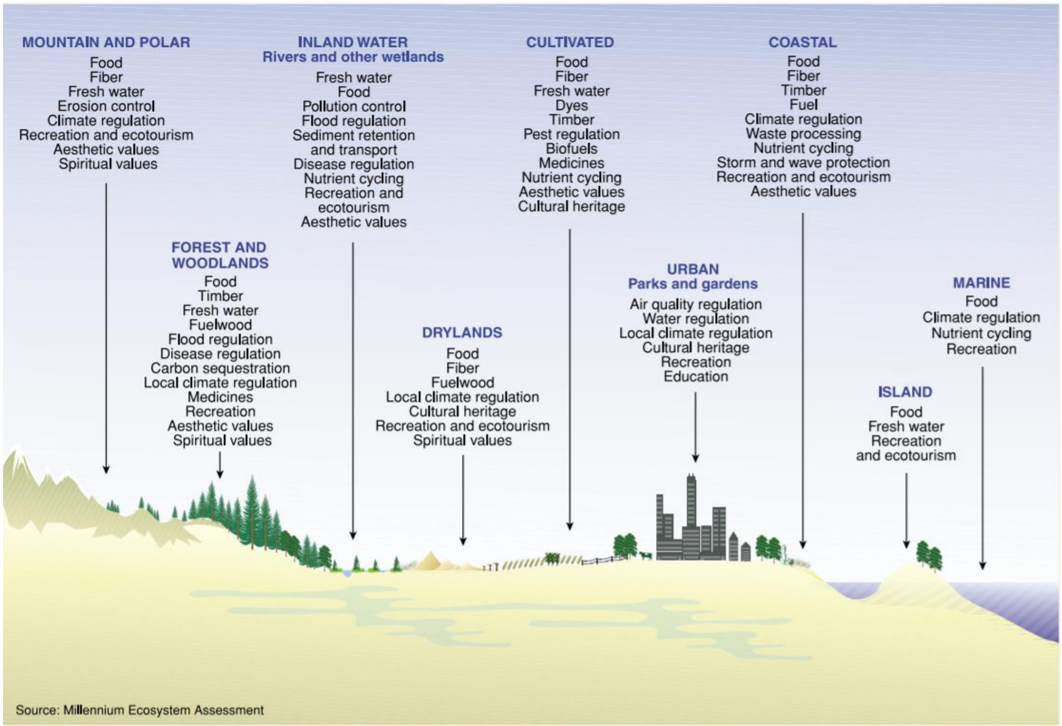
1.2 Rationale of the Study

In the context of soil-human interactions and the profound impacts of anthropogenic interventions on SoES, the research highlights two distinct conceptual gaps, which were considered the major driving forces behind the study; **(1)** the absence of a complete classification and incorporation of SoES in the existing ES frameworks at international level and **(2)** the neglected significance of urban soils and SoES in climate change measures, spatial planning and related legislation.

Description (1): The findings of an in-depth literature review conducted within the scope of this study reveal that the recent ES frameworks have not thoroughly examined soil, thus there is currently no classification for SoES agreed upon at the international level.

As it was mentioned by Delibas et al, (2021), the ES framework roots back to the research of “Man's Impact on the Global Environment” sponsored by the Massachusetts Institute of Technology in 1970 (Ronchi, 2018). The term ‘environmental functions/services’ used in research captures the recent concept of ES. Although there has been a growing interest in the analysis of services provided by ecosystems since the 1970s, the ES approach has been popularized by the Millennium Ecosystem Assessment (MEA) Report (MEA, 2005a). MEA presents a strong and essential relationship between human well-being and the provision of ES, which is well-acknowledged in the scientific literature and inspired by several researchers (Adhikari and Hartemink, 2016; Breure et al, 2012; Burkhard et al, 2009; Dominati et al, 2010; Schwilch et al, 2016). The report provides a clear nomenclature for the ES framework under 4 major function groups (provisioning, regulating, supporting, and cultural) and evaluates the impacts of ecosystem transformation on human welfare.

In time, divergences of opinions regarding the most suitable classification of ES have brought some revisions including the Common International Classification of Ecosystem Services (CICES) developed by the European Environment Agency, United Kingdom National Ecosystem Assessment, the Economics of Ecosystems and Biodiversity (TEEB) committee and the United States National Ecosystem Services Classifications Systems all expand on the MEA (Almenar et al, 2018; EPA, 2015; Robinson et al, 2013). Although substantial efforts have been made to conceptualize, classify, quantify, and value ES as well as to incorporate the ES framework into spatial decision-making processes (Costanza et al, 1997; de Groot et al, 2002; Dominati, 2013; Ronchi et al, 2019), very limited attention has been devoted to soils for their classification in the ES framework. As Dominati et al, (2010) argue, MEA as a leading reference underpinning the ES concept, has adopted an extensive ecosystem approach in which soil received little or no attention apart from its role in soil formation. Adhikari and Hartemink, (2016) and Dominati (2013) agree that the MEA report discusses ES from an aboveground perspective (Figure 1.1), which neglects soil and its services and disregards the vital interconnectedness among the belowground and aboveground ecosystems as a whole. In the framework, forests, grasslands, mangroves, and even urban areas are regarded as an ecosystem providing different services to society, while the soil is given only a supporting role in soil formation. Thereby, the provision of other soil services was not explicitly explained and some knowledge gaps in critical SoES have remained obscure in the report (Delibas et al, 2021; Baveye et al, 2016; Jónsson and Davíðsdóttir, 2016; Robinson et al, 2013).



Source: Millennium Ecosystem Assessment

Figure 1.1 : Multi-contexts of ecosystems and their basic services (MEA, 2005b, reproduced with the permission of the World Resources Institute).

Description (2): The research findings indicate a knowledge gap in safeguarding SoES through spatial planning (Delibas et al, 2021). As Hewitt et al, (2015) stated, soil, as an overlooked component in the ES studies, was correspondingly disregarded in planning and policy decisions as well. As a result of their extensive analysis comparing the urban plans and reports of seven cities worldwide, Silva et al, (2018) conclude that soil and SoES were poorly addressed in the process of implementing and monitoring urban development strategies and plans. Similarly, Geitner et al, (2019) emphasize the need for locally adapted strategies for efficient and sustainable planning and management of soil. The research also advocates the idea of giving soil protection more room in urban spatial planning to contribute to well-functioning urban soils with multiple benefits, one of which is to fight the urban heat island effect.

Given the central role in land management, spatial planning is an important discipline for developing sustainable and adaptive land use strategies for protecting and enhancing the capacity of soil in ES provision and climate change policies (Drobnik et al, 2020; Siva et al, 2018). Therefore, it is crucial to consider the interrelations among SoES, climate change, and spatial planning, which have not been thoroughly studied in the scientific literature. Although a large number of studies have been conducted up to date associated with soil, climate change, and spatial planning, the studies focusing on their complex interactions are limited (Delibas et al, 2021). Recently, their influence on each other has been given a central role in soil degradation and climate change (FAO, 2019; IPBES, 2018; IPCC, 2019). Thus, further research is needed to understand and formalize their interdependencies.

According to Rodrigo-Comino et al, (2020), IPCC, (2019), and Geitner et al, (2019), the multifaceted relationship between soil, climate change, and spatial planning requires an integrated, multidisciplinary and comprehensive approach to identifying and managing their mutual interactions. Therefore, it was intended by this research to analyze their interactions within the 'Nexus' framework and to discuss the measures needed for the integration of SoES into the spatial decision-making process considering (i) the critical role of soil in climate change; (ii) threads expected to be added on the soil by climate change; (iii) influence of LULC and spatial planning on their interactions. Herein, the study focuses on the soil and its threats in the urban context since urban areas are considered as a "cause and solution" to soil degradation.

1.3 Hypothesis and Research Questions

The study argues that the main solution to global soil degradation lies in local actions. Since cities are the centers for innovation, cultural exchange, and economic development and, at the same time, the key contributors to environmental problems (Elmqvist et al, 2013; Mohan et al, 2011; Marcotullio et al, 2008), measures and actions to be taken at the urban scale determine the severity and form of large-scale human influence on the environment.

Soil as one of the vital, yet heavily threatened and damaged natural resources globally, needs to be considered by the local strategies and actions to cope with the destructive impacts of anthropogenic interventions. Recent literature indicates diverse threats to soil varying from climate change to improper agricultural practices. Among the factors influencing global soil resources adversely, urbanization and associated transformations in LULC pattern cause a major decline and deterioration in soil properties, functions, and services, which lead to serious environmental problems and some natural hazards such as floods and erosion (Pouyat et al, 2020, Naumann et al, 2018, Pavao-Zuckerman and Pouyat, 2017, Peccol and Movia, 2012, Marcotullio, 2008). FAO and ITPS (2015) consider LULC change as one of the leading contributors to global soil degradation while Effland and Pouyat (1997) and Pickett and Cadenasso (2009) described the anthropogenic disturbances and indirect impacts of urbanization as the sixth factor affecting soil formation processes and together with Pavao-Zuckerman, (2008) they defined ‘urban soils’ as a novel soil type.

Soil in urban areas is highly disturbed and modified by human activities, it is sealed, compacted, and contaminated (Pouyat, 2020; Pickett and Cadenasso, 2009). However, as Pouyat et al, (2010) state, urban soils still have the potential to provide essential functions and services as their rural counterparts despite the devastating effects on them.

From this point of view, the study is based on the hypothesis that: “Spatial decision-making processes that consider SoES-based knowledge neglected at the local level (settlement scale) can be used as an effective tool to protect, strengthen and maximize the functions and services of urban soils”. Thereby, the integration of local SoES information into urban spatial planning can contribute to the improvement of the deteriorating state of global soil problems in the long run.

In the scope of the research problems, objectives, and hypothesis, several research questions are identified to address the interactions between the problem and objectives of the study and guide the overall research content. The central research question supporting the hypothesis is: “How does SoES-based urban spatial planning safeguard and enhance the provision of soil functions and services against LULC change in urbanizing landscapes?” In light of the main research question, several sub-questions were defined to designate the structure and organization of the thesis content. The questions asked are as listed below:

Research question 1: How can we define soil from a multidisciplinary aspect?

Research question 2: What are the services provided by soil?

- Sub-question 2.1: How were “ES” defined and developed?
- Sub-question 2.2: Which services does soil provide?
- Sub-question 2.3: Where do SoES stand in the global ES frameworks?
- Sub-question 2.4: How can we classify SoES under the MEA Framework?

Research question 3: What are the pressures on soil in the Anthropocene Epoch and how do the changes in LULC affect SoES?

- Sub-question 3.1: What does the “Anthropocene” epoch refer to?
- Sub-question 3.2: What are the threats to soil?
- Sub-question 3.3: How does urban LULC change affect SoES?
- Sub-question 3.4: What is urban soil? How is it characterized?
- Sub-question 3.5: Where do soil problems stand in the recent global agenda?
- Sub-question 3.6: To what extent do climate change measures and urban spatial planning strategies take SoES into account?
- Sub-question 3.7: How do SoES, climate change, and urban spatial planning interact?

Research question 4: How can we integrate SoES into the existing urban spatial planning framework in Turkiye to i) control and minimize the impacts of LULC change on urban soils; ii) sustain the provision of its functions and services and; iii) contribute to tackling the climate change by maximizing soil’s ability to store carbon?

- Sub-question 4.1: What are the impacts of LULC change on SoES in the Buyukcekmee Watershed case?
- Sub-question 4.2: How can the case study findings be translated into legal frameworks and spatial planning strategies?
- Sub-question 4.3: What are the suggestions for future studies?

The research questions are among the fundamental elements of the thesis. In this regard, both the central question and sub-questions play a vital role in establishing the overall structure of the thesis content. By connecting the problem statements with research objectives, they provide a framework for investigating the characteristics, functions, services, and problems of the soil ecosystem, while exploring the potential integration of SoES into urban spatial planning processes. The interconnections among research problems, questions, and objectives are illustrated in Figure 1.2.

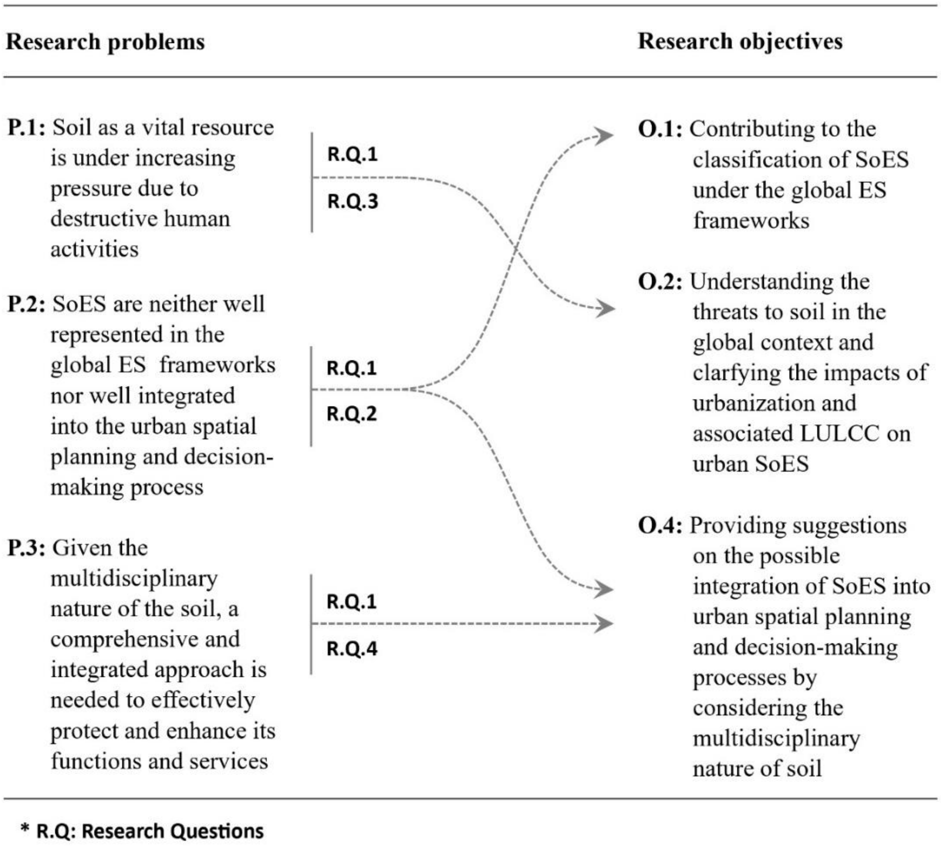


Figure 1.2 : The linkages between research components.

1.4 Thesis Outline

The thesis is composed of three stages, which summarize the overall research process in eight steps (Figure 1.3).

The first phase encompasses “Chapter 1: Introduction” and “Chapter 2: Understanding the Challenges and Opportunities of Soil in the Anthropocene Epoch”, which corresponds to the introductory and theoretical parts of the research. In this phase, research problems, objectives, and questions were addressed and a brief overview of the rationale of the study was presented. Moreover, an in-depth literature review was conducted to identify the research gaps and develop a conceptual framework considering the interactions between SoES, LULC, climate change, and spatial planning. The studies completed in the first phase are summarized in three core steps.

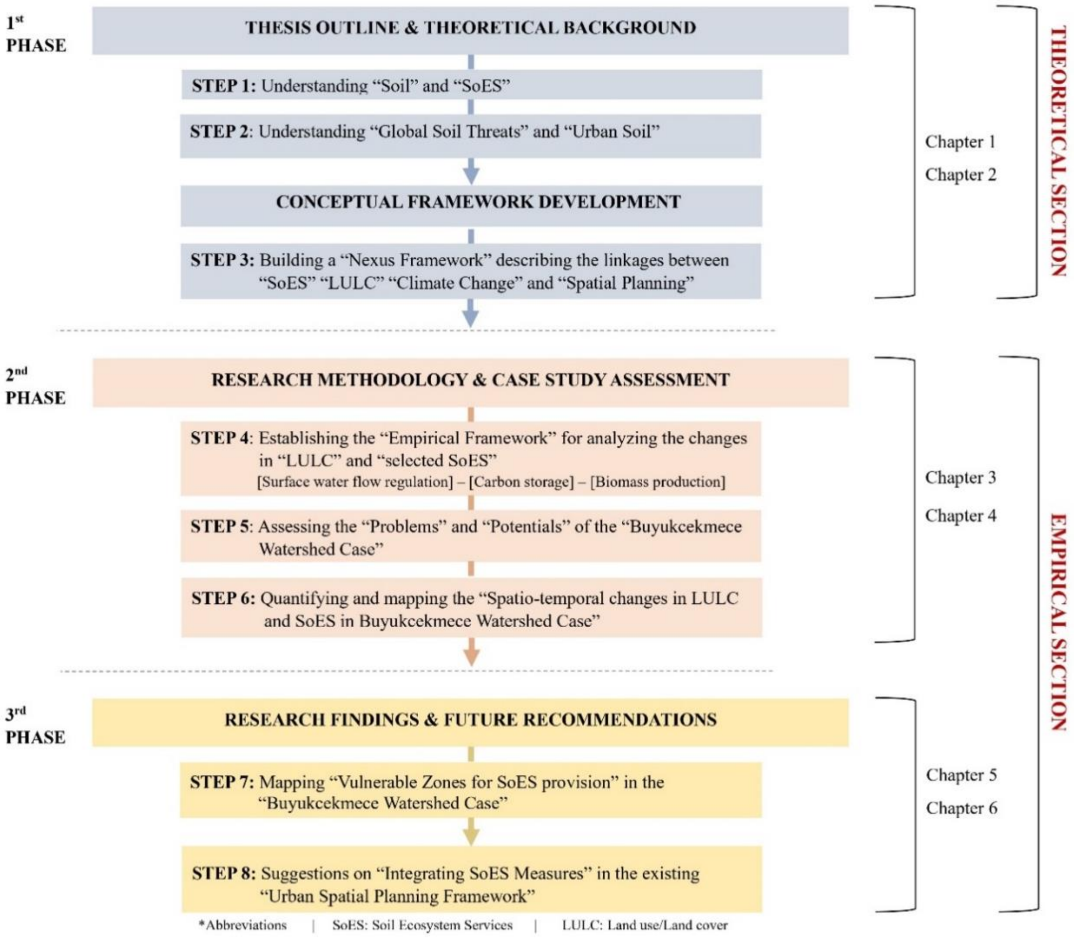


Figure 1.3 : Thesis flowchart

The second phase consists of "Chapter-3: Quantifying the Nexus Methodology with Buyukcekmece Watershed Case" and "Chapter-4: Analyzing the Changes in LULC and SoES in Buyukcekmece Watershed". Following the introduction and the hypothetical background given under the previous phase, the chapters here are organized to provide a clear understanding of the research methodology and the case study analysis.

In this context, appropriate research methods and the related preliminary work (research design, data acquisition, and dataset building) were explained, general characteristics of the case study area were identified, and finally, spatio-temporal changes in the LULC pattern and SoES provision were analyzed in Buyukcekmece Watershed case. The second phase, which is summarized in three steps corresponds to the empirical part of the research.

The last phase includes “Chapter-5: Results and Discussion” and “Chapter-6: Conclusion” and provides an evaluatory section for the empirical analysis conducted in the previous section. In this phase, the findings of the case study analysis were assessed, critical zones in Buyukcekmece Watershed were identified and suggestions for integrating SoES measures in the urban spatial planning process were thoroughly discussed. In this section, the research process is summarized in two steps.

To sum up, the thesis outline illustrates the organization of the thesis and explains the three phases that correspond to the theoretical and empirical parts of the study. Each phase highlights the core milestones of the research which provide; (i) introduction and theoretical background; (ii) methodological design and quantitative analysis in a selected study case; and finally (iii) the overall evaluation of the case study findings and future recommendations.

2. UNDERSTANDING THE CHALLENGES AND OPPORTUNITIES OF SOIL IN THE ANTHROPOCENE EPOCH [1]

The Anthropocene Epoch, a term introduced to the scientific community in recent decades, refers to the present geological age characterized by human activities and their significant impact on the environment (Chester et al, 2019; Crutzen and Eugene, 2000). The era is mainly distinguished by climate change, biodiversity loss, as well as changes in atmospheric composition and land use.

The impact of these changes on soil is a growing concern at the global level due to soil's crucial role in life-sustaining processes and the vital functions and services it provides. In the last decades, anthropogenic activities such as mining, deforestation, agriculture, and urbanization have fostered alterations in the physical and chemical properties of soil, leading to soil degradation, contamination, erosion, and loss of soil fertility (Pereira et al, 2017; Bajocco et al, 2012). As it was mentioned by EEA (2019) and Olsson et al. (2019), due to the complex relationship between soil and climate change, the increase in GHG emissions and the subsequent changes in climate patterns have also further impacts on soil (e.g., altering its structure, microbial activity, nutrient content, and water availability), while vice versa, soil can contribute to GHG emissions and exacerbate climate change as well as due to the mismanagement of land. Therefore, it is essential initially to assess and understand the threats on soil in the Anthropocene Epoch and take necessary measures to mitigate the consequent results.

In the context of "Chapter 1: Introduction", the scope and content of the study are presented under four sub-chapters namely: Problem statement and research objectives; Rationale of the study; Hypothesis and research questions, and; Thesis outline.

In the context of "Chapter 2: Understanding the Challenges and Opportunities of Soil in the Anthropocene Epoch", the theoretical framework of the study is presented under five sub-chapters namely: Background information on soil and ecosystem services;

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[1] A significant portion this chapter has been excerpted from the article titled "Towards embedding soil ecosystem services in spatial planning" prepared by Delibas, M., Tezer A., and Bacchin, T.K (2021).

Soil in the urban context: does it still function?;Soil in the global agenda; The nexus approach for SoES, climate change, and urban spatial planning interactions, and; Summary of the chapter. Following the first chapter, which presents the thesis outline and key arguments, this second chapter mainly specifies the theoretical background of the study, delimitates research content, and highlights the critical research gaps.

2.1 Background Information on Soil and Ecosystem Services

This chapter provides an overview of the perspectives adopted by different disciplines regarding soil, establishing the groundwork for multidisciplinary soil research. The study, aligning with the complex nature of the soil, embraces a multidisciplinary approach. The reconciliation of diverse terminologies necessitates the incorporation of fundamental soil information. To facilitate this process, Appendix I presents detailed information regarding the foundational soil data and the pertinent terminology utilized in the research. The overall understanding of the well-known ES approach and the classification of SoES within the existing ES frameworks are also thoroughly examined in the context of this chapter.

2.1.1 The multidisciplinary nature of soil

Given the multidimensional and complex nature of soil science, the research stands at the intersection of multiple disciplines (such as geology, hydrology, anthropology, forestry, biology, agriculture, landscape ecology, and spatial planning) and thus necessitates an introductory chapter before the subsequent sections to built a shared background. The chapter seeks to answer the question of "What does soil mean?" for diverse disciplines associated with soil studies. By doing so, it aims to provide a common understanding of soil that encompasses these approaches and interpret them from the perspective of landscape and spatial planning.

Soil is a crucial resource and an integral part of the natural environment, serving as the foundation for all terrestrial ecosystems (Ronchi et al, 2019; Baveye et al, 2016; Dominati et al, 2010; Gobat et al, 2004). Through processes such as decomposition, nutrient cycling, and weathering, it is responsible for storing, transporting, and transforming various materials including organic and inorganic matter, water, gases, and energy (Quinton, 2015; Robinson et al, 2013; Palm et al, 2007). This constant exchange of inputs and outputs facilitates the vital biochemical cycles that connect the atmosphere, hydrosphere, biosphere, and lithosphere and thus, supports life on Earth (Li et al, 2012; Dominati et al, 2010).

Due to the intricate and dynamic nature of these processes, soil can be considered a complex system. Therefore, it has not been easy to understand the soil entirely (Brevik et al, 2015; Wall, 2004; Brady and Weil, 2017). Despite the extensive research on soil, there are still many aspects of this vast, dynamic, and living ecosystem that remain unknown, as stated by Oguz (2008) and Gobat et al. (2004).

Soil science itself studies these obscurities and deals with soil as a natural resource covering the world's surface (Pany, 2014). Today, the characteristics, functions, and management of soils are studied by several branches of soil science including soil physics, soil microbiology, soil fertility, soil technology, soil mineralogy, soil genesis and classification (pedology), soil chemistry, soil survey, and edaphology (the study of how soil affects human utilization of land for plant growth) (Pany, 2014; Oguz, 2008). Due to this complexity and the multidisciplinary nature of soil, the understanding of soil can differ depending on the scientific discipline and the context it is being used in (FAO and ITPS, 2015; Brevik et al, 2015; Erpul, 2014). For example, geologists or mining engineers are interested in the origin, composition, and structure of the soil and they might refer to it as the "fragmented pieces of rock or rubble that cover the rocks" while a civil engineer might describe it as "the ground or underlying material used for building homes and roads" as they are more concerned with its physical and engineering properties as a construction material. An economist, on the other hand, approaches soil as a resource for human use and often considers it as a factor of production in the economy, so might refer to it simply as "land" (Brady and Weil, 2017).

Soil, in its traditional meaning, can be defined as *"a three-dimensional entity that covers the surface of the earth in a thin layer, consisting of a mixture of variously decomposed rocks and organic materials, harboring a diverse community of living organisms within and on top of it, serving as a medium and a source of nutrients for plants, and containing certain amounts of water and air"* (Akalan, 1988).

In this research, the understanding of "soil", along with its top and sub-layers, is based on a holistic approach developed by the contributions of experts from four different disciplines (soil scientist, geologist, landscape architect, and urban planner). From an agricultural and geological point of view, FAO and ITPS (2015) and Erpul (2014) describe soil as the unconsolidated surface formations found in the uppermost layer of the Earth's crust, which undergoes transformations through weathering, as well as physical, chemical, and biological processes. These formations can easily be distinguished from hard rocks and serve as a natural medium for the growth of plants. In geological studies, soil properties are crucial for the selection and management of solid waste disposal sites and (sanitary) landfill areas that directly affect soil and groundwater quality (Joos and De Tender, 2022 and FAO and ITPS, 2015; Karagüzel and Mutluturk, 2005). In addition to the groundwater balance estimations and flow models, soil is used in geological and geotechnical investigations for assessing landslide risks and selecting dam sites (Sans et al, 2020). Similar to geo-hazards, soil information is also critical for studies on erosion and hydrological modeling, desertification, agricultural production, food security, climate change, and land and soil degradation (Alori et al, 2020; FAO, 2019; UNCCD, 2017; EC, 2011; Tilman et al, 2002).

From a spatial perspective, soil, which is the foundation of all terrestrial vegetation and medium for plant growth, is an important element for landscape ecology and design due to its fundamental role in vital ecological processes (e.g., nutrient cycling, water retention, and carbon storage) that shape natural and built environment (Getither et al, 2019; Ronchi, 2018; Ponge, 2015). Understanding soil conditions and the fundamentals of soil science, together with the interactions between soil, water, climate, and plants both in disturbed and undisturbed soils, is therefore of great importance for landscape architects to plan and design sustainable and liveable environments in different climatic and topographic conditions. Likewise, for urban and regional planners, soil is one of the key natural factors determining the land capabilities, constraints, and suitability for different land use patterns, thereby soil knowledge contributes significantly to urban spatial planning and decision-making processes (Tezer et al, 2020; Silva et al, 2018). In addition to its role in agriculture and its common use as physical support for urban infrastructures, soil in urban planning is also associated with land ownership under applicable laws and regulations, and with cultural heritage regarding the conservation of historic city centers and archeological sites (Adhikari and Hartemink, 2016; Dominati, 2013). Therefore, a thorough understanding of soil as a spatial element (by considering its spatial distribution and properties) is not essential only for effective design and management of land, but also for adaptive and suitable designation of land use decisions while promoting essential ES provision.

2.1.2 Ecosystem functions and services

The widely used term 'ecosystem' was first used in print by Tansley (1935) by referring to it as both a physical and biological system including*: "the whole complex of organisms inhabiting a given region"*. (Delibas et al, 2021). According to Ponge (2015), Tansley (1935) has introduced an epistemological break in the ecological literature by shedding light on the physical environment in addition to the organic factors that are taught as the fundamental part of ecological systems. Odum (1953), another influential ecologist, enhanced this concept and conceived the ecosystem as a major unit of ecology that can be characterized by its functions and structure.

According to Tansley (1935)'s approach, the structure of an ecosystem is identified by living (biotic) and non-living (abiotic) components. Their composition, amount, and distribution define the structure of an ecosystem (McKay, 2015). The biotic component includes all living organisms in an ecosystem while the abiotic component refers to the surrounding physical environment. This includes organic and inorganic compounds as well as climatic and physical factors such as temperature, air, solar radiation, and water. The complex interactions that occur in an ecosystem result in a number of -physical, chemical, and biological- processes that sustain major global biogeochemical cycles such as water, carbon, nitrogen, and phosphorus (Delibas et al, 2021). According to Sekercioglu (2010), the climate, ecosystems, and creatures of the planet are strongly linked through these vital cycles and any change in one component can cause drastic effects on another.

In short, an ecosystem is characterized by a set of biotic and abiotic components that interact and sustain vital ecological processes (Figure 2.1).

The overall mechanisms controlled by the ecosystem structure and processes are described as 'ecosystem functions.' By controlling the exchange of energy and materials, ecosystem functions play a critical role in maintaining the balance of nature and Earth's ecosystems (McKay, 2015; Sekercioglu, 2010). Besides its vital importance for nature, ecosystem functions are critical also for human survival. The subset of ecosystem functions that are useful to humans is defined as 'ES' (Kremen,

2005) by referring to the contribution of ecosystems to human wellbeing (MEA, 2005a). Although ecosystem functions encompass the ecological processes that result in the supply of ES (EC, 2018), it identifies the benefits broader and less anthropocentric than the notion of 'service' (Baveye et al, 2016). According to de Groot et al. (2002), ecosystem functions can be defined as the inherent capability of natural processes and elements to offer services that fulfill human needs, whether through direct or indirect means (Delibas et al, 2021). These include critical services for the survival of mankind such as climate regulation, air purification, and crop pollination, and the ones that contribute to social and psychological well-being (de Groot et al, 2002). In the MEA Report, ES are defined as *"the benefits that people acquire from ecosystems."* (MEA, 2005a) with an emphasis on the dependency of human well-being on the earth's natural capital including the most biologically active zones of soil (Barrios, 2007).

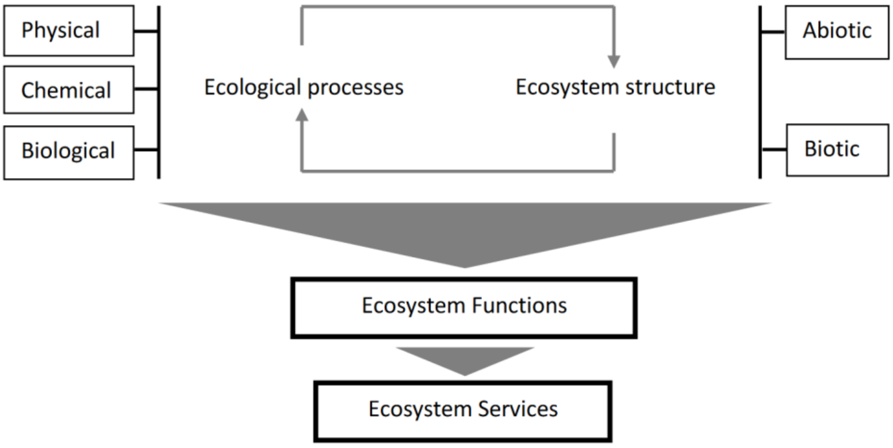


Figure 2.1 : Description of ecosystem components, functions, and services.

The concept of ES dates back to 1970, mentioned as 'environmental functions/services' (Ronchi, 2018). The terms 'ecological, environmental, nature's or landscape services' have also been used by many scholars until a clear concept was defined in the 1990s by de Groot (1992), Costanza et al, (1997), and Daily et al, (1997). De Groot (1992) determined 37 functions under 4 groups (regulative functions, carrier functions, production functions, and information functions) and defined environmental function as: *"the capacity of natural processes and components to deliver goods and services that fulfill human needs, whether directly and/or indirectly"*.

Following this classification, Costanza et al, (1997) made the first attempt at the economic valuation of ES and reorganized the defined categories by proposing seventeen services including; biological control, gas regulation, nutrient cycling, genetic resources, waste treatment, raw materials, climate regulation, erosion control and sediment retention, recreation, soil formation, water regulation, food production, disturbance regulation, refugia, cultural values, water supply, pollination. In the early 2000s, the concept was updated by recognizing the multiple and interrelated connections between ecosystem processes and services and the four groups of ES, namely, habitat functions, regulation functions, information functions, and production functions have been expanded into a comprehensive set of 23 distinct functions by de Groot et al, (2002) (Burkhard et al, 2009; Ronchi, 2018). Due to uncertainties in defining and classifying ES, the international debate was diverted to the provision of a common and standardized system for naming and defining ES (Delibas et al, 2021). To this end, the MEA project, based on the 'Functions of Nature' approach developed by de Groot (1992), Costanza et al, (1997), and Daily et al, (1997), was carried out between 2001 and 2005 to support decision-making processes at different levels by evaluating the impacts of alterations in ecosystems on human welfare (MEA, 2005a; Ronchi, 2018). The study in question is widely regarded as a milestone in ES research (Burkhard et al, 2009).

The assessment report categorizes ES into four groups: provisioning services encompass the tangible goods and resources derived from ecosystems. Regulating services encompass the benefits derived from the regulation of ecosystem processes, such as the maintenance of air quality and climate stability. Supporting services are fundamental to the production of all other ES. Lastly, cultural services encompass the intangible benefits that individuals derive from ecosystems, including spiritual enrichment, cognitive development, contemplation, recreational activities, and aesthetic experience (MEA, 2005a). Herein, supporting services have a significant role in supporting all other services (Palm et al, 2007). As a landmark study on assessing the human impact on the environment, MEA popularized the term 'ES' and stimulated a noteworthy discourse at the international level concerning the interdependencies between ecosystems and human well-being (Delibas et al, 2021; Dominati et al, 2010).

Although MEA has been recognized as the first international science policy assessment that provides an inclusive overview of the impacts of ecosystem alterations on human well-being (Petz, 2014), new approaches have been developed in recent years to establish a consensus regarding the classification of ES (Adhikari and Hartemink, 2016; Baveye et al, 2016; Robinson et al, 2013; Ronchi, 2018). In 2008, the TEEB project slightly adjusted the ES categories defined by MEA and identified 22 types of ES under four categories: provisioning services, regulating services, cultural and amenity services, and a novel classification termed 'habitat services' was introduced to replace the supporting services identified by MEA, as they do not directly generate societal benefits (Dominati, 2013; Jónsson and Davíðsdóttir, 2016; TEEB, 2010). Similar to the TEEB re-classification of ES, the European Environment Agency launched CICES to be used in Europe and support the integration of ES in environmental accounting (Baveye et al, 2016; EEA, 2011a). The classification recognizes 3 ES groups: provisioning services, regulating and maintenance services, and cultural services. Regulating and maintenance services are characterized as being in concordance with the regulating services presented in the TEEB report, as well as with the regulating and supporting services in the MEA assessment. (EEA, 2011a).

Recently, the structure and scope of CICES have been revised (CICES V5.1) with hierarchical service categories including two different definitions (biophysical output and contribution) for each service (Delibas et al, 2021; Haines-Young and Potschin-Young, 2018). According to the study carried out by Rendon and colleagues in 2019, the MEA classification system was the most frequently utilized (86%) among the analyzed academic papers, as well as national and international reports on European case studies that were published between 2000 and 2017. The CICES classification was used in 11% of the documents, while the TEEB classification was used in only 3%.

The frameworks and related studies have provided a scientific basis and context to conceptualize, classify, and value ES since the early 1970s. However, soil as the major supplier of critical ES has not been considered in all its aspects, its role and ability to provide services have been partly neglected, not recognized, or not well understood, and thus not explicitly incorporated into ES frameworks developed by de Groot (1992), Costanza et al, (1997), de Groot et al, (2002), MEA (2005a), CICES (2011a; Haines-Young and Potschin-Young, 2018) and TEEB (2010) (Silva et al, 2018; Adhikari and Hartemink, 2016; Baveye et al, 2016; Dominati et al, 2016; Jónsson and Davíðsdóttir, 2016; Robinson et al, 2013; Breure et al, 2012; Dominati et al, 2010).

According to Delibas et al, (2021), soil, in the mentioned frameworks, is mostly related to soil formation, nutrient cycles, soil quality, erosion regulation, water regulation, and natural hazard regulation (Baveye et al, 2016) while the consensus on the classification and valuation of SoES has not been formulated yet (Robinson et al, 2009).

2.1.3 Soil ecosystem services (SoES)

In the long history of the ecosystem concept and its divergent definitions in modern ecology, soil has been conceived as a physical component of -terrestrial- ecosystems (Ponge, 2015). However, Gobat et al, (2010), Lavelle et al, (2006), and Ponge (2015) argue that the ecosystem concept must be applied to the soil as well due to its living character. In light of Tansley’s (1935) description of ecosystems, they claim that soil is indeed an ecosystem itself based on its biotic and non-biotic components and the critical functions it ensures through a network of interactions. According to Ponge (2015), the increasing number of published articles using the expression ‘soil ecosystem’ also reveals the common application of the ecosystem concept to soil in the scientific community.

The concept of soil functions, which can be accepted as an early configuration of today’s concept of ‘ecosystem functions and services of soil’ originates from the descriptive analysis conducted by Blum (1993) (Baveye et al, 2016; Peccol and Movia, 2012). In the research, the functions of soil were grouped into two categories: ‘ecological functions’ and ‘non-ecological functions’ linked to human activity. The ecological functions consist of biomass production, filtering, buffering and transforming action, biological habitat, and gene reserve while non-ecological functions include providing physical medium, origin of the raw materials, and geological and cultural heritage. Besides, soil functions were given an earlier emphasis as a fundamental concept for linking soil science to policy and decision-making processes (Blum, 1993).

Similarly, Daily et al, (1997) highlighted the inclusion of soils in the policy documents and ES frameworks by recognizing soil as an important determinant of a country's economic standing. The research used the term ‘ES’ instead of ‘soil functions’ and defined 6 major services provided by soil: moderating the hydrologic cycle; physical support of plants; retention and delivery of nutrients to plants; disposal of wastes and dead organic matter; renewal of soil fertility; regulation of major element cycles.

Andrews et al, (2004) used the definition of soil ecosystem 'services' and 'functions' interchangeably and categorized them under 6 classes: nutrient cycling, water relation, physical stability, and support; filtering and buffering; resistance and resilience; biodiversity and habitat. Herein, resilience and resistance, as mentioned by Daily et al, (1997), are related to the functional stability of soil and are defined as: *"resistance is the ability of a soil to maintain function in the face of disturbance while resilience is the ability of a soil to bounce back after a disturbance".*

Further studies have contributed to the conceptualization and classification of SoES. Wall (2004) underlined the strong relationship between soil biodiversity and the delivery of critical ES from an ecological perspective, while Warr and Ayres (2004) focused on the productive role of soil and land resources from an economic aspect. The latter defined SoES in two groups: 'soil eco-services (such as energy and biomass production, filter, buffer, transform, and habitat) and 'soil socio-economic services' including spatial requirements and physical basis, raw materials, and the memory of geogenic and cultural history. An alternative classification indicated by Warr and Ayres (2004) is: 'direct services'; those with unique monetary value and 'indirect soil services'; the results and benefits of complex processes.

Considering the increasing awareness of the crucial role of soil biota in SoES delivery, Lavelle et al, (2006) presented a conceptual overview of biotic interactions in soils. The study highlights the relationship between invertebrates and other soil organisms and their roles in overall soil functioning. The contributions provided by soil invertebrates to SoES are associated with production services (water supply); support services (nutrient cycling, soil formation, primary production); and regulation services (flood and erosion control, climate regulation). The roles of soil biota in nutrient cycling, carbon sequestration, biological control of pests/diseases, regulation of soil erosion, water flow, and storage are also mentioned by Barrios (2007). Palm et al, (2007) distinguished provisioning SoES in relation to key soil properties and processes such as material and energy flows and transformations based on the natural capital of soils.

Another approach incorporating natural capital in the ES concept is presented by Dominati et al, (2010). The research presents a comprehensive overview of SoES classification by conceptualizing natural capital stock within the ES approach related to the list of 'Hierarchy of Needs', the classic work of Maslow (1943) (Baveye et al, 2016; Robinson et al, 2013). More recently, Dominati et al, (2016) quantified soil performance and ES through a new methodology based on dairy-based agroecosystems and determined the economic value of each service. The research found that regulating services had greater economic value than provisioning ones. The total economic value of the ES provided by soil was estimated at approximately 1.4 trillion USD by McBratney et al. (2017), and compared with the gross domestic product of the USA which was 15 trillion USD in 2015. Jónsson and Davíðsdóttir, (2016) and Latawiec et al, (2022) have also studied the methodical aspects of SoES valuation and emphasized the depletion of soil natural capital and associated economic loss related to soil degradation. Similar to many other scholars, both studies shed light on the absence of a common consensus or systematic approach required to classify SoES and estimate its economic value (Silva et al, 2018; Adhikari and Hartemink, 2016; Baveye et al, 2016; Dominati et al, 2016; Robinson et al, 2013; Dominati, 2010; Robinson et al, 2009).

Given the overview of the conceptual background regarding SoES and the divergences in classifying them, this study mainly discusses the partial inclusion of SoES in the global ES frameworks. As Adhikari and Hartemink (2016) and Dominati (2013) declared, despite their vital importance, the functions and services provided by soil are not completely incorporated into the existing ES Frameworks and the provision of SoES is disregarded apart from its role in soil formation.

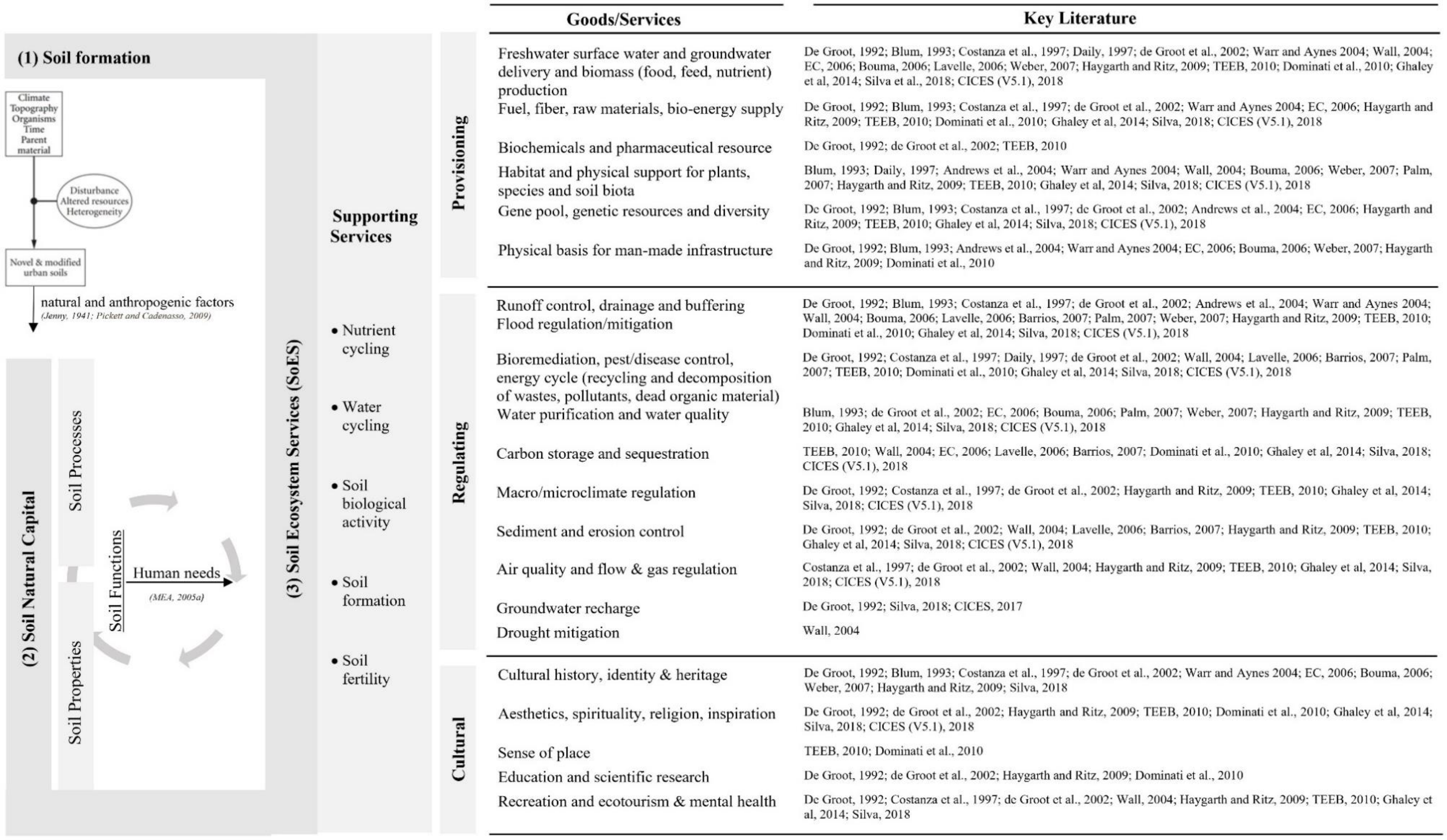
In light of the thesis’ central argument that advocates the “efficiency of ES-based spatial planning tools in protecting and improving the natural environments”, the absence of SoES categorization under the well-known ES frameworks represents a research gap, which is key to having a complete understanding of soil ecosystem and developing measures for its protection, particularly in urbanizing landscapes. Therefore, the findings obtained from the in-depth literature review conducted within the scope of this study were organized and presented as an integrated framework for the classification of SoES under the ES categories introduced by the MEA (Figure 2.2). The framework consists of three subsections including (i) in-situ factors of soil formation; (ii) soil natural capital; and (iii) SoES provision. Considering the effects of soil properties on ES delivery, the natural and human-based factors that influence soil in the urban context are identified through the state factor approach that is adopted by Jenny (1941) and modified by Pickett and Cadenasso (2009). In the second part, the scheme introduced in Figure 2.1 is adopted to define the properties (structure), processes, and functions of the soil ecosystem, which is hereby mentioned as ‘soil natural capital’. De Groot et al, (2002) and Dominati et al, (2010) describe natural capital as the inventory of natural resources that generate valuable ES with an understanding of stock-delivering flows of functions and services (Baveye et al, 2016).

The schematic representation of soil-related processes indicates the importance of soil both as a natural capital and ES provider (Dominati et al, 2010). Therefore, linking ES flows with the natural capital concept provides a complete picture of the overall system functioning. In the final section, SoES are incorporated and classified under the ES categories suggested by MEA (2005a). The classification framework is based on the findings of an in-depth literature review to contribute to a better understanding, characterization, and representation of SoES in the ES framework and related implementations on soil management. The vital importance and services of soil can be briefly summarized as follows:

1. Soil is the major supplier of multiple ES that sustain life on Earth (Daily et al., 1997; Ronchi, 2018). Besides, it is the source of food and biomass production. It contributes to the supply of fuel, fiber, pharmaceuticals, and raw materials (Dominati et al., 2010), retains plant nutrients for uptake, serves as a platform for man-made constructions, gene pool, and habitat for a myriad of organisms (Lavelle et al., 2006; Wall, 2004).

2. Soil and biodiversity: Simply, soil is not soil without its biotic component. In healthy soils, soil microbial community (microbes, fungi, bacteria, invertebrates, etc.), that equals almost one-quarter of global biodiversity (FAO, 2013), forms a complex web of biological activity central to support and moderate biogeochemical recycling; nutrient balance and nutrient acquisition by the vegetation (Vitousek et al., 1997); carbon sequestration and atmospheric GHG emission (Breure et al., 2012; Petz, 2014); primary production (Daily et al., 1997); regulation of water flow, storage and purification (Bouma, 2006); soil stabilization (FAO, 2013), which are vital for overall ecosystems’ functioning (Finvers, 2008; J´onsson & Davíðsd´ottir, 2016).

3. Soil and biogeochemical cycles: Soil regulates Earth’s fundamental processes (decomposition and recycling of wastes and dead organic material, pest and disease control, purification, bioremediation, gas regulation, air quality control) and major cycles (carbon, nitrogen, water, nutrients) (Barrios, 2007; Pereira et al., 2017).



	Goods/Services	Key Literature
Provisioning	Freshwater surface water and groundwater delivery and biomass (food, feed, nutrient) production	De Groot, 1992; Blum, 1993; Costanza et al., 1997; Daily, 1997; de Groot et al., 2002; Warr and Aynes 2004; Wall, 2004; EC, 2006; Bouma, 2006; Lavelle, 2006; Weber, 2007; Haygarth and Ritz, 2009; TEEB, 2010; Dominati et al., 2010; Ghaley et al, 2014; Silva et al., 2018; CICES (V5.1), 2018
	Fuel, fiber, raw materials, bio-energy supply	De Groot, 1992; Blum, 1993; Costanza et al., 1997; de Groot et al., 2002; Warr and Aynes 2004; EC, 2006; Haygarth and Ritz, 2009; TEEB, 2010; Dominati et al., 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Biochemicals and pharmaceutical resource	De Groot, 1992; de Groot et al., 2002; TEEB, 2010
	Habitat and physical support for plants, species and soil biota	Blum, 1993; Daily, 1997; Andrews et al., 2004; Warr and Aynes 2004; Wall, 2004; Bouma, 2006; Weber, 2007; Palm, 2007; Haygarth and Ritz, 2009; TEEB, 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Gene pool, genetic resources and diversity	De Groot, 1992; Blum, 1993; Costanza et al., 1997; de Groot et al., 2002; Andrews et al., 2004; EC, 2006; Haygarth and Ritz, 2009; TEEB, 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Physical basis for man-made infrastructure	De Groot, 1992; Blum, 1993; Andrews et al., 2004; Warr and Aynes 2004; EC, 2006; Bouma, 2006; Weber, 2007; Haygarth and Ritz, 2009; Dominati et al., 2010
Regulating	Runoff control, drainage and buffering Flood regulation/mitigation	De Groot, 1992; Blum, 1993; Costanza et al., 1997; de Groot et al., 2002; Andrews et al., 2004; Warr and Aynes 2004; Wall, 2004; Bouma, 2006; Lavelle, 2006; Barrios, 2007; Palm, 2007; Weber, 2007; Haygarth and Ritz, 2009; TEEB, 2010; Dominati et al., 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Bioremediation, pest/disease control, energy cycle (recycling and decomposition of wastes, pollutants, dead organic material)	De Groot, 1992; Costanza et al., 1997; Daily, 1997; de Groot et al., 2002; Wall, 2004; Lavelle, 2006; Barrios, 2007; Palm, 2007; TEEB, 2010; Dominati et al., 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Water purification and water quality	Blum, 1993; de Groot et al., 2002; EC, 2006; Bouma, 2006; Palm, 2007; Weber, 2007; Haygarth and Ritz, 2009; TEEB, 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Carbon storage and sequestration	TEEB, 2010; Wall, 2004; EC, 2006; Lavelle, 2006; Barrios, 2007; Dominati et al., 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Macro/microclimate regulation	De Groot, 1992; Costanza et al., 1997; de Groot et al., 2002; Haygarth and Ritz, 2009; TEEB, 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Sediment and erosion control	De Groot, 1992; de Groot et al., 2002; Wall, 2004; Lavelle, 2006; Barrios, 2007; Haygarth and Ritz, 2009; TEEB, 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Air quality and flow & gas regulation	Costanza et al., 1997; de Groot et al., 2002; Wall, 2004; Haygarth and Ritz, 2009; TEEB, 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Groundwater recharge	De Groot, 1992; Silva, 2018; CICES, 2017
	Drought mitigation	Wall, 2004
Cultural	Cultural history, identity & heritage	De Groot, 1992; Blum, 1993; Costanza et al., 1997; de Groot et al., 2002; Warr and Aynes 2004; EC, 2006; Bouma, 2006; Weber, 2007; Haygarth and Ritz, 2009; Silva, 2018
	Aesthetics, spirituality, religion, inspiration	De Groot, 1992; de Groot et al., 2002; Haygarth and Ritz, 2009; TEEB, 2010; Dominati et al., 2010; Ghaley et al, 2014; Silva, 2018; CICES (V5.1), 2018
	Sense of place	TEEB, 2010; Dominati et al., 2010
	Education and scientific research	De Groot, 1992; de Groot et al., 2002; Haygarth and Ritz, 2009; Dominati et al., 2010
	Recreation and ecotourism & mental health	De Groot, 1992; Costanza et al., 1997; de Groot et al., 2002; Wall, 2004; Haygarth and Ritz, 2009; TEEB, 2010; Ghaley et al, 2014; Silva, 2018

Figure 2.2 : The framework of SoES and the key literature citing relevant services (synthesized from; Baveye et al, 2016; Dominati et al, 2010; Pickett and Cadenasso, 2009 and MEA, 2005a).

4. Soil and water: Soil and water are inherently connected. Soil is responsible for the infiltration, transpiration, storage, percolation, and distribution of water in the hydrological cycle (Jónsson and Davíðsdóttir, 2016). According to Quinton (2015), it is estimated that approximately 195.500 km^3 of the earth's water is retained in soil which primarily serves as a source for root uptake, supports plant growth, facilitates groundwater recharge, and sustains soil organisms.

5. Soil and carbon storage/sequestration: Soil is a major and the largest terrestrial global carbon reservoir holding over double the quantity of carbon currently present in the Earth's atmosphere (Jeffery et al., 2010). By that, it regulates the atmospheric composition and supports climate change mitigation by offsetting GHG emissions (IPCC, 2019; FAO and ITPS, 2015).

6. Soil and culture: Soil provides cultural identity and heritage and enables aesthetics, spiritual, recreational, educational, and scientific research experiences (Dominati, 2013).

2.2 Soils in the Urban Context

Soils in urban areas are distributed across diverse domains (e.g., urban parks, forests, watersheds, agricultural areas, riparian corridors, and urban coastal areas). The term *'urban soils'* as used within the scope of this study, describes these diverse soils located in the urban context and characterized by different LULC patterns.

In this context, this chapter discusses the pressures on soil ecosystems particularly in urbanizing landscapes, and focuses on the destructive impacts of the urbanization process and the associated LULC change on urban soils and SoES.

2.2.1 Natural and anthropogenic soil threats

Given the significance of the soil ecosystem, safeguarding its functions and services is highly critical for environmental sustainability, human welfare, and socio-economic development in the long term (FAO, 2019; Schwilch et al, 2016; Quinton, 2015).

However, as it was emphasized by Rodrigo-Comino et al, (2020), Smith et al, (2016), and FAO and ITPS (2015), soil, at the global level, is exposed to varying degrees of pressure induced by anthropogenic and/or natural factors that ultimately threaten soil properties and processes. The natural influences mainly include the topographic and climatic conditions (e.g., the slope of the terrain, wind, or rainfall), which affect soil structure and stability and cause soil denudation (more critically loss of the nutrient-rich topsoil) through erosion and landslides (Geitner et al, 2019; Tóth et al, 2008). In the regions with cold climates, freezing-thawing cycles can also contribute to the detachment of soil particles and cause soil erosion through snowmelt and surface runoff (Stolte et al, 2016) while in the arid and semi-arid areas or during dry periods, the formation of surface crust (in other words soil water repellency) prevents water infiltration into the soil and leads to increased runoff and erosion (Petz, 2014). The erosion of soil incited by wind and water mostly results in disrupted soil characteristics and functions increased flood risk, and reduced rates of soil fertility, SOM, and soil biodiversity. Therefore, according to Stolte et al. (2016) and FAO and ITPS (2015), wind and water-induced soil erosion is often considered a serious environmental problem and one of the most severe and prevalent land degradation and desertification processes worldwide.

Besides natural factors, recent studies point out the distinct influence of direct or indirect human disturbance on soil and describe anthropogenic activities as the major global driver and root cause of land and soil degradation (Joos and Tender, 2022; Rodrigo-Comino et al, 2020; EEA, 2017; FAO and ITPS, 2015; Crowther et al, 2014; Glæsner et al, 2014; Poeplau et al, 2011; Marcotullio et al, 2008).

Agriculture, one of the key practices directly linked to human survival throughout history, is today one of the most influential anthropogenic activities posing serious threats to soil. Although the transition from hunter-gatherer societies to an agrarian lifestyle has excessively affected our modern lives and changed the course of human history (Parikh and James, 2012), this critical human intervention in soil has distorted the natural balance and functioning of soil, altered nutrient cycling processes, and consequently affected the resilience of soil ecosystem against extreme weather conditions and environmental transformations (FAO and ITPS, 2015; Crowther et al, 2014; Tóth et al, 2008; Vitousek et al, 1997). Particularly, conventional techniques (e.g., mechanical tillage, chemical inputs, overgrazing, improper land cultivation, and irrigation), intensive farming, and large-scale (industrial) agricultural practices -due to the rising demand of the global population- affect soil and its long-term ecological processes. Briefly, they cause soil compaction, desertification, soil erosion, degradation in soil structure and characteristics, altered hydrological regimes and nutrient (NPK) fluxes, damaged species composition and activity, and reduced SOM and soil fertility. Yet, the long-term implication of synthetic pesticides and fertilizers cause soil and groundwater pollution, increase soil acidity and soil erosion risk, while irrigation may also lead to alkalinization, chemical soil compaction, salinization, and reduced water infiltration due to the dissolved mineral salts it contains (Alori et al, 2020; FAO and ITPS, 2015; Tilman et al, 2002). Extensive use of such mineral fertilizers further causes eutrophication, algae blooming, atmospheric pollution, and GHG emissions (Sharma et al, 2018; Smith et al, 2016). As FAO and ITPS (2015) state, agricultural soils are potential zones for carbon storage. However, unsustainable agricultural practices decrease the capacity of soil to sequester and store carbon as well, thereby depleting soil organic carbon (SOC) and turning soil from a carbon sink into a source of carbon dioxide (CO_2) (Geitner et al, 2019).

As the human population and consequently the demand for food, fiber, and energy is expected to increase in the upcoming years, it is critical to sustain fertile soils and biomass production (FAO and ITPS, 2015). In this context, several scholars have reported the significance of sustainable agricultural practices (e.g., cover cropping, conservation tillage system, crop rotation, and organic amendments) for minimizing soil disturbance and improving soil health, while improving overall SoES provision and contributing to climate change mitigation by increasing carbon storage and sequestration in agricultural soils (Alori et al, 2020; Geitner et al, 2019, FAO and ITPS, 2015; Stolte et al, 2016; EC, 2011; Tilman et al, 2002). The Sustainable Agriculture and Soil Conservation (SoCo) project, supported by the European Parliament between 2007 and 2009 also confirmed that conservation agriculture practices that limit agrochemical inputs and promote minimal soil disturbance (i.e., decreased or no tillage, organic farming, permanent soil cover, and crop rotation) reduce soil erosion, increase soil carbon stocks, improve water quality, soil functions, and soil biodiversity (EC, 2011).

In addition to improper agricultural practices, industrial activities are also another type of disruptive human intervention that exacerbates soil degradation at the global level. According to FAO and UNEP (2021), throughout history, industrial processes (e.g., mining, quarrying, manufacturing, recycling, oil extraction, heavy metal smelting, chemical production, and power plant operations) have been the major cause of soil contamination due to high levels of trace elements and organic contaminants they contain. Most of the emissions and hazardous chemicals released from industrial activities into the environment (including adjacent water bodies and the atmosphere) end up in soil due to surface runoff, leaking, and percolation to groundwater, while industrial accidents, landfills, and improper disposal of wastes also contribute directly to soil and groundwater pollution (EEA, 2022).

As indicated by FAO and UNEP (2021), mining serves as the primary source of trace elements, and therefore, the extraction of coal, platinoids, gold, tin, uranium, wolfram/tungsten, and polymetallic sulfides leads to severe instances of soil contamination. The construction and demolition industry and transportation are also responsible for producing large amounts of contaminants and trace element pollution in soil. Similarly, the manufacturing processes of plastics, food, agrochemicals, lead acid batteries, textiles, and leather generate chemically enriched wastes and release dangerous substances, heavy metals, and trace elements, including nickel, copper, lead, arsenic, cadmium, mercury, cobalt, iron, dyestuffs, zinc, and cellulose. Microplastics, as stated by Joos and Tender (2022) and Rodrigo-Comino et al, (2020), are one of the most common human-induced pollution and a new stressor on soil chemistry, soil microbial activity, and plant growth.

Moreover, industrial activities (directly or indirectly) led to soil compaction (due to heavy machinery), soil erosion, acidification, and decline/loss of soil biodiversity due to disrupted soil characteristics. Most importantly, the accumulation of trace elements and toxic pollutants causes deterioration of soil quality, structure, and functioning, and ultimately poses critical risks for soil and human health. In other words, soil contaminants, jeopardize the food chain, soil fertility, and food security, which are essential for human survival (EEA, 2022).

Rodrigo-Comino et al, (2020) claim that the most severe impacts of human interactions on land take place in agricultural, industrial, and urban areas, while Khan (2022), Pouyat et al. (2020), EEA (2016), Lavy et al. (2016), Smith et al. (2016), Pavao-Zuckerman (2008) and Marcotullio et al. (2008) highlight the destructive human intervention on soil, particularly in urban landscapes. They state that, among the anthropogenic land uses, cities and urbanization processes have further adverse effects on the soil ecosystem due to urban expansion (urban sprawl) and associated changes in LULC pattern.

The third and perhaps the most influential anthropogenic threat to soil functions and services is urbanization, population growth, and associated changes in LULC pattern. The research findings regarding the pressures and threats on soil in urban landscapes are explained in detail in the following chapter “2.2: Impacts of urban LULC change on SoES”.

2.2.2 Impacts of urban LULC change on SoES

Mosel et al, (2016, p. 9) define the urbanization process as: *“the increase in the proportion of the urban resident population that is overwhelmingly the result of net rural to urban migration caused by economic growth and industrialization, political and social conflicts, rural impoverishment, and natural disasters”*.

Urbanization, rise in population, and economic growth increase the additional demand for natural resources, and so, stimulate dramatic changes and transformations specifically on land in and around megacities and peri-urban areas (Bajocco et al, 2012; Mohan et al, 2011). According to the CBD Report (2012), the land area occupied by cities increases at higher ratios than the rising ratios of the urban population. Likewise, a global sample of 120 cities observed between 1990 and 2000 shows that while the population grew at a rate of 17%, the built-up area grew by 28% (NYU, 2015).

The conversion of land to built-up is often considered as one of the most problematic trajectories of LULC change (Smiraglia et al, 2016) due to its distinct impacts on air quality (Elmqvist et al, 2013), habitat and landscape fragmentation (Sala et al, 2000), biodiversity loss and alteration in nutrient cycles (Vitousek et al, 1997), soil degradation (FAO and ITPS, 2015; Pavao-Zuckerman and Pouyat, 2017), flood and drought risk (Carlson and Arthur, 2000), surface runoff and consequently the hydrological cycle with an influence on climate processes at local, regional and global levels (Bacchin et al, 2014; Chase et al, 2000).

Mundhe and Jaybhaye (2014) characterize urbanization as a process in which the productive agricultural land, forests, and surface water bodies are irreversibly declined due to LULC changes. The negative environmental impacts associated with urbanization are strongly linked to the unplanned changes in LULC caused by poorly designed and coordinated urban sprawl (Pauleit et al, 2005). Therefore, the indicators of LULC changes can be used as proxies in detecting the pressures and effects on ecosystems (OECD, 2018).

Due to unsustainable LULC changes and the intensity of land use, soils have been exposed to direct or indirect human disturbances at multiple scales (FAO and ITPS, 2015; Marcotullio et al, 2008). As it was stated in Table 2.1, some changes in LULC pattern such as afforestation or change of arable to intensive grassland can lead to an increase in soil carbon and nutrient levels, thus, they positively affect the provisioning of SoES (FAO and ITPS, 2015; Hooijer et al, 2010).

On the other hand, transformations from forest to pasture or arable land (deforestation) and a decrease in peatlands and wetlands alter soil microbial communities drastically. Consequently, they increase erosion risk, disturb soil physical properties, modify the climate through GHG (carbon dioxide, methane, etc.) emissions to the atmosphere, and result in loss of soil carbon and other nutrients (Crowther et al, 2014; Poeplau et al, 2011). Herein, urbanization is conceived as the major driver of LULC changes with respect to increasing artificial (built-up) surfaces causing numerous adverse effects on soil.

According to Lavy et al, (2016), urbanization leads to changes in soil through two distinct but interconnected processes, namely soil disturbance and soil sealing. Lavy et al. (2016) define soil disturbance as *"the modification of soil properties by urban activities, such as top-soil removal, soil compaction, and soil contamination"*, and Stolte et al. (2016) describe soil sealing as the deterioration or covering of soil by impervious artificial materials (e.g., asphalt, concrete) due to the construction of man-made structures (e.g., buildings, infrastructure).

Urbanization-driven LULC changes have been associated with the advance of impervious surfaces through soil sealing and land take (Prokop et al, 2011; Marcotullio et al, 2008). The land take refers to any conversion of agricultural, natural, or semi-natural land cover to an 'artificial' area while soil sealing means the destruction or permanent covering of an area of land and its soil by fully or partially non-permeable artificial materials such as asphalt or concrete (FAO and ITPS, 2015; Prokop et al, 2011). Sealing, characterized as the most extensive type of land take, causes irreversible degradation or loss of soil properties and severely limits the ES provided by soil (EEA, 2016; Naumann et al, 2018). As it was mentioned by EEA (2017), about

1.007 km^2 of soil, which is almost the size of the city of Berlin, has been lost annually due to land take in Europe.

In practice, sealing of soil leads to extensive loss of upper topsoil, which is the most productive layer that supports key SoES (EC, 2012). As sealing completely separates above and belowground environments, it cuts off the soil from the atmosphere and results in cascading effects in soil characteristics and services (Pavao-Zuckerman and Pouyat, 2017; Stolte et al, 2015; EC, 2012; Prokop et al, 2011; Marcotullio et al, 2008; Scalenghea and Marsan, 2009; Toth et al, 2008; Craul, 1992) including:

- prevention of the exchange of gases and infiltration of rainwater
- altered soil water regimes and shift in the hydrological (water) cycle
- decrease in water infiltration, storage, percolation and evapotranspiration
- decrease in water purification and groundwater recharge
- increased surface runoff
- increased risk of flooding, groundwater depletion and water scarcity
- decline in water quality due to runoff
- decline in soil carbon sequestration, storage, and climate mitigation
- modified surface temperature and microclimate
- decline in soil biodiversity
- reduced microbial activities due to habitat fragmentation and loss
- decline/loss in root growth, soil fertility, food, and biomass production
- disturbed nutrient cycling, chemical reactions, and energy flow
- decreased waste decomposition and detoxification
- changed production of industrial and pharmaceutical products
- decreased food, fibre, raw materials production/ availability
- decreased primary production

Table 2.1 : A conceptual summary of the multifaceted effects of LULC change on SoES.

Conversions	**Land Use and Land Cover (LULC) Classes**		
from to	**Artificial surfaces**	**Agricultural land and Pastures**	**Forests and semi-natural areas**
Artificial surfaces		increased impervious surface decreased water infiltration, storage decreased genetic diversity reduction of rainfall (water) recycling decreased waste decomposition & detoxification decreased soil organism activity	decreased food, fibre, raw materials production/ availability decreased biomass and water availability for agricultural use decreased primary production decreased soil organism activity nutrient recycling is reduced if no inputs decreased water infiltration, storage
Agricultural land	increased water purification increased C sequestration and storage increased surface water flow regulation increased production of food, fibre, raw materials increased soil biodiversity and microbial activity increased primary production and nutrient recycling increased habitat for plant species & soil organisms increased primary production, nutrient cycling improved water infiltration and retention		decreased soil C sequestration, storage and GHG flux increased erosion and sediment yield reduced regulation of water flow and quality increased water and air pollution due to fertilization increased production of food, fibre, and crops reduced availability of natural raw materials potential change in hydrology/water availability changed genetic resources, pest and disease control changed production of industrial & pharmaceutical products
Pastures	habitat for plant species and soil organisms increased primary production and nutrient cycling increased C sequestration and storage increased water purification improved water infiltration and retention increased soil organism activity increased water purification increased primary production	increased C sequestration and storage stress on ecosystem health changed soil structure/ increased soil compaction decreased porosity and water-holding capacity (due to possible soil compaction) increased genetic diversity associated with mixed pastures	decreased C sequestration and storage reduced availability of natural raw materials changed genetic resources, pest and disease control changed production of industrial and pharmaceutical products decreased surface water regulation reduced availability of natural raw materials changed production of industrial & pharmaceutical products
Forests and semi-natural areas	habitat for plant species and soil organisms increased primary production and nutrient cycling increased C sequestration and storage increased water purification and regulation Increased production of food, fibre, raw materials increased soil organism activity	increased C sequestration and storage increased regulation of water flow and quality primary production may be changed increased water recycling raw material provision may be increased decrease in agricultural production	

2.2.3 Urban soils: do they still function?

Pouyat et al, (2010) and Effland and Pouyat (1997) describe the soil in human-dominated landscapes through its different characteristics. According to them, the adverse human impacts, spatiotemporal modifications on natural soil-scape, and changing climate conditions form a new, physically, chemically, and biologically altered soil structure, which is characterized as ‘urban soil’.

The term urban soil was first used by Zemlyanitskiy (1963) to describe the characteristics of highly disturbed soils in urban areas (Pouyat et al, 2020). Bockheim (1974) defines urban soil as: “a soil material having a non-agricultural, man-made surface layer more than 50 cm thick, that has been produced by mixing, filling, or by contamination of land surfaces in urban and suburban areas.”

Besides the studies focusing on the definition, classification, quantification, and valuation of SoES, the effects of changing physical conditions on soil formation have been analyzed due to their critical role in determining the quantity and quality of soil functions and services. In this context, Effland and Pouyat (1997) and Pickett and Cadenasso (2009) expanded the classical ‘state factor approach’ that describes the factors that influence natural soil formation processes (Figure 2.3) in light of anthropogenic disturbances. As a foundation for explaining the formation and variation of native and agricultural soils, Jenny (1941) mentioned five major factors (climate, organisms, relief, parent material, and time) interact to create different soil types (Brady and Weil, 2017).

Effland and Pouyat (1997) extended this approach by considering the important role of new or modified parent material in the formation and classification of novel urban soils. He emphasized the human effects and the development of anthropogenic soils in such substrates (Pickett and Cadenasso, 2009). This conception is enhanced by a comprehensive framework developed by Pickett and Cadenasso (2009). They indicated the possible influence of human actions on each of the five state factors with respect to physical disturbances, altered resource availability, and spatial heterogeneity. Thus, the classical state factors approach of Jenny (1941) is modified due to anthropogenic processes in cities.

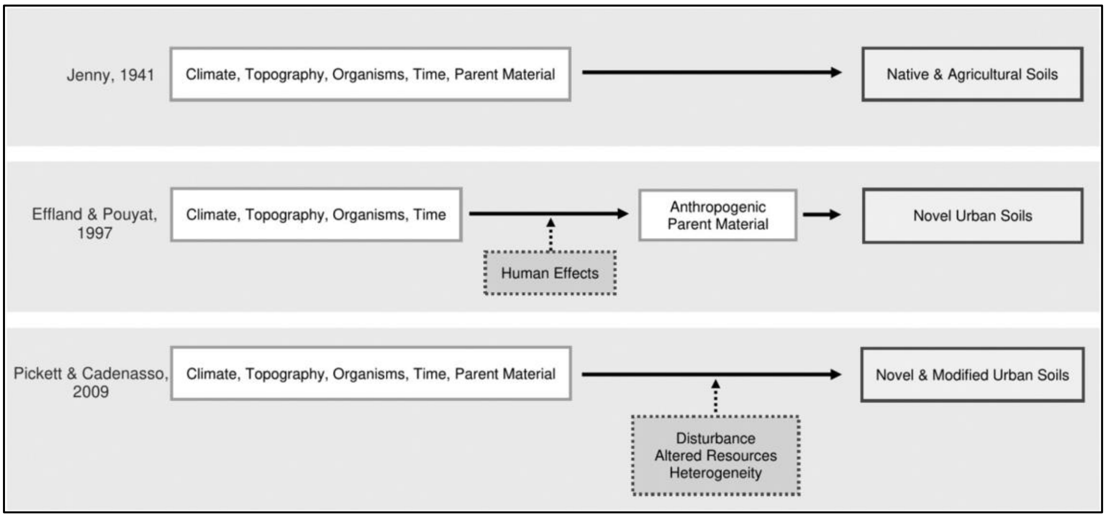


Figure 2.3 : Factors affecting the modification of soil formation process (reproduced with the permission of Pickett and Cadenasso, 2009).

In short, Effland and Pouyat (1997) and Pickett and Cadenasso (2009) translated five state factors described in the absence of humans into the urban realm by considering the anthropogenic disturbances and indirect impacts of urbanization as the sixth factor influencing soil formation processes.

Although soils in these urban landscapes are altered, Pouyat et al. (2010) and (Effland and Pouyat, 1997) advocate for the inherent capacity of urban soils to sustain many of the ES provided by their rural counterparts. According to them, they can function by reducing the bioavailability of pollutants, supplying plant nutrients, providing the substrate for soil biodiversity and plant growth, storing carbon and nutrients, and moderating the hydrologic cycle through absorption, storage, and supply of stormwater. ES provision potential of modified urban soils has been confirmed by the studies conducted under the Baltimore Ecosystem Study (2010). The study revealed that urban effects on soils occur at multiple scales, yet, urban landscapes are biologically active in pervious areas and still have a high potential for water filtration, carbon storage, and nitrogen retention which are significant for climate and water flow regulation.

2.3 Soil in the Global Agenda

In response to the growing concerns about soil degradation and the recent recognition of its central role in food security and climate change, numerous projects, initiatives, and actions have emerged at the global level.

In 2011, the Global Soil Partnership (GSP) was established by the FAO to address the global challenges related to soil management and conservation (GSP, 2014). The GSP aims to raise awareness about the critical role of soil in global food production, ecosystem services, and sustainable development. It also promotes sustainable soil management practices, supports capacity building, enhances research and data collection, develops global soil information, and facilitates international collaboration among governments, researchers, civil society organizations, and other stakeholders at the national, regional, and international levels (FAO, 2017; GSP, 2016).

In 2013, the 68th United Nations General Assembly designated the 5th of December as 'The World Soil Day' and declared the year 2015 as the 'International Year of Soils' with an intent to raise awareness about the importance of soil and its essential ecosystem functions (FAO and ITPS, 2015) while supporting the Post-2015 agenda and SDGs.

In the context of SGDs, the importance of soil and spatial planning relationship is highlighted clearly under "SDG 15: Life on land". The goal specifically addresses the importance of protecting, restoring, and promoting the sustainable use of terrestrial ecosystems, including forests, wetlands, mountains, and, by extension, soil. It was mentioned, soil conservation and sustainable land management practices are crucial components of achieving this goal, as healthy soil is essential for food production, biodiversity, and combating desertification and land degradation (UN, 2023).

Although "SDG 15" directly addresses soil-related issues, there are other SDGs that are indirectly related to soil. Soil health and sustainable land management practices have cross-cutting impacts on various aspects of sustainable development, including:

- SDG 2 (Zero Hunger): Healthy soils are essential for food security and agricultural productivity. Sustainable soil management practices contribute to increased crop yields, reduced soil erosion, and improved nutrition.
- SDG 6 (Clean Water and Sanitation): Soil plays a role in filtering and purifying water as it moves through the ground. Healthy soils help maintain water quality and prevent water pollution.
- SDG 11 (Sustainable Cities and Communities): Soil quality and urban development are interconnected. Sustainable urban planning and construction practices can minimize soil degradation and promote green infrastructure.

- SDG 13 (Climate Action): Soil is a carbon sink and plays a critical role in climate regulation. Sustainable land management practices can enhance soil carbon sequestration, contributing to climate change mitigation.
- SDG 14 (Life Below Water): Soil erosion and land degradation can lead to increased sediment runoff into rivers and oceans, negatively impacting marine ecosystems.
- SDG 17 (Partnerships for the Goals): Collaboration and knowledge-sharing among countries and stakeholders are essential for addressing soil-related challenges on a global scale.

While these SDGs may not focus exclusively on soil, they highlight the interconnectedness of soil health and sustainable land management with broader sustainability goals. Therefore, effective soil management can contribute significantly to achieving multiple SDGs simultaneously.

In addition to the significance of soil in SDGs, the role of soil in climate change mitigation is also highlighted at the global level. The IPBES (2018) report addressed the strong links between climate change and land degradation by underlying the importance of soil's role in decreasing GHG emissions through its carbon storage function. For a sustainable low-carbon future, the goal to offset the rises in GHG concentrations through carbon sinks was initially introduced by the Paris Agreement on Climate Change signed in December 2015 (Streck and Gay, 2017). Therefore, the year 2015 could be designated as a landmark for soil and global environmental assessment in reference to the outcomes of international dialogues.

Besides the crucial role of soil in mitigating climate change by sequestering CO_2 from the atmosphere, the importance of sustainable soil management practices for food security is also emphasized by the UN (2023) and FAO and ITPS (2015). To meet the rising global food demand, preserving soil health and fertility is defined as "vital". Moreover, as (UNCCD, 2016) states, various forms of soil degradation, including erosion, salinization, and desertification, are posing significant threats to arable land cause loss of fertile land worldwide. Therefore, combating land degradation and promoting soil conservation are paramount in safeguarding our agricultural resources.

The challenges and risks to soil quality and health are also subject to comprehensive examination at the European Union (EU) level. The Soil Thematic Strategy, adopted by the EU in 2006, established a formal framework to address the risks posed to soil and its diverse functions. In the context of the draft Soil Framework Directive proposed by the strategy document, five distinct soil threats were specified: Soil compaction, erosion by water and wind, salinization, contamination, organic matter decline, landslides of soil and rock material, and soil sealing. Recently, the technical report of the European Commission Joint Research Centre (Stolte et al, 2016), UNCCD (2017), and FAO and ITPS (2015) have provided an expanded framework for understanding global soil threats that contribute to land and soil degradation. According to their specifications, these threats are; soil erosion, soil contamination, desertification, soil compaction, soil salinization, flooding and landslides, soil sealing, soil acidification, decline in soil biodiversity, decline in SOM (SOC), and nutrient imbalance.

2.3.1 Land and soil degradation

According to IPBES (2018); UNCCD (2016) and FAO and ITPS (2015), mismanagement practices, over-exploitation of land resources, and long-term adverse interferences on land, triggered land and soil degradation, which has been acknowledged and recognized as serious threat to the world’s carrying capacity and human welfare.

Land and soil degradation are often used interchangeably but they differ in their definitions and contexts. Land degradation refers to the deterioration or loss of economic productivity, environmental quality, resource potential, and productive capacity of the land (Smiraglia et al, 2016; UNCCD, 2016). Whereas, soil degradation means the degradation of the physical, chemical characteristics, and biological processes of soil causing a diminution or loss of its capacity to provide goods and services with an overall decline in soil health status (FAO, 2019). In other words, soil degradation can be described as a subset of processes related to land degradation and is, in itself, an indicator of land degradation (IPCC, 2019).

According to Tóth et al, (2008), soil degradation can be reflected by the decrease in soil fertility, SOM and organic carbon content, loss of biodiversity, loss of water retention capacity, disruption of water, nutrient and gas cycles, and reduced capacity to degrade contaminants.

D'Odorico and Ravi (2016) assert that the degradation of land and soil resources is occurring at a concerning pace. A UNEP-funded project ‘Qualitative Assessment of

Global Degradation’ mapped human-induced soil degradation in 1991 as a first attempt based on the experts’ opinion and it claimed that 15% of the terrestrial land surface was affected by soil degradation (Caspari et al, 2015). Following this pioneering study, its successor project ‘Global Assessment of Land Degradation and Improvement’ (2006–2009) analyzed remotely sensed trends and the status of global land and soil degradation and found that almost one quarter (24%) of the total land was undergoing degradation in the period 1981–2003 (Caspari et al, 2015) with cumulative effects on biomass productivity (Bai et al, 2011). The recent reference document of the United Nations on the status of global soil resources states that: *“...the majority of the world’s soil resources are in only fair, poor or very poor condition. Today 33 % of the land is moderately to highly degraded due to the erosion, salinization, compaction, acidification, and chemical pollution of soils”* (FAO and ITPS, 2015).

Soil degradation poses a threat not only to global food security and the well-being of a considerable segment of the global population, estimated at 1.3 to 3.2 billion people, but also reduces the ability of societies and ecosystems to adapt to the impacts of climate change (IPCC, 2019; IPBES, 2018). Given the fact that urbanization is rapidly increasing, the urban population is expected to rise from the current 55% to 68% by 2050, representing a significant global demographic shift (UN, 2018). Between the years 2000 and 2030, there is a foreseen trend that could lead to an annual depletion of 1.6 to 3.3 million ha of valuable agricultural land, according to UNCCD (2018). Therefore, soil and land degradation is considered a serious concern that needs to be addressed since it poses a significant environmental problem and threat to humanity as a result of its negative effects on agricultural productivity, environmental quality, food security, and climate change (D’Odorico and Ravi, 2016).

Land and soil degradation is recognized as an urgent priority also by the IPBES (2018) report to protect biodiversity and ES vital for life. To avoid, reduce, and/or reverse the degradation process as a “pervasive and systematic phenomenon that occurs in all parts of the terrestrial world” (IPBES, 2018), the UN Convention to Combat Desertification formulated the goal to achieve zero net land degradation under ‘Land Degradation Neutrality (LDN)’ framework. LDN was first brought to the international agenda at the United Nations Conference on Sustainable Development held in 2012 and officially adopted by the SDGs (Target 15.3) by 2015 (UNCCD, 2016). The framework advocates a paradigm shift in land management strategies and implementations that prioritizes counterbalancing the expected loss of productive land through recovery. The central role of integrated management of soil functions and services in LDN-sensitive land use planning is emphasized by UNCCD (2016) with a need to incorporate local data and knowledge to land use objectives.

2.3.2 The role of soil in climate change impacts

IPBES (2018) defines climate change as *a "statistically significant variation in either the mean state of the climate or in its variability, persisting for a prolonged duration (usually spanning several decades or more)"* and it emphasizes the distinct influence of humans on climate change (IPCC, 2013).

According to UNEP (2012), urban areas comprise only around 3% of the land surface of the earth, but they use approximately 75% of the earth's natural resources and emit 60% to 80% of GHG emissions. GHG play a vital role by trapping the solar energy in the atmosphere and influencing the climate of the planet; known as the 'GHG effect' (EPA, 2017). This naturally occurring process is vital and provides higher and liveable temperature ranges on the earth. However, the increase of atmospheric GHG in exponential ratios intensifies the GHG effect, alters the energy balance, causes an increase in Earth's temperature, and results in climate change (Scharlemann et al, 2014).

Due to greater amounts of GHG emissions mainly caused by energy generation, vehicles, industry, biomass use, and human alteration on LULC (EPA, 2017), the global surface temperature in the past decade was detected as 0.8 °C higher than the beginning of the 20th century (Carteret al, 2015). According to NOAA (2018), CO_2 is of greatest concern in all of the GHG, since it contributes the most to climate change. Atmospheric CO_2 levels in 2009 were measured higher than at any time in the past 800,000 years and it is continuing to increase at an accelerating rate (EPA, 2017). Scharlemann et al, (2014) indicate that carbon emissions resulting from changes in LULC are the second-largest source of human-caused carbon emissions to the atmosphere after emissions from fossil fuel combustion.

Recent studies emphasize the under-estimated role of soil in climate protection (EEA, 2019; IPCC, 2019; IPBES, 2018; EPA, 2017; Prokop et al, 2011). Soil, as the largest terrestrial carbon sink, regulates climate by capturing and storing atmospheric carbon as soil organic carbon. Sequestration of carbon by healthy soils and vegetation is an important part of the continual cycle of CO_2, and crucial for key soil functions such as stabilization of soil structure (erosion control), the flow of plant nutrients (productivity), and water infiltration and storage in soil (Pereira et al, 2017). The carbon stored in soil supports soil organisms to perform in biogeochemical cycles and improve soil fertility (FAO, 1995). In the terrestrial carbon cycle, the amount of carbon stored in the soil is documented by Batjes and Sombroek (1997) as twice as the carbon in the atmosphere, and about three times more than the carbon stored by the vegetation, which puts soil as the second-largest carbon reservoir after oceans (EPA, 2017).

In the Kyoto Protocol signed in 1997, the earlier emphasis was given to the links among soil carbon sequestration, soil conservation, and mitigation of climate change (Dumanski, 2004). The limited interest in the enhancements of soil carbon sinks has been enlarged by the recent political agenda (e.g. Paris Climate Summit in 2015; UN Climate Change Conference in 2017) with an ultimate aim to increase the global carbon stocks.

The idea has brought the inclusion of the ‘land factor’ in the climate change mitigation agenda and the goals are supported by the ‘4p1000’ initiative (Rumpel et al, 2019), which recently received considerable attention at the UN Climate Change Conference held in 2018. The initiative launched in 2015 aims to increase carbon sequestration in soil to mitigate fossil fuel combustion emissions of GHG. Through its name, it addresses that only an annual growth rate of 0.4% of standing global SOC stocks would have the potential to counterbalance the current increase in atmospheric CO_2 (Rumpel et al, 2019). Moreover, in line with the growing interest in soil carbon stocks, FAO has launched the first Global Soil Organic Carbon Map of the World (FAO, 2017) by compiling national data from over 100 member countries. The map indicates the degradation of one-third of the world’s soils which has already prompted an enormous release of carbon into the atmosphere (FAO, 2017).

2.3.3 The position of soil in urban spatial planning

In addition to the strong interconnectedness of soil and climate change impacts, FAO and ITPS (2015) emphasized the necessity of incorporating soil-related knowledge into urban spatial planning processes as well.

Spatial planning, in the wider context, is a systematic and integrated approach to managing land, resources, and the built environment (Almenar et al, 2018; Ministry for the Environment, 2010). It addresses the tensions and contradictions among sectoral policies while promoting the delivery of economic, social, and environmental benefits (UNECE, 2008). If correctly administered, spatial planning may have an important role in environmental protection and improvement. In urban and peri-urban landscapes, spatial planning plays a key role in managing conflicts and developing strategies for the effective and efficient use of land. It adopts an inclusive approach to provide multiple benefits by assessing the trade-offs between different land-use options (FAO, 2020). With regard to human-environment interactions, the ES approach, as an interface between science and policy, can contribute to spatial planning to translate scientific knowledge into spatial strategies (Breure et al, 2012; Tezer et al, 2020). In the case of soil degradation, linking SoES-related strategies to spatial planning is central to drawing a framework to prevent, diminish, and reverse the deteriorating effects of LULC change on the soil (Drobnik et al, 2020; Ronhi, 2018).

Nevertheless, soil has traditionally been incorporated into urban spatial planning primarily for its utility as arable land, the foundation for urban infrastructure and civil engineering structures, as well as a resource for geothermal energy and archaeological-cultural history. Its broader significance and SoES have often been overlooked in urban spatial planning processes (EC, 2018). By analyzing seven recent urban planning reports, Silva et al, (2018) conclude that soil and soil-related ES receive little attention during the execution and surveillance stages of urban planning even for globally leading cities. According to Silva et al., (2018), although the profound effects of urbanization on soil and the central role of LULC in soil degradation process have been well-researched and documented by the scientific community and pioneering global organizations, incorporating soil knowledge into the spatial planning framework is still challenging. All of these findings have a common ground that, there is a necessity for enhanced and widespread recognition of the roles and benefits of urban soils in urban spatial planning. This can start with an initial step of defining and understanding the soil in the urban context.

In the urban context, LULC is an important determinant of environmental health and SoES provision. The influence of LULC on SoES can enhance or decrease the quality and quantity of the services provided by soil. For example, in the context of climate change, afforestation increases the capacity of soil to offset GHG emissions by increasing the stored carbon. Thus, it makes a positive contribution to the mitigating role of soil in climate change. In contrast, due to the transformation of natural land into a built-up area or some agricultural practices such as tillage, the stored carbon in soil can even be released back into the atmosphere. In this case, LULC change reverses the role of soil in climate change impacts. Soil as an important carbon sink naturally, acts then as a contributor to climate change.

Spatial planning plays a key role in managing conflicts on land. In particular, complex systems such as the SoES, climate change, and LULC present multidimensional problems, which can be translated into (social, economic, and environmental) benefits through efficient and inclusive spatial planning strategies. In this context, acknowledgment of SoES and climate change link by spatial planning decision-making processes is essential to;

(i) prevent/decrease the deleterious effects of LULC change,

(ii) ensure soil functions and maximize the benefits of SoES,

(iii) mitigate climate change and manage disaster risks in urban areas.

Linking soil potentials and threats to spatial planning received earlier attention at the EU level and lately has gained significant political momentum (EC, 2017; Glæsner et al, 2014). In the context of the EU’s Common Agricultural Policy launched in 1962 - and strengthened in 2013-, concrete attempts for a comprehensive soil management strategy have been initiated in the early 2000s as a partnership limited by the link between agriculture and society (EC, n.d.). It was aimed by the EU Member States to develop a common policy considering the growing pressures on European soils and their services.

In 2002, the European Commission presented its approach to soil protection in a Communication entitled “Towards a Thematic Strategy on Soil Protection”. The main threats that cause soil degradation were identified as sealing, compaction, decline in organic matter, erosion, contamination, loss of biodiversity, and salinization (EP, 2003). Floods and landslides were added later with a separate Directive on flood risk management prevention (Glæsner et al, 2014).

In order to bridge the gap in European environmental legislation and to provide a more holistic soil protection approach across the EU, the Commission presented a new policy in 2006 that was titled “Thematic Strategy for Soil Protection (COM (2006) 231)” which outlines the basic soil protection policy of EU (EC, 2006). The adopted strategy recognizes the need to improve integration measures for spatial planning and other related sectors that influence LULC, to protect soil functions and prevent soil consumption and degradation (EC, 2006; Peccol and Movia, 2012). Along with the strategy document, the European Commission presented a draft proposal of the Soil Framework Directive, which introduced soil functions provided for humankind in addition to soil threats. However, the proposal was opposed by some member states (France, Austria, the Netherlands, Germany, and the United Kingdom) based upon the subsidiarity and proportionality principles, expected costs, and administrative burdens (Glæsner et al, 2014).

In 2014, the pending proposal was withdrawn and the 7th Environment Action Programme 2020 was launched by recognizing soil degradation as a serious challenge (Endly and Berger, 2014). The program aims to “live well within the planet’s ecological limits” and admits that unsustainable use of land in the EU has an impact on ES, biodiversity, vulnerability to climate change and natural disasters, soil degradation, and desertification (EU, 2013). Under the program, research and innovation projects for advancing soil protection and a better understanding of soil management in the EU are financed by the ‘7th Framework Programme for Research’ and the HORIZON2020 such as the projects of RECARE, OpenNESS, URBAN SMS, ESMERALDA, INSPIRATION, Soil4Life, and SoilCare.

The discourse reflected by the program was also supported by citizen groups. The withdrawal of the Soil Framework Directive draft proposal and the current heterogeneous and un-coherent pattern of soil legislative frameworks in the EU resulted in a public reaction. Citizens from 26 member states protested the right to soil through the campaign launched in September 2016 and lasted for 12 months (EC, 2017). The ‘People 4 soil’ initiative underlined the increasing deterioration of EU soil in the absence of an overarching, integrated, and legally binding policy framework. By recognizing soil as a shared heritage, the initiative aimed at inviting the Commission to provide a common framework for EU-wide soil protection to be applied by the Member States. The campaign specified the need for the translation of ‘no net land take’ into legal principles while engaging soil-related SDGs into EU policies (Cattaneo, 2017). Although it was the first European Citizen’s initiative on a serious environmental problem, having the support of 516 European NGOs, research institutes, farmers associations, and environmental groups, the campaign could not gather the required number of statements of support within the one-year time limit (Cattaneo, 2017; EC, 2017). However, despite the lack of strategic coordination and little political attention soil received, this open-access network initiative highlighted the acknowledgment of ES provided by soil and the recognition of its importance for biodiversity conservation, food security, and climate change adaptation.

2.4 The Nexus Approach for SoES-Climate Change-Spatial Planning Interplay

The recognition of the need for adopting SoES into spatial decision-making processes has drawn attention to their interconnected nature. Despite this increased global interest, current efforts are not comprehensive enough to explain the diverse web of transitions and fluxes among them. As UNU-FLORES (2016) states, understanding the interrelated and interdependent nature of environmental resources is central to managing them. In reference to this administrative gap, the United Nations University Institute for Integrated Management of Material Fluxes and Resources introduced the ‘Nexus Approach’, which is based on system (nexus) thinking prioritizing solutions with multiple benefits instead of focusing on an individual component (UNU-FLORES, 2016). Although the concept has newly gained prominence in the context of the Water, Energy, and Food Security Nexus and it is still under evaluation, the multi-scaler and multi-contextual essence of the approach can be configured into the initial efforts in describing and analyzing the interactions between soil, climate change, and spatial planning.

From this point of view, the Nexus approach is adapted to the research context to figure out the interrelations among the pillars and build a conceptual framework, that emphasizes the central role of LULC change for sustainable soil and land management. The proposed framework consists of three pillars including SoES, Climate Change, and Spatial Planning (Figure 2.4).

The multi-scalar character of the framework introduces an interconnected network of knowledge both horizontally (among the pillars) and vertically (at different scales). The vertical network necessitates the transfer of knowledge and consistency between different spatial plans while the horizontal network requires data explaining the interrelated connections between three pillars.

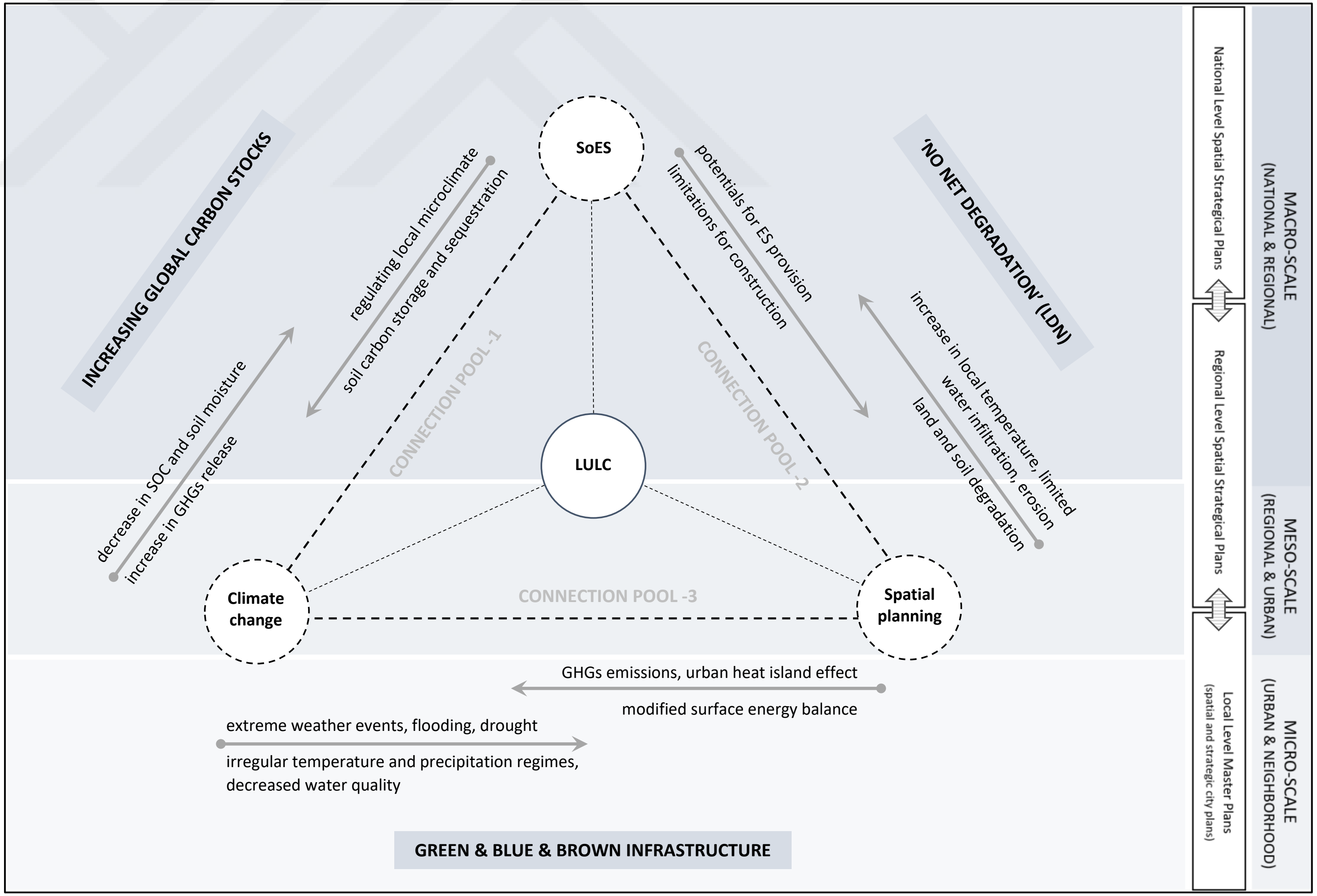


Figure 2.4 : SoES-climate change-spatial planning nexus framework.

The Nexus framework illustrates a complex web of interactions among the pillars which can be characterized as positive or negative due to the decisive role of LULC. It was aimed by this framework to define the interdependencies among selected pillars and provide insight into the multiple benefits of climate and SoES-sensitive spatial planning. The diagram is designed based on the connection pools, which describe the sections where the pillars interact.

In the first connection pool, the relationship between SoES and climate change is identified through the positive contribution of soil to climate regulation (through carbon storage and regulating microclimate) (EEA, 2019) and the negative effects of climate change on soil.

According to EEA (2012), higher temperatures may alter soil physicochemical and biological processes and cause organic carbon release from soil contributing to climate change while restoring currently degraded soils could eliminate 63 billion tons of carbon, which would counterbalance an important share of global GHG emissions (FAO and ITPS, 2015). Every connection pool is composed of positive and negative influences on each other, therefore relevant strategies are designated for each pool to counterbalance the negative effects. For the first connection pool, the objective of 'increasing global soil carbon', which was supported by the 4p1000 initiative officially recognized by the Paris Agreement can be suggested to be considered. Herein, soil carbon can be used as a mitigation strategy to combat climate change. Therefore, preserving the existing stocks in soils, and increasing the capacity of soil to store carbon through spatial planning can be an effective option to manage soil carbon to mitigate climate change.

The second connection pool is proposed to identify the relationship between SoES and spatial planning. Changes in LULC patterns have direct and indirect impacts on SoES that can accelerate carbon release from soil by deforestation and intense farming practices and cause increased temperatures, and a decrease in evapotranspiration, soil moisture, and soil fertility (EEA, 2012). In addition, land take and sealing have an enormous influence on soil's water infiltration and retention capacity, resulting in increased surface runoff and flood risk, erosion, decreased microbial activity, and extensive loss of the productive (top) soil (EC, 2014; Pouyat et al, 2010). They also cause reduced storage of carbon and an increase in local (surface and sub-surface) temperature (Streck and Gay, 2017). Other influences of anthropogenic interventions on soil include soil contamination, landslides, biomass, and organic matter loss, disruption of water, nutrient and gas cycles (Grimm et al, 2008; Pavao-Zuckerman, 2008). On the other side, soil is mostly considered in spatial planning documents and practices in terms of its suitability for agricultural practices.

The acknowledged importance of SoES at the global level addresses a critical gap in spatial planning regarding SoES. Yet, their integration is key for enhancing SoES potential and generating multiple benefits. To that end, it is critical to identify and prioritize the areas (zones) with high ES potential and develop site-specific plan decisions. By using local soil knowledge, site-specific land-use strategies can facilitate the flow of information between different spatial scales. In this pool, the strategy suggested to encounter the destructive impacts of LULC can follow the ‘No Net Degradation’ objective defined by the LDN approach (UNCCD, 2016). Restoration of degraded ecosystems by LDN principles could halt and reverse degradation. It also contributes significantly to climate change mitigation by increasing carbon storage and sequestration and reducing CO_2 concentrations in the atmosphere.

The third connection pool considers the interactions between climate change and spatial planning. According to IPCC (2019) and IPBES (2018), land degradation intensifies due to climate change, especially in low-lying coastal areas, river deltas, permafrost areas, and drylands. In urbanized landscapes, the impacts of climate change can be more destructive due to increased pressure on urban infrastructure, possible increase in natural disasters, epidemic diseases, local temperatures, and energy consumption (Carter et al, 2015). On the other side, LULC changes are one of the major contributors to climate change. In their complex relationship, LULC patterns affect the surface temperature and global concentrations of GHG (Scharlemann et al, 2014) through deforestation, impervious surface increase, rapid and unplanned urbanization, and urban sprawl. However, afforestation, conversions to grassland, and an increase in permeable surfaces can contribute positively to climate change mitigation (EEA, 2012; IPCC, 2013).

The strategy proposed for this pool is Green and Blue Infrastructure in connection with ‘brown’ infrastructure (Pouyat et al, 2020). The green-blue infrastructure approach simply evolved from landscape ecology and planning (Cannatella, 2017; EEA, 2011b). As it strengthens the ecological and hydrological connectivity within the city landscape (Bacchin et al, 2014), recognition of soil in this network system can contribute to multiple benefits while sustaining the SoES. The interconnected network of natural and semi-natural landscape elements can contribute significantly to building climate-resilient living environments while improving soil microbial activity, soil fertility, carbon storage and sequestration, nutrient cycling, groundwater replenishment, and regulation of microclimate (Bacchin et al, 2014; Mander et al, 2018). Several practices such as infiltration trenches, rain gardens, swales, green corridors, and constructed wetlands can be practical tools to support the provision of SoES at different scales.

Although Nexus thinking provides a comprehensive platform for stakeholders to think from a multi-contextual framework, it also includes some challenges due to the cross-sectoral nature of pillars. Some limitations of the SoES-Climate Change-Spatial Planning Nexus can be summarized below:

- Data: Availability of data and information in particular to soil substratum
- Multidisciplinary context: The language and knowledge gap between experts
- Organizational strains: Conflict of authority, bureaucratic limitations for the required changes
- Reference work: Lack of case study examples configuring their interconnected nature
- Property rights: Multi-stakeholder problems in land management
- Spatial planning: Challenges in translating the scientific data into spatial policies

By looking at the big picture, the Nexus approach provides an instrument for decision-makers to develop long-term strategies by identifying and mitigating trade-offs and utilizing the synergies (Rasul and Sharma, 2015). From this point of view, the approach offers some opportunities in terms of:

- Interconnectedness: Considers the connectivity instead of focusing on an individual component
- Comprehensive perspective: Provides a big picture of interactions
- Multiple benefits: It prioritizes the solutions with multiple benefits, it supports synergies
- Sustainability: Supports social, economic, and environmental development

- Multi-sectoral structure: Facilitates coordination, communication, and collaboration between sectors and stakeholders.
- Science-Policy interface: Provides a tool for decision-makers to translate data into policies
- Natural resource management and planning is one of the main concerns of the Nexus framework

In the context of translating the soil data into spatial planning policies, the framework can play a crucial role. In this process, an integrated approach with the close and active collaboration of all actors from related disciplines is of significant importance in generating multiple benefits. Successful implementation of the framework in cities necessitates local actions in harmony with superior strategies combatting soil degradation and climate change.

However, the complete implementation of the Nexus Framework requires more extensive research content and time, more comprehensive and detailed analyses, and a multidisciplinary approach that was beyond the capacity of the PhD research. Therefore, within the scope of the study, considering the content, objectives, and priorities of the research, the relationship between the single connection pool of the Nexus Framework, namely 'SoES-LULC-spatial planning,' has been thoroughly examined. Yet, due to the absence of sharp and clear boundaries between pillars and the connection pools they interact with, it can be stated that any study conducted in a specific connection pool will directly or indirectly impact other pillars and connection pool interactions.

2.5 Summary of the Chapter

This chapter provides a comprehensive overview of the current understanding of soil and identifies areas of knowledge that require further investigation in relation to the SoES, natural and anthropogenic impacts on soil, global response to soil threats, and the link between climate change, spatial planning, and SoES particularly in urban environments. The highlights of the research and the overall inferences addressing the contribution of the study to the existing literature are summarized below:

• The services provided by soil have not been fully incorporated into the ES discourse

There is still no consensus established to define, value, and classify SoES. In some studies, the benefits obtained from soil are mentioned as ‘soil function’ while some others use the term ‘SoES’. The same overlapping can be observed in the categorization and definition of the SoES.

- **The services provided by soil have not been classified under global ES frameworks**

As it was mentioned previously, MEA, as the prominent document in conceptualizing ES, disregarded the ES provided by soil except for soil formation, which was classified as one of the supporting services. In the following years, TEEB and CICES paid more attention to soil (including the services of nutrient cycling and erosion, water and hazard regulation) but still, the overall services provided by soil have not been incorporated, organized, and classified under a common framework, which is of significant importance for achieving global objectives in soil protection.

- **Land use/land cover changes have substantial impacts on soil**

According to FAO (2013), one-third of the planet’s land is severely degraded and the accelerating extent of some mismanagement practices and the changes in LULC threaten the availability of soil, its critical ES, and the life on Earth. Long-term adverse interferences on land cause ‘soil degradation’ which has been acknowledged and recognized as a serious threat to the world’s carrying capacity and human welfare.

- **Soil resources are often perceived as the second-tier priority in the spatial planning process**

Despite the critical importance of soil, the Report on the Status of the World’s Soil Resources (FAO and ITPS, 2015) addresses the increase of global soil deterioration due to urbanization, population growth, industrialization, and climate change. The growing attention on soils following the adoption of the International Year of Soils and SDGs has provided a clear understanding of the present condition of global soil resources., supported the improvement of soil data infrastructure, and put the unsustainable use of soils under a global debate. Nevertheless, continuing deficiency in global soil research collaboration and the lack of a comprehensive and coherent set of rules for soil management put soils under a growing threat.

- **Soil and SoES have gained a remarkable global awareness**

As an accumulation of international efforts such as; the EU Soil Thematic Strategy (2006), the foundation of the Global Soil Partnership (2012) and Intergovernmental Technical Panel on Soils (2013), the proposal of draft Soil Framework Directive (2006–2014), the designation of World's Soil Day (2015) and International Year of Soil (2015), Paris agreement (2015), adoption of SDGs with a specific target on LDN approach (2015), the Global Soil Organic Carbon Map by FAO (2017), emphasis on soil under the 7th Environment Action Programme (2013-2020) and several studies conducted at the regional, national and local scales, soil has been carried to the global agenda with rising awareness and concern on SoES.

• There is a concrete recognition of the need to adopt soil and its services into the decision-making process in urban areas

Given the acknowledged importance of ES for human well-being and, on the contrary, the destructive effects of urbanization-driven LULC change on soil, the need for recognizing the importance and role of SoES in spatial planning has started to be mentioned by the global authorities (EC, 2006; IPBES, 2018; UNCCD, 2016). The central role of integrated management of soil functions and services was also emphasized by the LDN concept (UNCCD, 2016). This paves the way for better integration of SoES-based measures in planning processes.

• The role of SoES in climate change regulation has been highlighted

The benefits of storing more carbon in soil have been encouraged by scientific studies, international policy documents, and initiatives to decrease atmospheric CO_2 concentrations in the atmosphere. Although the opponents are skeptical of its efficiency and realism, the approach can be employed as a complementary method in addition to other climate mitigation measures focusing on reducing CO_2 emissions. Soil, as the earth's largest terrestrial carbon pool, (Lal, 2008), and largest water filter and storage tank (FAO and ITPS, 2015) should be considered an important system component of urban climate change and flood regulation policies.

• Urban areas can function as a living laboratory performing sustainable development of the relationship between SoES, climate change, and spatial planning

As growing cities and changing population densities lead to accelerating human interventions and unprecedented changes in LULC pattern, the complex interactions between LULC, soil, and climate change can be investigated through a set of indicators including land and soil degradation, soil sealing, soil compaction, land take, urban sprawl, changing temperature and precipitation patterns, urban heat island effect, soil carbon storage and sequestration, SOM and changing water regimes. Considering the global recognition of sealing and land take as the major sources of environmental changes, urban areas can be the most appropriate research labs for working on the integration of SoES in spatial planning. Herein, spatial planning tools can translate the knowledge into practice in light of climate regulation and land and soil protection.

Based on the findings of the literature review, effective measures are required to be taken to protect and sustain the soil ecosystem, its functions, and services in urban landscapes. These measures encompass the following aspects:

(i) Understanding and mapping the impacts of urbanization and associated LULC change on SoES

(ii) Identifying the critical zones with high potential for SoES provision

(iii) Ensuring the legal protection and support of these identified areas through the integration of SoES into spatial planning and decision-making processes.

At this point, the methodology to be followed should involve a detailed analysis of the SoES provided by urban soils and the LULC changes in the area, aiming to understand their interactions. The obtained findings should contribute to the clarification of the relationship between urban soils, climate change, and spatial planning. Furthermore, it is of great importance to prioritize the monitoring of global soil conservation strategies and practices that are currently at the forefront of the global agenda in addressing climate change and to establish local initiatives that align harmoniously with global policies.

3. QUANTIFYING THE NEXUS METHODOLOGY WITH BUYUKCEKMECE WATERSHED CASE

Following -and based on- the first two chapters, which provide an outline and contextual framework for the study, the third chapter facilitates the transition to the implementation phase and describes the overall methodology of the research.

The conceptual framework (i.e., Nexus approach) developed in the previous section provides a foundation for the organization and design of the research methodology. The framework holds significant importance for the multifaceted and holistic perspective it provides in elucidating the mutual interactions among SoES, LULC, climate change, and spatial planning. It emphasizes the central role of LULC in this dynamic network and states that the preservation and enhancement of SoES, alongside contributing to climate change mitigation and achieving multiple benefits for sustainable environments are interconnected. This implies that any intervention in one component of the system will directly or indirectly affect the others and lead to cumulative effects.

In the context of this holistic framework, the thesis focuses on the "Connection Pool-2" which evaluates the interactions between "SoES," "LULC," and "Spatial Planning" (Figure 3.1). In fact, within this framework, all components interact with each other, and based on this data, the relationships between “SoES and climate change” or “climate change and spatial planning” can also be examined. However, due to the research's primary focus on soil and SoES, the scope of this study has been limited to quantitative analyses related only to the components in this connection pool. Yet, given its interconnected nature, expanding the approach to other connection pools would likely provide a more comprehensive assessment of the research.

At this point, the study develops a multi-tiered approach by combining different analysis techniques and aims to understand and interpret the spatio-temporal changes in LULC pattern and three specific SoES (regulation of surface water flow, carbon storage, and biomass production) in Buyukcekmece Watershed case in a specific time period.

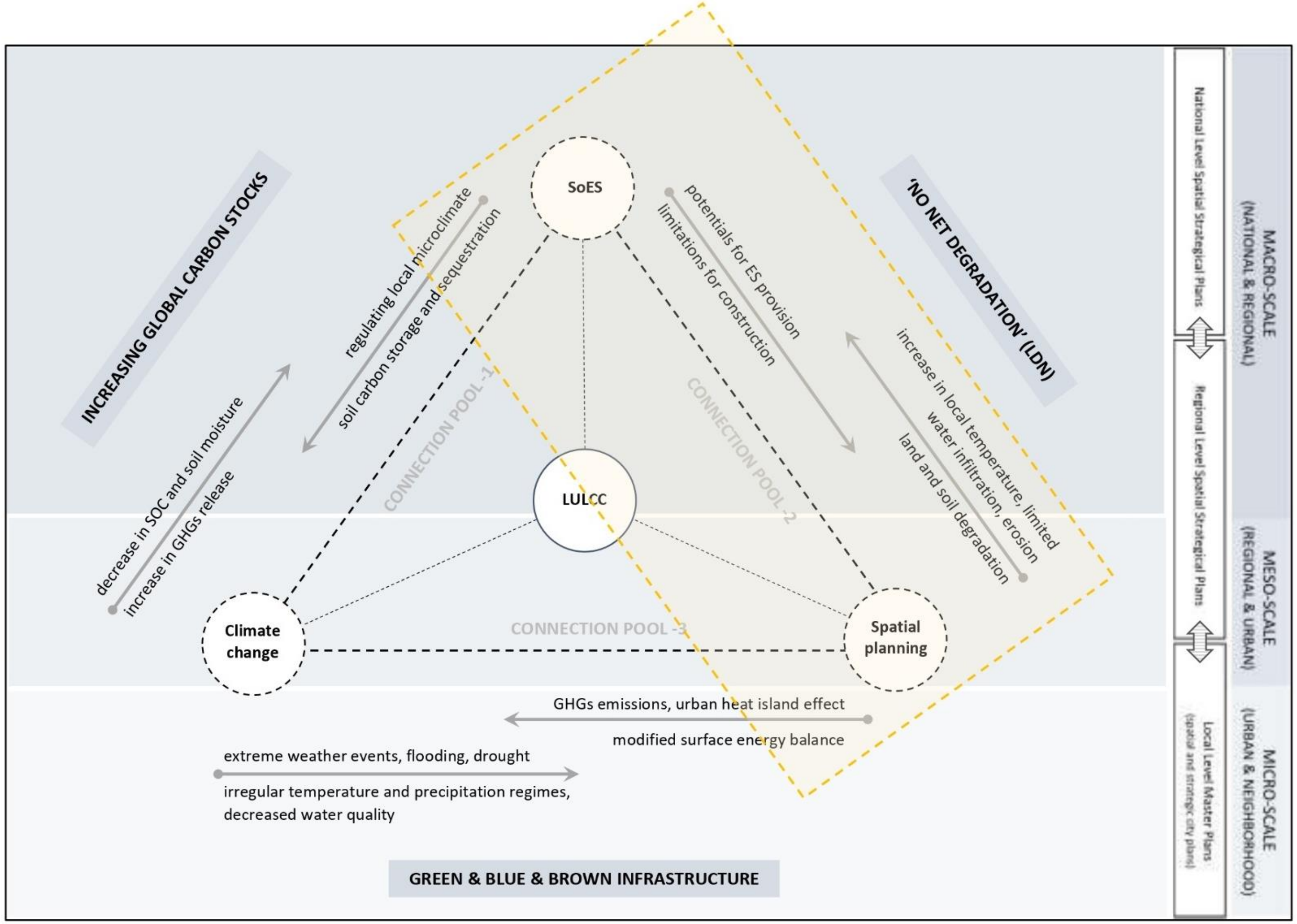


Figure 3.1 : Delimitation of the case-based research within the conceptual -Nexus- framework.

Based on the premise that urbanization issues are most effectively tackled within urban areas, the research focuses on urban watersheds, as areas significantly impacted by the pressures of urbanization in Istanbul. Istanbul is a metropolis where urban development and environmental issues are intricately interconnected. The ongoing urbanization dynamics and the increasing population are steadily exacerbating the pressure on the natural environment in the city.

In the context of the research, focusing on the protection and enhancement of SoES against the adverse effects of LULC, the reasons of choosing the watershed scale can be briefly outlined as follows:

(i) One of the most crucial ecological functions provided by soils is water-related SoES (i.e., water infiltration, storage, transpiration, distribution, and percolation). Therefore the analysis, modeling, and management of surface and groundwater must be conducted at the watershed scale.

(ii) Moreover, urban watersheds serve as a planning unit representing urban soils, and;

(iii) Watersheds are ecological units with unique characteristics and processes, addressed within the context of ecological planning principles.

Furthermore, as stated by Dawei and Jingsheng (2001), the most suitable scale for intervention, where different sectors and resource users are considered together, and threats and opportunities are evaluated in the long term, is the watershed scale. Therefore, watershed scale should be the fundamental consideration in the management of natural resources.

From this point of view, in line with the scope and objectives of the research, Buyukcekmece Watershed is selected as the case study area, representing one of the prominent urban watersheds in Istanbul.

The analysis was carried out in the Buyukcekmece Watershed due to its critical location at the periphery of a rapidly growing city. The watershed is located on the European side of Istanbul, known for being one of the city's significant sources of drinking water. Istanbul stands as a metropolis where urban development and environmental issues are intertwined, due to several factors including high population density, socio-economic dynamics, and challenges related to urbanization. The escalating trends in development dynamics and the mounting population pressure are steadily increasing the threats to the natural areas in the city.

It is well-documented that the watershed, situated on the peripheries of the city, faces intense population growth and urbanization pressures, consequently posing risks of pollution, erosion, and landslides. As a result of urbanization-induced alterations in LULC, along with industrial and agricultural activities, and the development of residential areas in the watershed, it was determined that the ecological integrity of the watershed is under threat. This, in turn, exerts adverse effects on SoES in the entire watershed.

Furthermore, it is anticipated that large-scale projects carried out within the city and those planned for the future, such as Istanbul Airport (3rd Airport), Northern Marmara Motorway, and Yavuz Sultan Selim Bridge (3rd Bridge), will have notable impacts on the LULC pattern of the watershed in the coming years.

The third chapter, in brief, describes the methodological design of the study under three sub-chapters, namely “3.1: Research Design”; “3.2: Datasets and Data Analysis”; and “3.3: Assumptions and Limitations”.

Prior to delving into the sub-chapters, it may be useful to elucidate the position and significance of this particular chapter within the overarching organization of the thesis. As can be seen in Figure 3.2, the thesis comprises six main chapters, in which the first chapter, aims to identify the research gaps through an in-depth literature review and outlines key research components while the second chapter establishes a conceptual background to provide a comprehensive overview of the theoretical underpinnings that inform the research methodology.

Herein, the third chapter plays a central role in the thesis context and structure, as it links the two main parts, theoretical background, and empirical analysis, of the thesis. Therefore, it holds significance as it provides a bridge and facilitates a transition between theory and implementation.

Following the third chapter, the analyses carried out in the study case are presented under the fourth and fifth chapters including the discussions regarding the suggestions for the future incorporation of SoES into the urban spatial planning processes. Finally, the last chapter provides an overall evaluation of the research and discusses the findings in the light of research objectives and hypothesis.

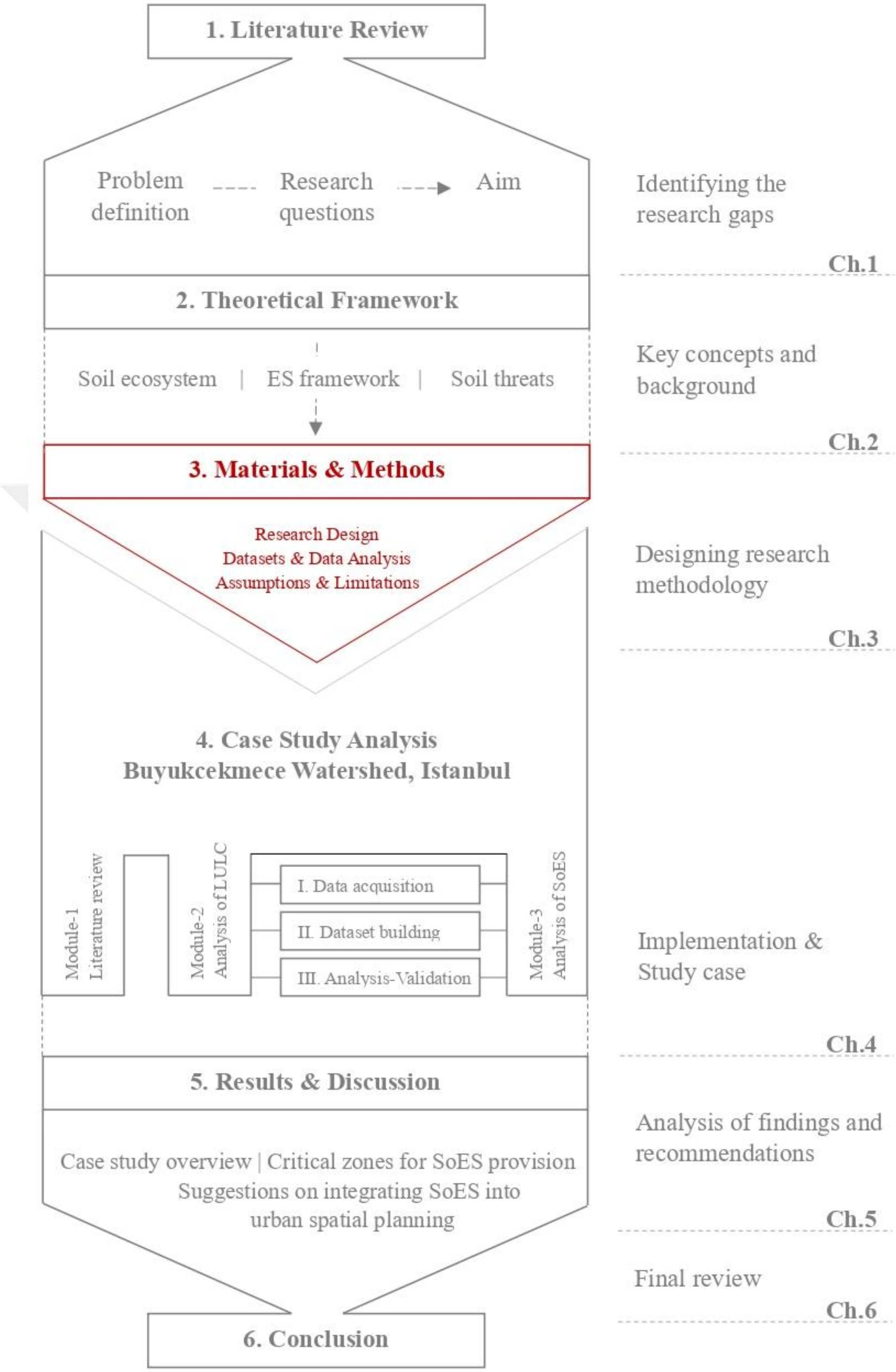


Figure 3.2 : The cohesive role of the 3rd chapter within thesis structure.

3.1 Case-based Research Design

This chapter describes the design of the research methodology and implementation process, which was divided into three distinct phases: Preparation, Analysis, and Findings.

As indicated in Figure 3.3, each phase is composed of several steps of implementation. The preparation phase comprises five steps, which primarily focus on laying the groundwork necessary for subsequent data analysis. The second -analysis- phase is composed of three steps and it elaborates on the quantitative analysis process of LULC change and SoES provision. Lastly, the phase of findings summarizes, evaluates, and discusses the research outcomes in two steps.

Phase 1: Preparation

Step 1 involves the selection of an appropriate case study area. To this end, several important criteria were taken into consideration, including the presence of urban soil, exposure to LULC change driven by urbanization, and the ecological, social, and economic significance of the area. After careful evaluation of these factors, the Buyukcekmece Watershed, located on the European side of Istanbul, was chosen as the study case of this research.

One of the main reasons for selecting this area was its status as an urban watershed that has been subject to increasing pressure (which is expected to continue in the upcoming years) from urban development processes since the 1980s. In addition, the watershed is of critical importance to the local population, as it serves as the third-largest drinking water reservoir in Istanbul. Moreover, it holds ecological significance as an Important Bird Area (IBA) and Important Plant Area (IPA) under the Natura 2000 Network. Hence, it was deemed appropriate to choose this area as a suitable study case for understanding and evaluating the pressures on urban soils in the context of urbanization-driven LULC change.

Step 2 involves the division of the implementation process into two parts, which begins with the analysis of LULC change (section 1), followed by the assessment of SoES provision (section 2). These two sections are the key pillars of the analytical part of the research and guide the following stages.

Figure 3.3 : Methodological research design.

Step 3 involves determining the time frame for the analysis process. In this context, the time span that encompasses the years 1990, 2000, 2006, 2012, and 2018 was selected based on the availability of LULC data.

Additionally, in this step, the selection of the SoES to be analyzed was made. Herein, several factors such as data availability, accessibility, and the quantifiability of the service were taken into consideration. Moreover, considering the interconnected and interdependent nature of the Nexus framework, particular emphasis has been placed on selecting SoES that provide multiple benefits and are relevant to each pillar. Consequently, the conducted analyses will yield valuable insights into other related SoES that cannot be examined due to inadequacies in data, challenges in data accessibility, or technical constraints.

Taking into consideration the aforementioned factors, three SoES were selected for assessment: Surface water flow regulation (categorized under regulating services); Storage of SOC (categorized under both regulating and supporting services); and biomass production (categorized under provisional services) that are classified with overall SoES in Figure 2.2 in the previous chapter.

Step 4 involves the selection of the appropriate methods and tools for analyzing the changes in LULC pattern and SoES provision within Buyukcekmece Watershed case over the selected time frame. In this step, specific assessment criteria were identified as well for each service.

Step 5, as the final pace of the preparation stage, involves determining the required data, their acquisition, processing, and preparation for the analysis.

Phase 2: Analysis

Steps 6, 7, and 8 involve the quantitative analysis and validation studies. Initially, the "state" of the LULC pattern and SoES provision were analyzed and mapped for each study year. Thereafter, the "changes" in LULC and SoES provision are analyzed in 5 different periods (i.e., between 1990-2000, 2000-2006, 2006-2012, 2012-2018, and 1990-2018). At the final stage, the "transformations" in LULC and SoES provision were analyzed and compared between 1990 and 2018 to assess the relationality between those two variables, LULC and SoES. The findings were tested by validation processes.

Phase 3: Findings

Step 9 involves identifying and mapping the critical zones in Buyukcekmece Watershed, where the provision of selected SoES is high. This step is crucial for the subsequent stages of the research, particularly for the discussions about the integration of SoES into urban spatial planning processes.

By identifying the areas that are particularly critical to changes in LULC, decision-makers and planners can make informed choices about how to manage and develop these areas in a way that supports the provision of SoES. In essence, highlighting the critical zones for SoES provision in Buyukcekmece Watershed can inform urban spatial planning decisions that prioritize the protection and enhancement of SoES and ensure the sustainable provision of these services in the watershed.

Step 10, the last stage, involves developing recommendations for the possible integration of SoES into the current urban spatial planning and decision-making processes based on the Buyukcekmece Watershed case.

3.2 Datasets and Data Analysis

This study involved the implementation of four distinct analyses, each of which was executed through the use of appropriate methods and tools.

The methodological approach employed in each analysis was selected based on a review of the existing literature, as well as consultations with the thesis supervisor and committee members. The data utilized in each analysis was obtained from either open-source repositories or related institutions, with the requisite permissions being obtained via official petitions submitted through Istanbul Technical University.

Below, each analysis is summarized in detail, including a description of the methods, tools, materials, and software programs employed in each.

The first analysis aimed to identify and map the changes and transformations in LULC in the Buyukcekmece Watershed. For this analysis, the CORINE Land Cover (CLC) database was utilized.

The CLC inventory was initiated by the European Union's Copernicus Programme in 1985 and was first applied for the reference year of 1990 (Url-2). Since then, updates have been produced for 39 European countries, and databases for the years 1990, 2000, 2006, 2012, and 2018 are currently available. The CLC database has been used in various studies, reports, and projects across Europe, providing a scientifically reliable and comparable dataset that minimizes user errors for researchers in various disciplines, including those with limited knowledge and expertise in satellite data and remote sensing analysis techniques required for LULC change analysis (Aune-Lundberg and Strand, 2021). The database enables in-depth analysis and inventory of changes in 44 land cover classes, which can be updated or compared as long as the database is updated by the program. These advantages, namely reliability, user-friendliness, and comparability, led to the selection of the CLC data for this analysis. In order to analyze the LULC change in the Buyukcekmece Watershed, raster LULC data were obtained from the open-source database on the EU-Copernicus official website in the selected time series (1990, 2000, 2006, 2012, and 2018) and analyzed by using ArcGIS (Geographic Information System) software.

The second analysis in this study aimed to evaluate the surface water flow (runoff) regulation capacity of the soil (SoES-1) and its change over the selected time period. For this analysis “Soil Conservation Service (SCS)- Curve Number (CN)” method was employed and the required data was obtained from various sources.

The SCS-CN method, which was first introduced in the "TR-55 Urban Hydrology for Small Watersheds" document by the United States Department of Agriculture, SCS in January 1975, is a commonly used hydrological model for estimating direct runoff resulting from rainfall events in small to medium-sized watersheds (USDA, 1986). The method utilizes CN values and rainfall data to calculate the runoff. To determine the CN values, a table is used that represents the combination of hydrologic soil groups and LULC types in the watershed. The data required for this analysis includes LULC data, which was obtained from the CLC database, hydrologic soil groups data, which was acquired from the 1:25,000 scaled National Soil Database, rainfall data obtained from the State Meteorological Institute (MGM) for the years 1985-2018, and flow gauging stations (AGI) data, which were acquired from the State Hydraulic Works (DSI) to validate the results. For calculations and generating the maps, ArcGIS and Microsoft Excel programs were used.

The third analysis focuses on evaluating changes in SOC storage (SoES-2) in the Buyukcekmece Watershed. For this analysis, the InVEST Carbon Storage and Sequestration model was utilized.

The InVEST model is a software tool that was developed by the Natural Capital Project at Stanford University and is designed to calculate, map, and assess the value of ES. It employs LULC maps to estimate the quantity of carbon stored in four carbon pools (Url-3). To estimate the overall carbon content held within the soil, the model required two essential inputs, namely LULC data and the biophysical carbon storage densities for each land use class. The LULC data used in the study was extracted from the CLC Database for the specified time frame. However, due to some physical and technical constraints, soil samples could not be collected from the study area and analyzed in the laboratory to estimate the quantity of carbon stored in the four carbon reservoirs. Therefore, previous studies were used to obtain the reference values for the biophysical carbon storage densities for each land use class. The suitability of these studies was evaluated based on the geographical characteristics, distance to the selected study area, climatic conditions, and scientific quality and reliability of the data. The results obtained were then compared with those of the Soil Organic Carbon Project, which is aimed at calculating the total SOC stock in Turkey through field observations and soil sample analysis. This project was a joint venture between the Republic of Turkey Ministry of Agriculture and Forestry and TUBITAK BILGEM YTE (Software Technologies Research Institute) between 2017 and 2018.

The fourth and final analysis in this study examines the changes in the biomass production service of soil (SoES-3). Biomass production is the amount of living plant material produced by vegetation, which is closely associated with primary productivity. Box et al. (1989) note that the Normalized Difference Vegetation Index (NDVI) is a widely used remote sensing index and a reliable predictor of primary productivity. Since NDVI is positively correlated with both biomass and primary productivity, it is employed in this research to estimate changes in biomass production within the Buyukcekmece Watershed during the selected time period. To conduct this analysis, satellite images from Landsat 4-5 TM and Landsat 8 OLI/TIRS were obtained through the USGS Earth Explorer platform, and then analyzed and mapped in a GIS. All these four analyses conducted within the scope of the study, as well as the methods and tools used, are summarized in Table 3.1.

Table 3.1 : The methodological framework of the study.

		ES Category	**ES description**	**Assessment criteria**	**Indicator(s)**	**Method**	**Materials/Source**	**Software/ Program**
Section-1 LULC	**LULC change**		—	Transformations in LULC pattern		Change Detection Analysis	1) Land use and Land Cover data Coordination of Information on the Environment (CORINE) database (1990, 2000, 2006, 2012, 2018)	ArcGIS MS Office Excel
Section-2 Ecosystem services provided by soil (SoES)	**SoES-1**	Regulating	Water regulation	Surface runoff	CN value & Runoff volume	SCS-Runoff Curve Number (CN) Method	1) Land use and Land Cover data Coordination of Information on the Environment (CORINE) database (1990, 2000, 2006, 2012, 2018) 2) Soil data: 1/25000 scaled National Soil Database 3) Meteorological data (1985-2018) The State Meteorological Institute (MGM) 4) Flow gauging stations (AGI) The State Hydraulic Works (DSI)	ArcGIS MS Office Excel
	SoES-2	Supporting	Nutrient cycling	Carbon storage	Soil Organic Carbon (SOC)	InVEST Carbon Storage and Sequestration model	1) Biophysical C storage (Mg/ha) (Literature review) 2) Land use and Land Cover data Coordination of Information on the Environment (CORINE) database (1990, 2000, 2006, 2012, 2018)	InVEST model ArcGIS MS Office Excel
	SoES-3	Provisioning	Biomass production	Photosynthetic activity	Mean NDVI value	Normalized Difference Vegetation Index (NDVI)	1) Landsat imagery (USGS Earth Explorer) 2) Landsat 4-5 TM (1990, 2000, 2005, 2011) 3) Landsat 8 OLI/TIRS (2017)	ArcGIS MS Office Excel

3.3 Assumptions and Limitations of Case-based Research

The research applies a multi-disciplinary perspective for integrating the knowledge of soil science, hydrogeology/geological engineering, landscape architecture, and urban planning disciplines to better understand and interpret the ecological consequences of LULC change on SoES. In this context, the assumptions and limitations below should be taken into consideration when interpreting the results:

- The CLC dataset has been utilized in the study due to its advantages and provision of comparable data. However, the analyses performed with a 25 ha/100 m minimum mapping unit/width may lead to some thematic accuracy problems, data loss, and insufficient resolution of information at the local scale.
- The SCS-CN method also relies on certain assumptions when calculating surface runoff. Firstly, the accuracy shortcomings of the LULC data, mentioned in the previous stage, are still valid in this analysis, as the SCS-CN method uses the LULC data from the previous stage to generate results. Additionally, factors such as slope, temperature, and evaporation, which are considered in detailed hydrological classifications, are excluded from this method, assuming that some of the water from precipitation infiltrates into the soil, while the rest directly runs off the surface. Furthermore, the lack of information about the soil data is among the factors influencing the outcomes. In the context of this research, the collection of soil samples from the field and their subsequent analysis in the laboratory was unfeasible, leading to the utilization of the national soil database. However, this dataset does not include information about urban soil and hydrologic soil groups (HSG). Therefore, the categorization of HSG was conducted in alignment with methodologies employed in similar studies found in the literature. In terms of meteorological data, it was found that only three stations were available to measure daily precipitation data for all years between 1990 and 2018 among 21 stations in the European side of Istanbul. Besides, these stations were located outside of the study area. Due to the insufficient number of stations and their remote locations from the watershed, the Thiessen polygon method, which is used to calculate the distribution of rainfall, could not be applied. As a result, it was assumed that the rainfall was evenly distributed across the sample area. Therefore, when compared with AGI data for validation, inconsistencies between the results may arise from certain assumptions and data inadequacies in the processing steps. To work with the movement

of water on the soil surface and subsurface in a more detailed manner, 3D hydrological models can be utilized.

- In the process of calculating carbon stored in the soil, the lack of field and laboratory analyses has led to conducting the analysis based on some assumptions. The carbon density values stored for each land class have been obtained from similar studies in the literature and interpreted for the case in the Buyukcekmece Watershed. Therefore, the accuracy of the unit carbon stored in carbon pools, may not be representative of the actual carbon stored in the watershed. In addition, the thematic accuracy problems in the LULC data also apply to this analysis.
- In the NDVI analysis, numerous constraints were encountered. Due to the cloud level of satellite images, which was above 10%, or the technical errors, the data from 1990, 2000, 2005, 2011, and 2017 were used instead of the selected time frame. Additionally, other factors affecting biomass production and vegetation health (such as agricultural patterns, temperature, humidity, and sun exposure) were excluded, and a general trend of vegetation health and structure was calculated by the NDVI analysis. In the context of the study, NDVI is considered a surrogate measurement of plant photosynthetic activity and biomass production, which may not always be the case. Therefore, biomass production can be measured and evaluated by more complicated analyses and tools

In brief, while the results of this study provide valuable insights into the SoES provided by the Buyukcekmece Watershed, it is essential to keep in mind the constraints and uncertainties related to the assumptions and data used in the analysis. Future studies should aim to address these limitations and uncertainties to improve the accuracy and reliability of SoES assessments.

4. ANALYZING THE CHANGES IN LULC AND SoES IN BUYUKCEKMECE WATERSHED

Chapter four is dedicated to the practical execution of the research methodology explained under “Chapter 3” and it presents a comprehensive analysis of the changes and interactions between LULC pattern and SoES provision in the Buyukcekmece Watershed. The primary objective of this chapter is to gain a better understanding of the effects of urbanization-induced LULC change on SoES while identifying the key drivers behind these changes in the case study area.

The chapter consists of three main sub-chapters, namely “4.1: Location and General Qualifications of Buyukcekmece Watershed”; “4.2: LULC Change Analysis“: and “4.3: Quantification of the Spatio-Temporal Changes in SoES Provision”.

The first section provides an overview of the general characteristics (e.g., location, size, significance) and problems of the watershed through literature reviews and site surveys. In this section, an in-depth analysis is presented regarding the challenges confronting the area, as well as an exploration of its inherent potential. The following chapters are devoted to explaining the empirical analysis on quantifying and mapping the spatio-temporal changes in LULC and SoES provision within the Buyukcekmece Watershed. In this empirical part of the research, firstly, the LULC patterns were thoroughly examined during the designated research period (1990, 2000, 2006, 2012, 2018), followed by the analysis of the changes and transformations in LULC. In the last sub-chapter, the changes in the selected SoES within the same designated research period are analyzed by using different methods and tools for each service. Given the diverse analytical approaches used for these variables, the research employed a multi-tiered methodological framework.

To sum up, the 4th chapter provides an overall analysis of the changes in the LULC and SoES provisions in the Buyukcekmece Watershed. The findings of this chapter are expected to contribute to a broader understanding of the implications of urban LULC change on SoES in urban landscapes, thereby providing valuable insights for future urban spatial planning and decision-making processes that aim to safeguard and sustain urban SoES, particularly in the urban watersheds.

4.1 Location and General Qualifications of Buyukcekmece Watershed

The Buyukcekmece Watershed is located on the European side of Istanbul, in the northwest region of Turkey. It encompasses 4 administrative districts, namely Buyukcekmece, Catalca, Arnavutkoy, and Silivri, incorporating a total of 51 neighborhoods within its boundaries (ISKI, 2019) (Figure 4.1).

According to TurkStat (2022), the total population of the Buyukcekmece Watershed is 243,167. This count of inhabitants is calculated by summing the populations of all the neighborhoods encompassed within the watershed boundaries. Specifically, in Buyukcekmece, the 17 neighborhoods falling within the watershed area have a total population of 173,225 people. Similarly, within the Catalca district, the 23 neighborhoods included within the watershed boundaries have a population of 40,339 individuals. Within the Arnavutkoy district, the four neighborhoods within the watershed boundaries have a combined population of 19,139 residents. Lastly, the Silivri district, comprising seven neighborhoods within the watershed area, has a population of 10,464 individuals. Comprehensive data on the population of districts and neighborhoods located within the boundaries of the watershed can be found in Appendix A. The spatial distribution of the population within the watershed, along with the corresponding districts and neighborhoods, is shown in Figure 4.2.

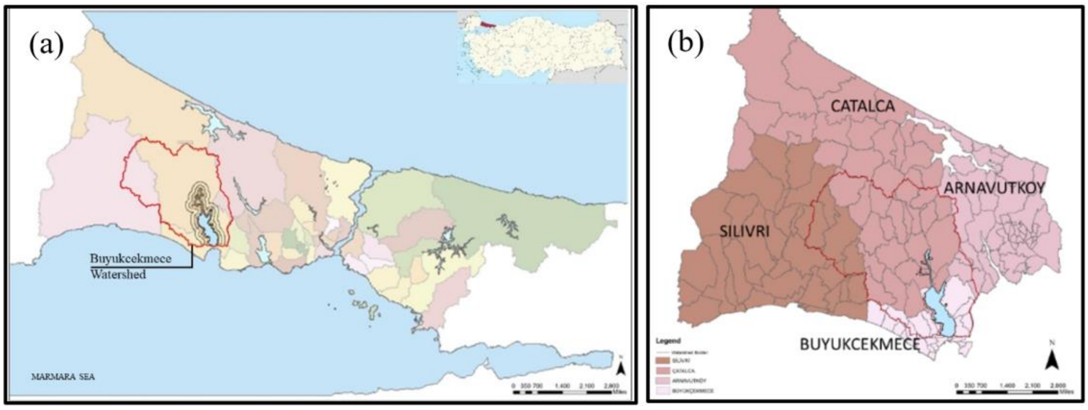


Figure 4.1 : a) Administrative boundaries of the districts in Istanbul and location of the Buyukcekmece Watershed b) Districts in the borders of Buyukcekmece Watershed.

In terms of climate and topography, the study area is characterized by a predominant Marmara climate, displaying distinct features of rainy winters and hot summers. Unlike conventional Mediterranean climates, the region encounters relatively milder summer drought conditions owing to its proximity to the Black Sea (ISKI, 2019). As Demirci and Karaburun (2012) indicate, the average temperature in the area ranges from 5°C during January and February to 23°C in July and August. Furthermore, the average annual precipitation in the study area amounts to 650 mm, with the majority occurring between October and February (Figure 4.3).

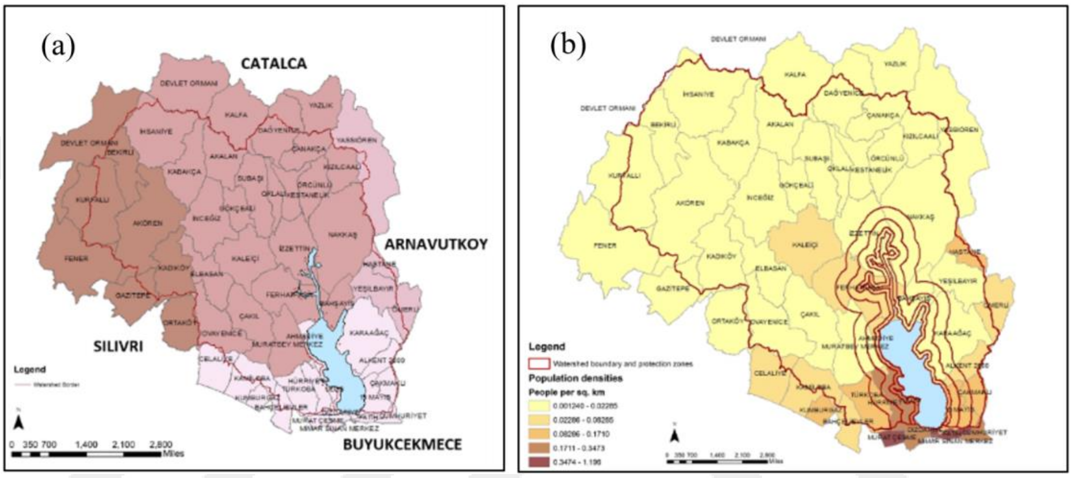


Figure 4.2 : (a) Districts and neighborhoods and (b) Spatial distribution of the population in Buyukcekmece Watershed (TurkStat, 2022).

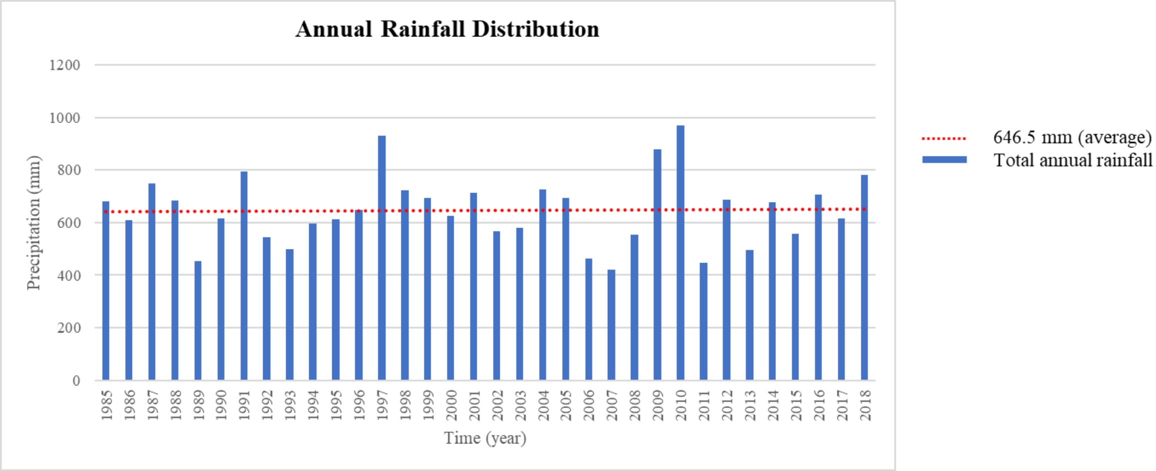


Figure 4.3 : Annual rainfall distribution in Buyukcekmece Watershed (Derived from data provided by the General Directorate of Meteorology, MGM).

The elevation within the study area varies from sea level to 323 m, generally ascending from south to north. The hills surrounding Buyukcekmece Lake contribute to the elevation profile, which continues northward (Guyer and Ilhan, 2011). Notably, the lake receives its water supply from several southward-flowing streams, including Karasu, Tahtakopru, Incegiz, Havza, Sarisu, and Cakil (ISKI, 2019).

The watershed has a 620 km^2 total drainage area including the Buyukcekmece Lake occupying an area of 28.50 km^2, as documented by Sertel et al. (2019) and Gulecal and Temel (2014). In terms of surface area, the lake is the second-largest lake on the European side of Istanbul (ISKI, 2019).

Although the reservoir was originally one of the coastal lagoons of the Marmara Sea, the construction of an earth-fill embankment dam between 1985 and 1987 by the DSI and Istanbul Water and Sewerage Administration (ISKI) shifted its character to a freshwater lake (Yardimci et al., 2018; Cosgun and Yalcin, 2014). The primary purpose of constructing the dam was to establish a water supply system for the city by isolating and disconnecting the lagoon from its marine connection (ISKI, 2019). The Buyukcekmece Dam is positioned at the juncture where Buyukcekmece Lake converges with the Marmara Sea, forming a transitional zone characterized by the coexistence of a saline lake, islands, and marshy regions (ISKI, 2019; Gulecal and Temel, 2014). These interconnected elements define a unique ecological landscape in the area.

At that point, two prominent and significant characteristics of the lake come to the forefront: its ecological value and its status as one of the most crucial watersheds providing drinking water to Istanbul.

From an ecological perspective Buyukcekmece Lake is protected under the "Regulation on the Conservation of Wetlands," prepared in line with the requirements of the Ramsar Convention, an international treaty concerning wetlands as habitats for waterbirds (ISKI, 2019). According to the criteria outlined in the convention, the lake and its surrounding wetland area have been designated as an important bird area (IBA) of international significance, serving as a vital breeding and resting ground for waterbirds as well as providing habitat for passage waterbirds during wintering and migration periods (Url-5).

Furthermore, Buyukcekmece Lake is recognized as one of the 305 Important Nature Areas (under the Natura 2000 Network) in Turkey according to assessments conducted in accordance with methodologies developed by conservation organizations such as BirdLife International, Conservation International, and PlantLife International (ISKI, 2019). The lake meets the criteria for an important nature area due to its role as a wetland area harboring diverse species groups and serving as a habitat for plant species that are globally threatened. (Url-6).

In addition to its ecological significance, the Buyukcekmece Watershed holds profound importance as a significant source of drinking water for Istanbul. According to Cuceloglu et al. (2017), surface sources such as active lakes and dams play a vital role in supplying approximately 99% of Istanbul's drinking water. Istanbul currently relies on 15 drinking-water reservoirs, situated both within the city's borders and in neighboring regions, as reported by van Leeuwen and Sjerp (2016). Among the primary drinking-water reservoirs and their watersheds, seven are (entirely or partially) located within Istanbul boundaries (Figure 4.4). These include Terkos, Buyukcekmece, Alibeykoy, and Sazlıdere on the European side, as well as Omerli, Elmalı, and Darlık on the Asian side. Other reservoirs, such as Istranca Creeks, Papucdere Reservoirs, and the Melen System, are located in nearby cities. The Melen watershed demonstrates the highest water potential, followed by the Omerli, Terkos, and Buyukcekmece watersheds, which are presently utilized for water resource management. According to Cuceloglu et al. (2017), these three watersheds will be crucial for meeting future water demand in the city, as they have the capacity to fulfill 25% of the total demand.

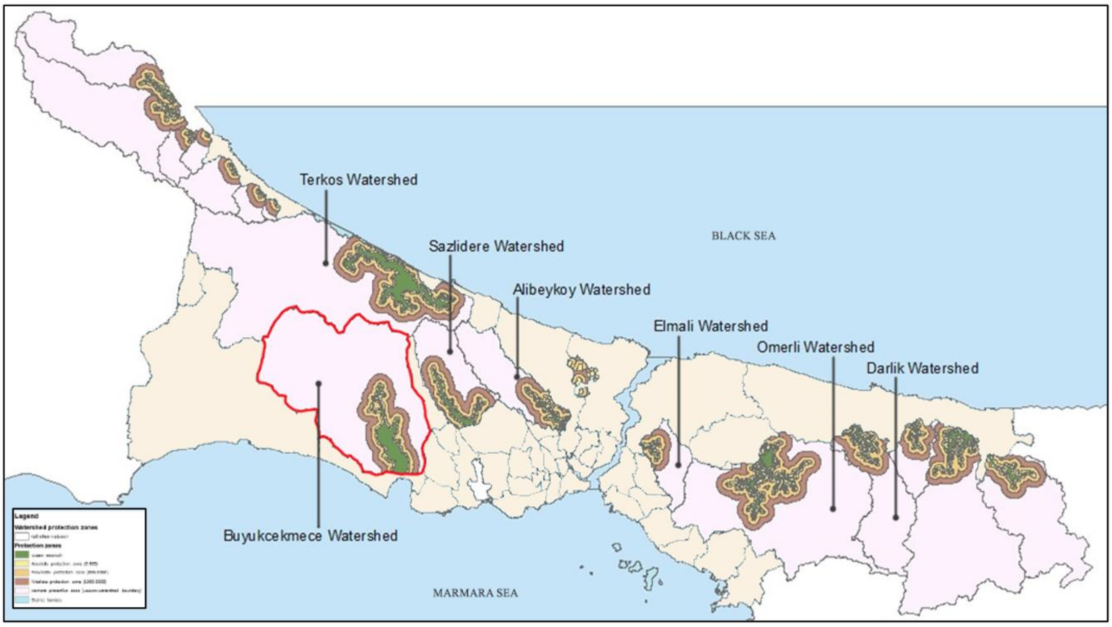


Figure 4.4 : Buyukcekmece Watershed and drinking water reservoirs in Istanbul.

According to Cosgun and Yalcin (2014) and Karakuyu et al. (2012), the Buyukcekmece Reservoir plays a significant role as a drinking water source for Istanbul, fulfilling approximately 17% of the city's daily water requirement and providing water to nearly 2 million people (Sertel et al, 2019). Among the seven main reservoirs in Istanbul, it ranks as the third-largest reservoir in terms of the annual water yield provided (Yardimci et al, 2018). Having a yearly water supply capability of 100 million cubic meters and a daily capacity of 400,000 cubic meters, the Buyukcekmece Watershed holds considerable importance as one of the city's primary water resources (Aykut et al, 2021; Cuceloglu, 2017).

The watershed is under the protection of the "Drinking Water Basin Regulation" implemented by ISKI. This regulatory framework is designed to safeguard the quality and quantity of the water within the drinking water reservoirs of Istanbul. The regulation defines distinct protection zones that entail varying degrees of restrictions and requirements related to land use, development activities, and environmental conservation. These zones include the absolute protection zone (0–300 m), short-distance protection zone (300–1000 m), middle-distance protection zone (1000–2000 m), and long-distance protection zone (beyond 2000 m from the water Watershed boundary). Within the absolute and short-distance protection zones, permanent settlements and industrial activities are strictly prohibited to prevent any potential contamination risks. In the middle-distance protection zone, limited residential development is permitted but with very low housing densities to minimize potential impacts on water quality. As for the long-distance protection zone, existing industries may be allowed to operate under special precautions to mitigate any adverse effects, while new developments are strictly prohibited to preserve the integrity of the water resources and the surrounding environment, (ISKI, 2011).

Notably, the areas close to the Buyukcekmece Lake are designated within the absolute, short-distance, and middle-distance zones, which mandate limited and closely monitored human activities (Figure 4.5). Although there are arable lands largely surrounding the lake, it has been observed that certain parts of the watershed have experienced encroachment by industrial and residential developments within the designated protection zones of the watershed (Turer Baskaya and Tekeli, 2016; Kaya and Kizildere, 2013).

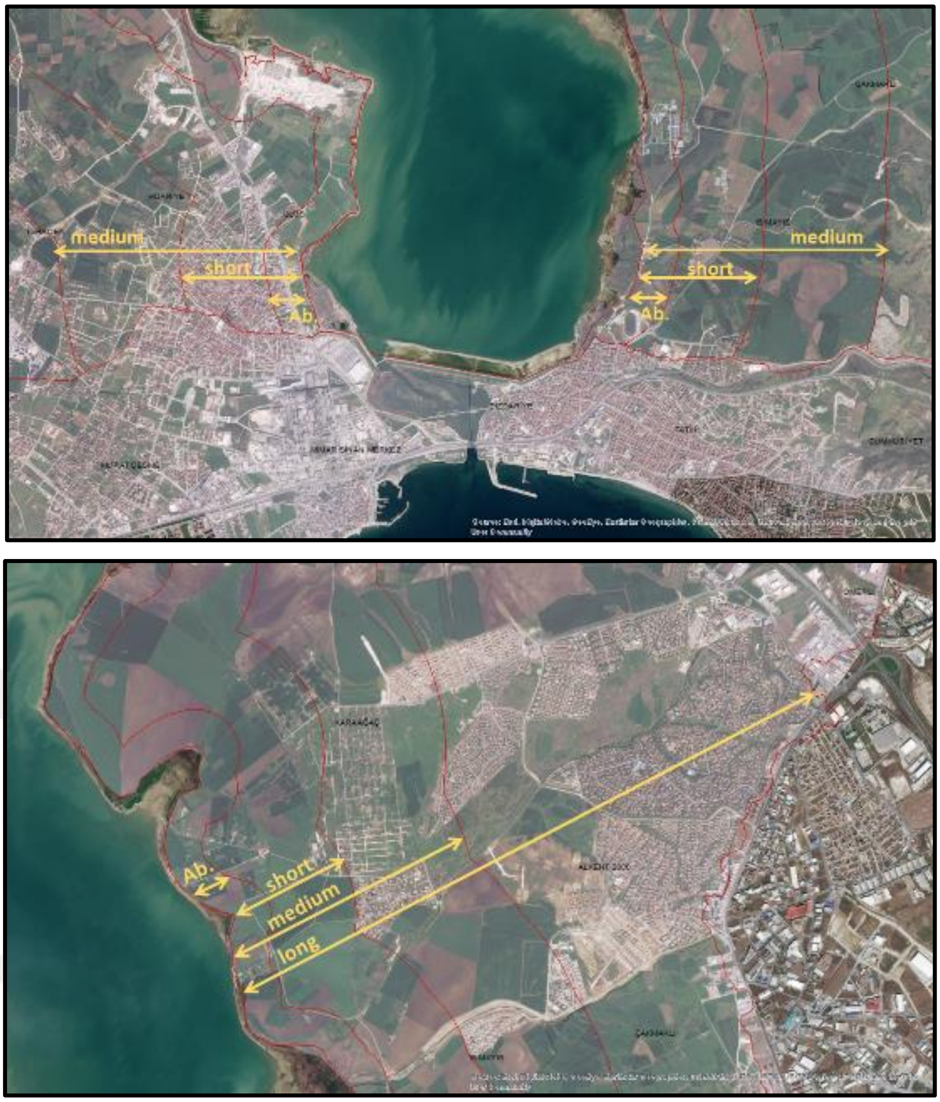


Figure 4.5 : Built-up areas in the protection zones of Buyukcekmece Watershed.

The non-compliance with this regulation has given rise to a wide range of interconnected challenges and problems in the area, accompanied by additional pressures.

Among those, anthropogenic pollution emerges as one of the prominent challenges in the Buyukcekmece Lake area. As noted by Aykut et al. (2021) and Guyer and İlhan (2011), Buyukcekmece Lake, characterized by its shallow nature with an average depth of 8,6 meters (Gulecal and Temel, 2013), is recognized as one of most contaminated drinking water reservoirs in Istanbul, being adversely affected by the discharge of domestic and industrial wastewater. Moreover, the lake is subject to additional contamination risks caused by the use of pesticides and artificial fertilizers in agricultural practices (Aydin and Talinli, 2013). These cumulative factors contribute to the deterioration of the water quality and ecological condition of the lake.

Notably, urbanization and the associated changes in the LULC patterns emerge as one of the significant drivers of the contamination problem observed in the Buyukcekmece Watershed.

According to Turer Baskaya and Tekeli (2016), the lake faces detrimental impacts due to non-integrated plans and rapid urban development, rendering it susceptible to contamination. The author claims that, although the Drinking Water Basin Regulation of ISKI provides some level of protection through the establishment of various protection zones based on proximity to the lake, there is still a lack of additional protection measures to address the ecological significance of the watershed while mitigating the adverse effects of urban development and pollution. The watershed area has witnessed significant LULC changes over the past few decades due to population growth and urban expansion (ISKI, 2019; Sertel et al. 2019). The transportation network herein plays a significant role in the expansion of the urban land and the transformation of LULC patterns. Three main arteries of Istanbul, namely the TEM, E-5, and Northern Marmara Motorway cut across the watershed area horizontally and cause pressure and disturbance on the watershed together with the newly constructed 3rd Bosphorus Bridge and nearby Istanbul Airport (Figure 4.6).

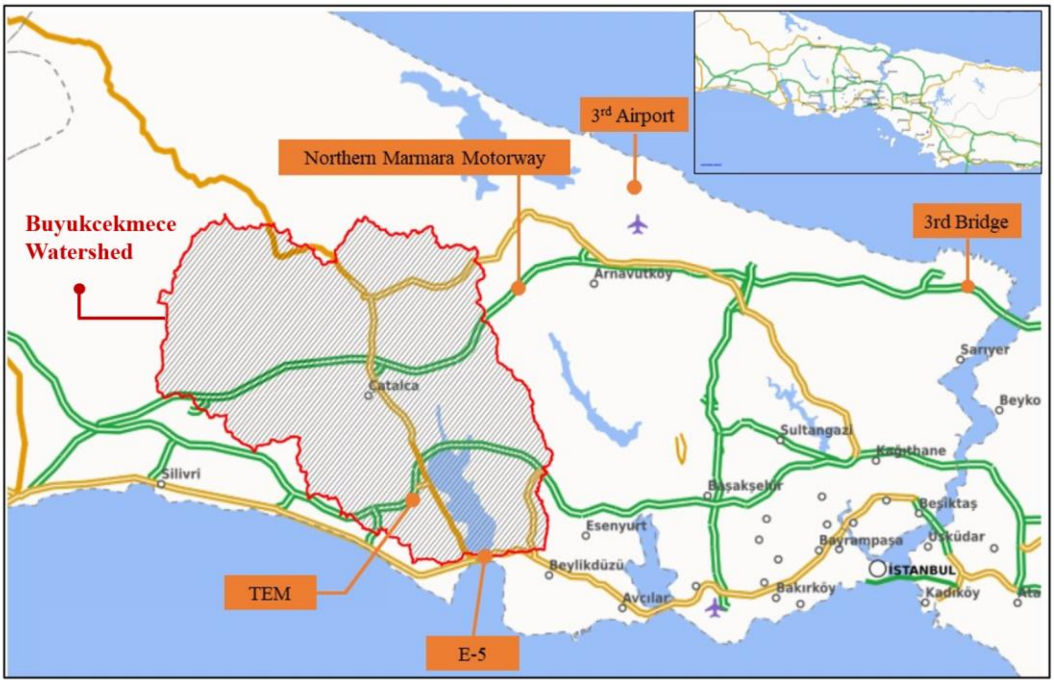


Figure 4.6 : Transportation networks in Buyukcekmece Watershed (Developed from Url-4).

The rationale behind choosing the Buyukcekmece Watershed as a case study area in this research is driven by the growing challenges it faces despite its ecological sensitivity and the vital role it plays as a significant drinking water reservoir located in a densely populated metropolitan area. Thus, the selection of the Buyukcekmece Watershed as a case study area presents a promising opportunity to investigate and evaluate the effects of urbanization-induced LULC change on urban SoES, due to the factors delineated below:

- The area is characterized by urban soil:

The research focuses on the interactions between LULC and SoES on urban soils. As Scheyer and Hipple (2005) stated, urban watersheds are one of the areas where urban soils can be found. The Buyukcekmece Watershed, therefore is considered as an appropriate choice for selection.

- It is located in a densely populated city:

The watershed is located in Istanbul, which is the most populated city in Turkey with 15, 907,951 inhabitants (TurkStat, 2022). Since the 1980s, the macroform of the city has been characterized by the expansion of built-up areas towards urban-rural fringes in the form of legal, illegal, and informal settlements, by putting profound pressure on Istanbul’s water reservoirs (Turer Baskaya, 2018), one of which is the Buyukcekmece Watershed.

- New urban development projects put considerable pressure on the watershed:

The pressure on the watershed has been triggered by the recent large-scale (mega) projects. Due to the completion of the 3rd Bosphorus Bridge (Yavuz Sultan Selim Bridge) in 2016 and the nearby airport (Istanbul Airport) in 2018, the Northern Marmara Motorway has become the third major highway that crosses across the watershed. Moreover, it is planned to implement the Canal Istanbul project on the European side of Istanbul, which involves the construction of an artificial waterway parallel to the Bosphorus, connecting the Black Sea to the Marmara Sea (Turer Baskaya, 2018). In addition to its environmental consequences, the Canal Istanbul project is expected to have substantial implications, specifically on the LULC dynamics within the Buyukcekmece Watershed, attributed to its proximity to the watershed and the transportation infrastructure associated with the project. Figure 4.7

illustrates the urban development trajectory of Istanbul and the proposed route of the Canal Istanbul project.

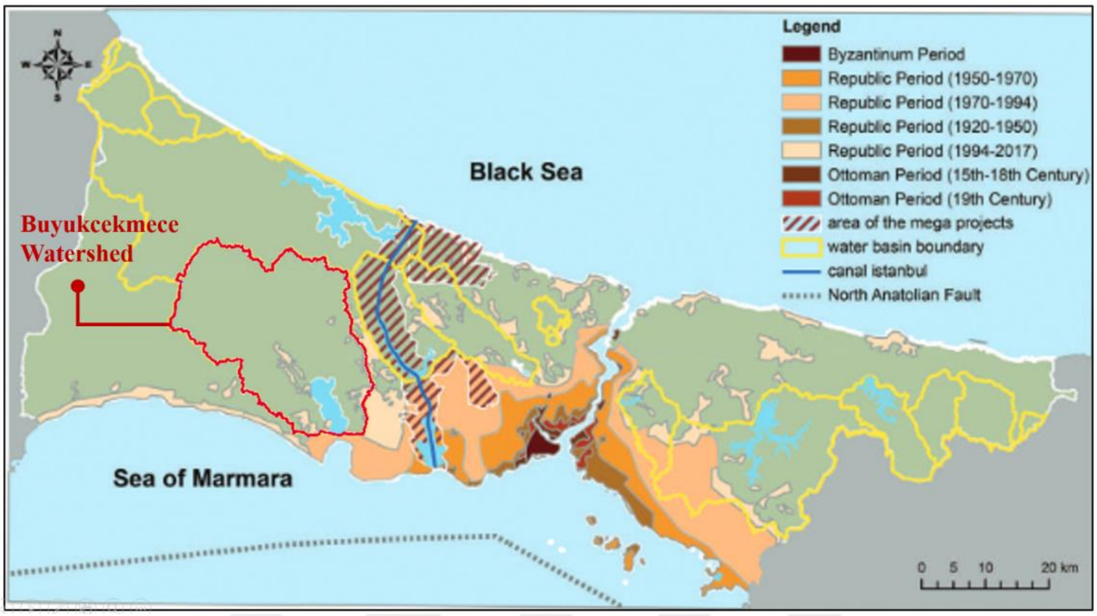


Figure 4.7 : The urban development process of Istanbul and the route of the proposed Canal Istanbul Project (Developed from Turer Baskaya, 2018).

- It stands as one of the largest and most significant drinking water sources in Istanbul:

The Buyukcekmece Watershed has a critical role as the third-largest drinking water reservoir in Istanbul, supplying approximately 17% of the city's water demand (Gulecal ve Temel, 2014). With the ongoing population growth in Istanbul, it is projected that there will be a proportional rise in daily water consumption (Cuceloglu et al., 2017).

- Its ecological status and importance:

Based on the criteria outlined in the Ramsar Convention, the Buyukcekmece Lake and its surrounding region have significant international value as a wetland ecosystem that provides a habitat for various bird species, including those at risk of extinction. Consequently, it serves as a critical environment for both local and migratory birds. Recognizing its importance, BirdLife International designated the watershed as an Important Bird Area (IBA) in 1989 due to its abundance of distinct and vulnerable waterfowl species. Furthermore, the area holds significance as a nature reserve within the Natura 2000 Network (ISKI, 2019).

- Critical environmental problems are observed in the watershed:

The lake within the Buyukcekmece Watershed has been subject to considerable pressure from rapid and unplanned urbanization since the 1980s, as highlighted by Coskun and Yalcin (2014). This urbanization, coupled with various activities such as livestock farming, industrial operations, and residential areas, poses a significant risk of contamination (Aykut et al, 2021; Aydin and Talinli, 2013). Currently, the lake and its watershed are classified as slightly polluted (2nd class), but there is a growing concern that they may move towards the third class, indicating a heightened risk of over-pollution and making the lake unsuitable as a future source of drinking water (Guyer and Ilhan, 2011).

Aydin and Talinli (2013) report the presence of uncontrolled wastewater discharges into the rivers and creeks within the Buyukcekmece Watershed. Among these water bodies, Ahlat and Beylikçayı Creeks exhibit the highest concentrations of pharmaceuticals, including antibiotics and caffeine. Furthermore, Gulecal and Temel (2014) note low phytoplankton diversity and elevated levels of chemical parameters in the Beylikcayiri Stream. Besides, the contamination of Cu, Ni, Cd, and Zn in the soils of the Buyukcekmece Watershed is closely associated with industrial establishments and residential areas according to the findings of Kurt and Aktan (2019).

The Buyukcekmece Watershed also faces significant challenges related to erosion and landslide risks, as highlighted by Martino et al. (2018) and Demirci and Karaburun (2012). The study by Demirci and Karaburun (2012) reveals that around 50% of the Buyukcekmece Lake watershed necessitates the implementation of efficient soil conservation strategies to address the risks associated with soil erosion. Particularly the eastern and western regions of the watershed, characterized by slope values exceeding 10%, exhibit notably elevated and severe risks of soil erosion.

The literature review and site survey findings indicate that the Buyukcekmece Watershed currently experiences significant pressure due to urbanization and anthropogenic activities, and the lack of necessary measures may jeopardize its potential to provide clean drinking water and sustain its ecological values. Therefore, it is crucial, first and foremost, to understand the dynamics of urbanization and LULC in the area, especially considering the spatio-temporal changes in the LULC pattern.

4.2 LULC Change Analysis

LULC change analysis is the first pillar of the implementation process and a fundamental step since it is used as input data for the subsequent (SoES change) analyses. The primary objective of this step is to elucidate the current state of the LULC pattern in Buyukcekmece Watershed and assess the changes and transformations within the specified time period.

In accordance with the information presented in the preceding section (Chapter 3.2: Datasets and Data Analysis), the CLC Dataset is used for LULC change analysis due to its widespread usage, established credibility, comparability, regular updates, and high level of accuracy. The CLC inventory was started in 1985 with reference to the year 1990, encompassing periodic updates every six years to establish a consistent and standardized dataset of LULC across Europe. Considering the availability of CLC data, the years 1990, 2000, 2006, 2012, and 2018 were selected to examine the changes in LULC and SoES within the Buyukcekmece Watershed.

The analyses conducted to assess the LULC changes in the Buyukcekmece Watershed case are summarized in the following three stages: (i) Data acquisition; (ii) Dataset building and pre-processing; (iii) Analysis and validation.

Data acquisition: The analytical process commences by acquiring the necessary data for further steps. For LULC change analysis, the CLC data is obtained from the official website of the Copernicus Land Monitoring Service. The website offers open access to LULC data covering 39 European countries, including Turkey. As shown in Table 4.1, the LULC data for the years 1990, 2000, 2006, 2012, and 2018 are currently available, by employing a minimum mapping unit of 25 ha for areal features and a minimum width of 100 meters for linear features (Url-2). The vector data in ESRI Geodatabase format is chosen to be acquired for the designated case study area.

Dataset building and pre-processing: Given that the downloaded dataset covers the LULC information for the entire of Europe, it is necessary to attain the required data of the study area from the overall dataset. In this context, the "Clip" tool within the ArcGIS environment is employed to extract the relevant LULC data specifically delineated by watershed boundaries. The obtained and prepared dataset for Buyukcekmece Watershed encompasses all the LULC classes present in the designated area in the selected time periods. The CLC database offers comprehensive information on LULC characteristics of the site organized into a hierarchical classification system comprising three levels. At the broadest level, Level 1, land cover is classified into five major categories: Artificial surfaces, agricultural areas, forests and semi-natural areas, wetlands, and water bodies. Level 2 provides further refinement and expansion of the land cover classes presenting several subcategories within each major category. The most detailed level, Level 3, encompasses a total of 44 distinct classes, providing a highly specific and detailed classification of land cover types within the CLC database. The CORINE nomenclature which provides a hierarchically categorized and standardized set of land cover classes and their corresponding codes is presented in Appendix B. The nomenclature is highly useful for understanding the coding equivalents of LULC data and interpreting the findings.

Table 4.1 : Technical specifications of the CLC dataset (Url-2).

	CLC1990	CLC2000	CLC2006	CLC2012	CLC2018
Satellite data	Landsat-5 MSS/TM single date	Landsat-7 ETM single date	SPOT-4/5 and IRS P6 LISS III dual date	IRS P6 LISS III and RapidEye dual date	Sentinel-2 and Landsat-8 for gap filling
Time consistency	6-1998	2000 +/- 1 year	2006+/- 1 year	2011-2012	2017-2018
Geometric accuracy, satellite data	≤ 50 m	≤ 25 m	≤ 25 m	≤ 25 m	≤ 10 m (Sentinel-2)
Min. mapping unit/width	5 ha / 100m	25 ha / 100m	25 ha / 100m	25 ha / 100m	25 ha / 100 m
Geometric accuracy, CLC	100 m	better than 100 m	better than 100 m	better than 100 m	better than 100 m
Production time	10 years	4 years	3 years	2 years	1.5 years
Access to the data (CLC, CHA)	unclear dissemination policy	dissemination policy agreed from the start	free access for all users	free access for all users	free access for all users
Number of countries involved	27	39	39	39	39

For the case study area, the available CLC data is used to quantify and map the LULC classes at each level. Hereby, the data is downloaded, clipped based on the watershed boundaries, classified based on the CLC nomenclature, and made ready for analysis.

Analysis and validation: In the initial stage, based on the CLC data obtained, a comprehensive LULC matrix is formulated, encompassing quantitative data on the area and percentage coverage of every LULC class in the Buyukcekmece Watershed (Table 4.2).

Table 4.2 : LULC matrix in Buyukcekmece Watershed (1990, 2000, 2006, 2012, 2018).

Level 1	Level 2	Level 3	Area (Ha)					Percentage (%)				
			1990	2000	2006	2012	2018	1990	2000	2006	2012	2018
1. Artificial surfaces	1.1. Urban fabric	1.1.1. Continuous urban fabric	1.84	1.84	1.84	123.91	123.91	0.003%	0.003%	0.003%	0.20%	0.20%
		1.1.2. Discontinuous urban fabric	1908.64	2428.67	1829.97	2346.87	2517.75	3.02%	3.85%	2.90%	3.72%	3.99%
	1.2. Industrial, commercial and transport units	1.2.1. Industrial or commercial units	58.35	446.33	841.14	990.41	1069.14	0.09%	0.71%	1.33%	1.57%	1.69%
		1.2.2. Road and rail networks and associated land	-	233.04	230.68	263.93	291.80	-	0.37%	0.37%	0.42%	0.46%
		1.2.3. Port areas	-	-	-	-	-	-	-	-	-	-
		1.2.4. Airports	-	77.94	25.67	25.71	25.71	-	0.12%	0.04%	0.04%	0.04%
	1.3. Mine, dump and construction sites	1.3.1. Mineral extraction sites	270.89	441.84	486.91	400.87	400.87	0.43%	0.70%	0.77%	0.63%	0.63%
		1.3.2. Dump sites	-	-	-	-	-					
		1.3.3. Construction sites	203.42	353.57	544.64	96.54	406.51	0.32%	0.56%	0.86%	0.15%	0.64%
	1.4. Artificial, non-agricultural vegetated areas	1.4.1. Green urban areas	-	-	-	-	-	-	-	-	-	-
		1.4.2. Sport and leisure facilities	-	-	-	-	-	-	-	-	-	-
2. Agricultural areas	2.1. Arable land	2.1.1. Non-irrigated arable land	39314.8	38375.37	35866.21	35763.16	35396.11	62.24%	60.76%	56.78%	56.62%	56.04%
		2.1.2. Permanently irrigated land	-	-	1303.02	1287.36	1287.36	-	-	2.06%	2.04%	2.04%
		2.1.3. Rice fields	-	-	-	-	-	-	-	-	-	-
	2.2. Permanent crops	2.2.1. Vineyards	-	-	-	-	-	-	-	-	-	-
		2.2.2. Fruit trees and berry plantations	-	-	31.76	31.76	31.76	-	-	0.05%	0.05%	0.05%
		2.2.3. Olive groves	-	-	-	-	-	-	-	-	-	-
	2.3. Pastures	2.3.1. Pastures	2001.26	1364.49	1778.27	1970.43	1811.05	3.17%	2.16%	2.82%	3.12%	2.87%
	2.4. Heterogeneous agricultural areas	2.4.1. Annual crops associated with permanent crops	-	-	-	-		-	-	-	-	-
		2.4.2. Complex cultivation patterns	1423.48	1322.04	2518.79	2506.56	2514.24	2.25%	2.09%	3.99%	3.97%	3.98%
		2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	2121.17	2200.86	2202.80	2137.27	2129.71	3.36%	3.48%	3.49%	3.38%	3.37%
		2.4.4. Agro-forestry areas	-	-	-	-	-	-	-	-	-	-
3. Forest and semi-natural areas	3.1. Forests-	3.1.1. Broad-leaved forest	8250.94	8247.39	9318.75	9670.88	9561.81	13.06%	13.06%	14.75%	15.31%	15.14%
		3.1.2. Coniferous forest	26.17	51.79	501.79	594.66	564.60	0.04%	0.08%	0.79%	0.94%	0.89%
		3.1.3. Mixed forest	858.87	1756.62	726.69	759.64	776.35	1.36%	2.78%	1.15%	1.20%	1.23%

Table 4.2 (continued) : LULC matrix in Buyukcekmece Watershed (1990, 2000, 2006, 2012, 2018).

	3.2. Scrub and/or herbaceous vegetation associations	3.2.1. Natural grasslands	450.44	450.44	471.82	307.36	307.36	0.71%	0.71%	0.75%	0.49%	0.49%
		3.2.2. Moors and heathland	-	-	-	-	-	-	-	-	-	-
		3.2.3. Sclerophyllous vegetation	-	-	-	-	-	-	-	-	-	-
		3.2.4. Transitional woodland-shrub	3824.46	2837.17	1899.79	1262.97	1372.04	6.05%	4.49%	3.01%	2.00%	2.17%
	3.3. Open spaces with little or no vegetation	3.3.1. Beaches, dunes, sands	-	-	-	-	-	-	-	-	-	-
		3.3.2. Bare rocks	-	-	-	-	-	-	-	-	-	-
		3.3.3. Sparsely vegetated areas	-	-	-	-	-	-	-	-	-	-
		3.3.4. Burnt areas	-	-	-	-	-	-	-	-	-	-
		3.3.5. Glaciers and perpetual snow	-	-	-	-	-	-	-	-	-	-
4. Wetlands	4.1. Inland wetlands	4.1.1. Inland marshes	-	-	-	-	-	-	-	-	-	-
		4.1.2. Peat bogs	-	-	-	-	-	-	-	-	-	-
	4.2. Maritime wetlands	4.2.1. Salt marshes	-	-	-	-	-	-	-	-	-	-
		4.2.2. Salines	-	-	-	-	-	-	-	-	-	-
		4.2.3. Intertidal flats	-	-	-	-	-	-	-	-	-	-
5. Water bodies	5.1. Inland waters	5.1.1. Watercourses	-	-	92.92	135.10	135.10	-	-	0.15%	0.21%	0.21%
		5.1.2. Water bodies	2447.72	2573.13	2489.07	2487.13	2439.35	3.88%	4.07%	3.94%	3.94%	3.86%
	5.2. Marine waters	5.2.1. Coastal lagoons	-	-	-	-	-	-	-	-	-	-
		5.2.2. Estuaries	-	-	-	-	-	-	-	-	-	-
		5.2.3. Sea and ocean	-	-	-	-	-	-	-	-	-	-
TOTAL			63162.5	63162.5	63162.5	63162.5	63162.5	100%	100%	100%	100%	100%

The matrix delineates the values associated with each LULC class identified in the watershed. In other words, the development process of LULC in the case study area is presented in the matrix for the years 1990, 2000, 2006, 2012, and 2018 by using the quantitative data obtained from the CLC dataset. The LULC data obtained from the CLC database is also used for mapping the spatial distribution of LULC in the watershed. The most recent data available, from 2018, reveals that agricultural lands dominate the watershed, encompassing approximately 68.35% of the total watershed area. Forest areas, predominantly situated in the northern region of the watershed, account for approximately 20% of the total area. Artificial surfaces, including urban and built-up areas, comprise approximately 7.66% of the watershed, while water bodies occupy approximately 4.05% of the total area (Figure 4.8).

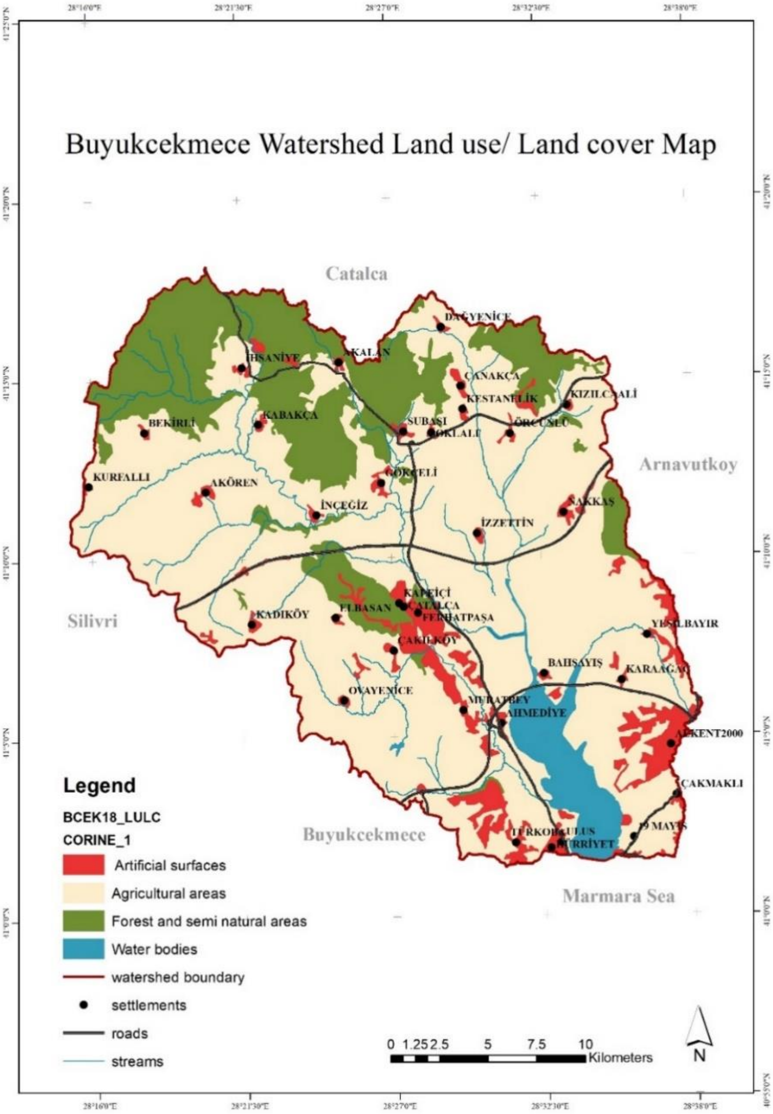


Figure 4.8 : LULC pattern in Buyukcekmece Watershed (2018).

In the assessment of the LULC pattern within the Buyukcekmece Watershed, mapping efforts do not only encompass the CLC-Level 1 categories, as illustrated in Figure 4.8 but also extend to the Level 2 and Level 3 to provide a more comprehensive understanding of the landscape composition in Buyukcekmece Watershed. Figure 4.9 provides the LULC map of the watershed at detailed levels based on the 2018 data. The Level-2 and Level-3 maps are generated also for the other study years, namely 1990, 2000, 2006, and 2012.

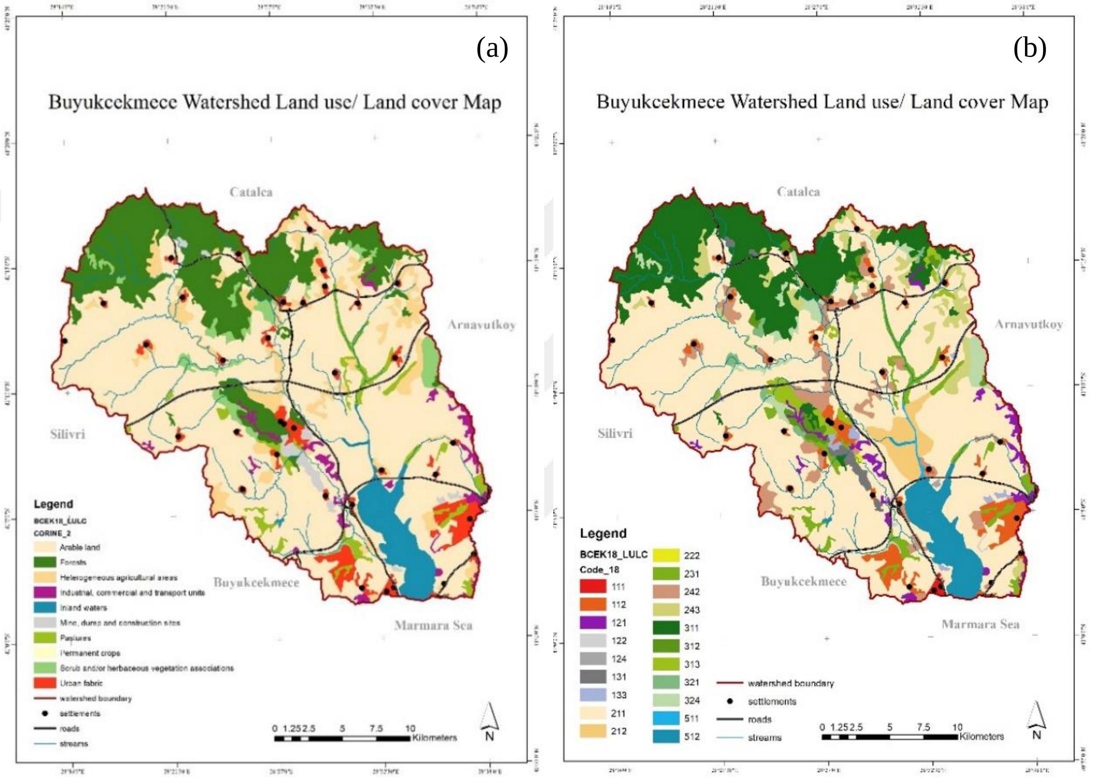
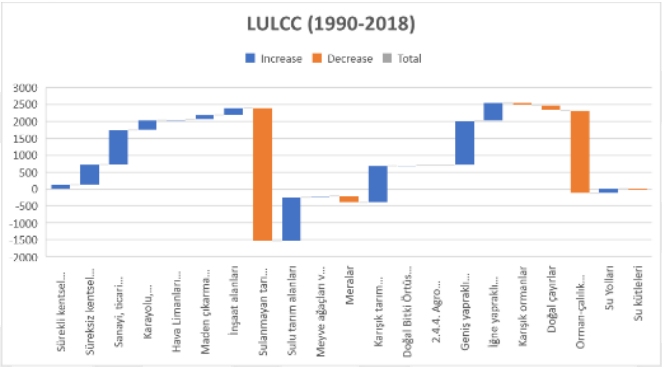


Figure 4.9 : LULC pattern in Buyukcekmece Watershed (2018) classified at (a) CLC Level-2 and (b) CLC Level-3.

Following the delineation and characterization of the LULC pattern within the designated case study area, the subsequent analysis focuses on detecting the changes in the LULC.

The initial analysis focused on the assessment of the present LULC pattern within the Buyukcekmece Watershed for each study period, without considering any comparative analysis. Subsequently, the following analysis progresses to a more in-depth examination of the changes occurring within each LULC class. This investigation of LULC change encompasses five distinct time periods: (1990-2000), (2000-2006), (2006-2012), (2012-2018), and (1990-2018) to understand the alterations in LULC pattern in Buyukcekmece Watershed.

In order to analyze the changes in LULC, the LULC matrix shown in Table 4.2 is used to calculate the differences in the area of each LULC class. By computing the discrepancies between the areas of corresponding classes, the magnitude and direction of change are determined for each specific land use category. The table which presents the spatial changes in land cover categories across the five different time periods is provided in Appendix C. The changes in LULC pattern are not only computed in terms of spatial extent but also described through graphical representation and the changes in LULC pattern between 1990-2018 are shown in Figure 4.10.



Areas decreased between 1990 -2018:

1. Non-irrigated arable land (3918ha)
2. Transitional woodland-shrub (2452ha)
3. Pastures (190ha)
4. Natural grasslands (143ha)
5. Mixed forest (82ha)

Areas increased between 1990 -2018:

1. Broad-leaved forest (1310ha)
2. Permenantly irrigated land (1287ha)
3. Complex cultivation patterns (1090ha)
4. Industrial or commercial units (1010ha)
5. Discontinious urban fabric (609ha)

Figure 4.10 : Changes in LULC in Buyukcekmece Watershed between 1990-2018.

The provided graphs facilitate a more comprehensive interpretation of the changes in LULC over the examined time intervals. Accordingly, during the specified time periods, certain LULC classes have shown a decrease, while others have exhibited an increase. These observed variations in the LULC structure of Buyukcekmece Watershed are analyzed and interpreted based on specific land use classes as follows:

Change in the urban fabric: The urban fabric in the area has experienced an increase of 731 ha between 1990 and 2018. Between 1990 and 2000, the increase occurred in the form of discontinuous urban fabric, while the continuous urban fabric remained stable. From 2000 to 2006, the continuous urban fabric maintained its stability, while a decrease was observed in the discontinuous urban fabric. This change is thought to be associated with the demolition work targeting unauthorized structures in the watershed area carried out by ISKI. Between 2006 and 2012, both categories witnessed an increase, while from 2012 to 2018, the continuous urban fabric remained stable, while the discontinuous urban fabric showed an increase. Consequently, the discontinuous urban fabric has exhibited continuous growth in the area, except between 2000 and 2006, while the continuous urban fabric remained stable, except between 2006 and 2012. Out of the total increase of 731 ha in the urban fabric, 609 ha have been developed in the form of discontinuous urban fabric. The greatest increase in both categories was observed between 2006 and 2012.

Change in industrial, commercial, and transportation units: The impermeable surface category, which encompasses these areas, has generally shown an increasing trend between 1990 and 2018. Out of the observed increase of 1328 ha in this category, a significant portion of 1010 ha has occurred in industrial and commercial areas. The industrial and commercial areas have exhibited continuous growth from 1990 to 2018, with a sudden increase observed between 1990 and 2000, while transportation connections have shown a continuous increase, except for a short decrease during the period of 2000-2006. The airport experienced an increase between 1990 and 2000, followed by a sudden decrease from 2000 to 2006. From 2006 to 2012 and 2012 to 2018, the airport remained stable, while the industrial and commercial areas continued to expand, including the construction of Catalca Wind Energy Power Plant, which was gradually commissioned in 2008 (phase 1) and in 2016 (phase 2) (Url-7).

Change in mine, dump, and construction sites: Mining extraction areas predominantly concentrated in the northern, northwestern, and western parts of the watershed, exhibiting an overall increasing trend in all years except for the period between 2006 and 2012. Mineral extraction sites experienced growth from 1990 to 2000 and 2000 to 2006, followed by a decline between 2006 and 2012, and subsequent stability from 2012 to 2018. Similarly, construction sites demonstrated a continuous expansion from 1990 to 2000 and 2000 to 2006, followed by a sudden decrease from 2006 to 2012 and a notable increase from 2012 to 2018. Analysis of satellite imagery suggests a linkage between these activities and ongoing construction projects, including new transportation infrastructure developments.

Change in arable land: The category of arable land represents the fundamental characterization of the study area, accounting for approximately 58-60% of the Buyukcekmece Watershed. However, a continuous decline in this category has been observed between 1990 and 2018. Non-irrigated arable land within this category emerges as the land cover type experiencing the highest loss among all LULC classes across the watershed. Particularly, a significant portion of the observed total decrease of 3912 ha, occurred in non-irrigated arable land (loss of 2509 ha) during the period from 2000 to 2006. In contrast, permanently irrigated arable land, which was absent before 2000 but showed an increase from 2000 to 2006, declined from 2006 to 2012 and remained stable from 2012 to 2018.

Change in permanent crops: The category of permanent crops primarily consists of fruit trees and berry plantations observed in the study area. This category, which was absent before 2000, experienced an increase from 2000 to 2006 and remained stable in all subsequent years (2006-2012-2018).

Change in pastures: Between 1990 and 2000, pastures experienced a decrease across the watershed, followed by an increase between 2000, 2006, and 2012. However, a subsequent decrease was observed between 2012 and 2018.

Change in complex cultivation patterns: These areas exhibited a decrease across the watershed between 1990 and 2000, followed by an increase between 2000 and 2006, and remained stable in subsequent years (2006-2012-2018). On the other hand, areas covered by natural vegetation experienced an increase between 1990 and 2000, followed by stability during the years 2000-2006-2012-2018.

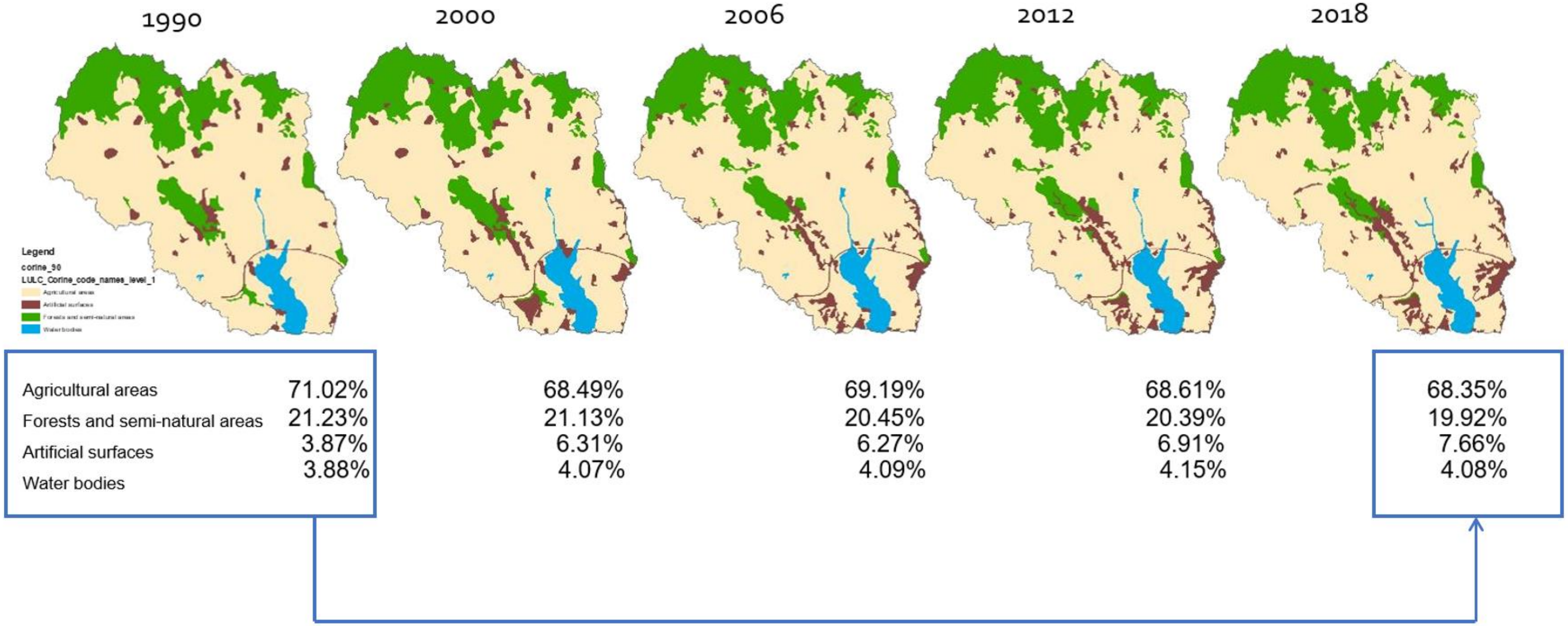
Change in forest areas: Broad-leaved forests remained stable between 1990 and 2000, experienced a significant increase during the 2000-2006 period, and continued to increase between 2006 and 2012, as well as between 2012 and 2018. Coniferous forests, on the other hand, increased between 1990 and 2000, followed by a similar sharp increase between 2000 and 2006. This increase is believed to be influenced by plantation activities conducted by ISKI. The area covered by coniferous forests decreased between 2012 and 2018. Mixed forests showed a sudden increase between 1990 and 2000, a sharp decrease between 2000 and 2006, and remained almost stable between 2006 and 2012 and 2018.

Change in natural grasslands: The natural grasslands remained stable between 1990 and 2000, experienced an increase between 2000 and 2006, and a decrease between 2006 and 2012. Additionally, transitional woodland scrub areas exhibited a continuous decrease throughout the study period from 1990 to 2018. Approximately 2452.4 ha of the total 2595.5 ha lost in natural areas belonged to this category.

Changes in water courses and water bodies: Throughout the years, the area covered by lakes and connecting water channels remained mostly stable. However, water courses showed an increase between 2000 and 2006 and between 2006 and 2012, but remained stable between 2012 and 2018.

The changes in the LULC pattern are mapped based on the CLC Level-1 categories as well to understand the transformations in the major land use classes (Figure 4.11). The findings reveal a decline in agricultural and forested areas, while a consistent increase in built-up areas is observed from 1990 to 2018. By considering the Level-1 category analysis, a comprehensive overview of the overall changes in the area enables a better understanding of the spatial patterns of LULC transformations.

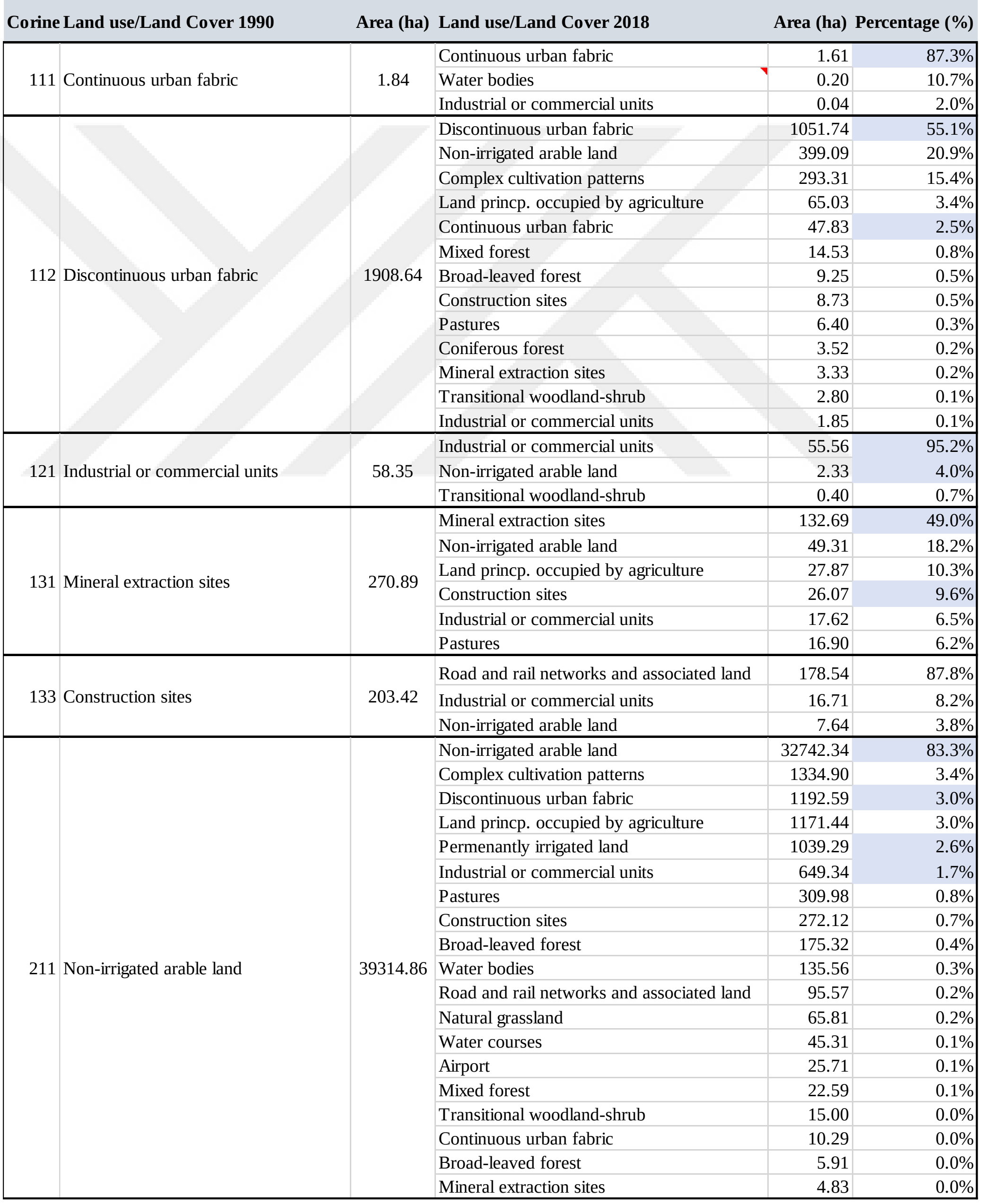
The final stage of the LULC analysis aims to examine the conversions between different land use categories. The phenomenon of LULC change encompasses the complex dynamics of land class transformations, whereby the interconversion of various land categories unfolds. While this process may exhibit positive implications for environmental sustainability on certain occasions, it predominantly entails adverse consequences. Examining the intricacies of LULC transformations is of paramount importance for understanding the consequences of land use decisions and interventions. The LULC transformations in Buyukcekmece Watershed are analyzed comprehensively by using Microsoft Excel and ArcGIS software tools. For this analysis, a pivot table illustrating the transformations between LULC classes is needed. By utilizing the "Intersect" function in ArcGIS, the LULC maps of the desired comparison years are processed and the intersecting areas of LULC classes are determined. In this context, the LULC transformations are assessed separately for each time period (1990-2000), (2000-2006), (2006-2012), (2012-2018), and (1990-2018). Yet, in order to obtain more distinct insights and better understand the long-term changes and transformation trends in the study area, particular emphasis is placed on the LULC transformations specifically between 1990 and 2018 (Figure 4.11). The following stages are executed with due consideration to this particular selection.



	1990	2000	2006	2012	2018
Agricultural areas	71.02%	68.49%	69.19%	68.61%	68.35%
Forests and semi-natural areas	21.23%	21.13%	20.45%	20.39%	19.92%
Artificial surfaces	3.87%	6.31%	6.27%	6.91%	7.66%
Water bodies	3.88%	4.07%	4.09%	4.15%	4.08%

Figure 4.11 : LULC changes in Buyukcekmece Watershed in study periods (CLC-Level 1).

Following the designation of intersecting land use classes, the areas of these newly identified parts are computed through the "Calculate Geometry" function of ArcGIS, and the generated information is transferred to Excel to create the pivot table. Based on the numerical data derived from the pivot table, a comprehensive analysis of LULC transformations is conducted, and the results are presented in tabular format. As one of these, Figure 4.12 demonstrates the LULC transformations in the Buyukcekmece Watershed between 1990 and 2018. The transformations in the time intervals of (1990-2000), (2000-2006), (2006-2012), and (2012-2018) are provided in Appendix D.



Corine	Land use/Land Cover 1990	Area (ha)	Land use/Land Cover 2018	Area (ha)	Percentage (%)
111	Continuous urban fabric	1.84	Continuous urban fabric	1.61	87.3%
			Water bodies	0.20	10.7%
			Industrial or commercial units	0.04	2.0%
112	Discontinuous urban fabric	1908.64	Discontinuous urban fabric	1051.74	55.1%
			Non-irrigated arable land	399.09	20.9%
			Complex cultivation patterns	293.31	15.4%
			Land princp. occupied by agriculture	65.03	3.4%
			Continuous urban fabric	47.83	2.5%
			Mixed forest	14.53	0.8%
			Broad-leaved forest	9.25	0.5%
			Construction sites	8.73	0.5%
			Pastures	6.40	0.3%
			Coniferous forest	3.52	0.2%
			Mineral extraction sites	3.33	0.2%
			Transitional woodland-shrub	2.80	0.1%
			Industrial or commercial units	1.85	0.1%
121	Industrial or commercial units	58.35	Industrial or commercial units	55.56	95.2%
			Non-irrigated arable land	2.33	4.0%
			Transitional woodland-shrub	0.40	0.7%
131	Mineral extraction sites	270.89	Mineral extraction sites	132.69	49.0%
			Non-irrigated arable land	49.31	18.2%
			Land princp. occupied by agriculture	27.87	10.3%
			Construction sites	26.07	9.6%
			Industrial or commercial units	17.62	6.5%
			Pastures	16.90	6.2%
133	Construction sites	203.42	Road and rail networks and associated land	178.54	87.8%
			Industrial or commercial units	16.71	8.2%
			Non-irrigated arable land	7.64	3.8%
211	Non-irrigated arable land	39314.86	Non-irrigated arable land	32742.34	83.3%
			Complex cultivation patterns	1334.90	3.4%
			Discontinuous urban fabric	1192.59	3.0%
			Land princp. occupied by agriculture	1171.44	3.0%
			Permenantly irrigated land	1039.29	2.6%
			Industrial or commercial units	649.34	1.7%
			Pastures	309.98	0.8%
			Construction sites	272.12	0.7%
			Broad-leaved forest	175.32	0.4%
			Water bodies	135.56	0.3%
			Road and rail networks and associated land	95.57	0.2%
			Natural grassland	65.81	0.2%
			Water courses	45.31	0.1%
			Airport	25.71	0.1%
			Mixed forest	22.59	0.1%
			Transitional woodland-shrub	15.00	0.0%
			Continuous urban fabric	10.29	0.0%
			Broad-leaved forest	5.91	0.0%
			Mineral extraction sites	4.83	0.0%

Figure 4.12 : LULC transformations in Buyukcekmece Watershed between 1990-2018.

231	Pastures	2001.26	Pastures	962.29	48.1%
			Non-irrigated arable land	388.79	19.4%
			Permenantly irrigated land	243.47	12.2%
			Mineral extraction sites	141.84	7.1%
			Complex cultivation patterns	113.65	5.7%
			Discontinuous urban fabric	84.05	4.2%
			Industrial or commercial units	36.96	1.8%
			Construction sites	24.24	1.2%
242	Complex cultivation patterns	1423.48	Complex cultivation patterns	561.45	39.4%
			Non-irrigated arable land	482.69	33.9%
			Discontinuous urban fabric	131.12	9.2%
			Industrial or commercial units	106.50	7.5%
			Continuous urban fabric	64.16	4.5%
			Mineral extraction sites	19.70	1.4%
			Road and rail networks and associated land	16.60	1.2%
			Mixed forest	14.76	1.0%
			Fruit trees and berry plantations	8.61	0.6%
243	Land princp. occupied by agriculture	2121.17	Non-irrigated arable land	859.87	40.5%
			Land princp. occupied by agriculture	729.74	34.4%
			Complex cultivation patterns	186.60	8.8%
			Transitional woodland-shrub	139.55	6.6%
			Broad-leaved forest	105.37	5.0%
			Natural grassland	61.47	2.9%
			Discontinuous urban fabric	29.46	1.4%
311	Broad-leaved forest	8250.94	Broad-leaved forest	7522.10	91.2%
			Transitional woodland-shrub	299.16	3.6%
			Non-irrigated arable land	172.09	2.1%
			Mixed forest	104.53	1.3%
			Coniferous forest	65.79	0.8%
			Land princp. occupied by agriculture	27.37	0.3%
			Mineral extraction sites	20.95	0.3%
			Natural grassland	16.92	0.2%
			Industrial or commercial units	12.57	0.2%
312	Coniferous forest	26.17	Coniferous forest	21.49	82.1%
			Transitional woodland-shrub	3.78	14.5%
313	Mixed forest	858.87	Broad-leaved forest	379.37	44.2%
			Mixed forest	251.51	29.3%
			Coniferous forest	92.98	10.8%
			Non-irrigated arable land	45.44	5.3%
			Industrial or commercial units	43.38	5.1%
			Transitional woodland-shrub	34.64	4.0%
321	Natural grassland	450.44	Pastures	200.54	44.5%
			Transitional woodland-shrub	176.96	39.3%
			Natural grassland	41.30	9.2%
			Non-irrigated arable land	21.70	4.8%
			Discontinuous urban fabric	6.90	1.5%
324	Transitional woodland-shrub	3824.46	Broad-leaved forest	1369.28	35.8%
			Transitional woodland-shrub	699.74	18.3%
			Coniferous forest	370.17	9.7%
			Mixed forest	363.37	9.5%
			Pastures	262.70	6.9%
			Non-irrigated arable land	191.22	5.0%
			Industrial or commercial units	148.38	3.9%
			Natural grassland	119.93	3.1%
			Land princp. occupied by agriculture	91.65	2.4%
			Mineral extraction sites	76.75	2.0%
			Construction sites	75.30	2.0%
512	Water bodies	2447.72	Water bodies	2295.24	93.8%
			Water courses	87.43	3.6%
			Pastures	46.94	1.9%

Figure 4.12 (continued) : LULC transformations in Buyukcekmece Watershed between 1990-2018.

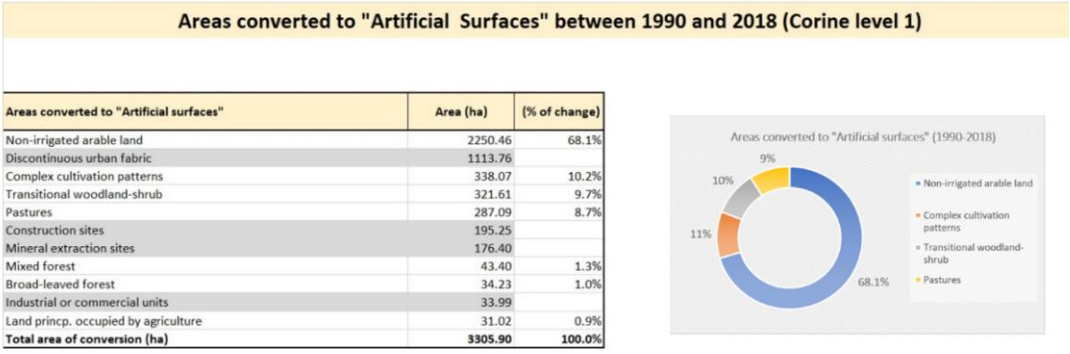
According to the findings, the urban fabric remains relatively stable, with approximately 97% of the continuous urban fabric and 95% of the industrial or commercial units remained unchanged. Around 20% of the discontinuous urban fabric transformed into non-irrigated arable land, while 2.5% transformed into continuous urban fabric. Mining extraction areas exhibit a 50% retention rate, with around 30% transitioning to agricultural areas and 10% transitioning to the continuous urban fabric.

Regarding construction areas, approximately 90% transition to the road, railway, and related areas, 8% transition to industrial and commercial units, and 4% transition to agricultural areas. The most fragmented transformations occur in non-irrigated agricultural areas, with 83% remaining unchanged. Of the remaining portion, 3% transformed to discontinuous urban fabric, 2% transformed to industrial-commercial units, 3.5% transformed to mixed agricultural areas, and 3% transformed to continuously irrigated agricultural areas.

Pastures experience a 48% retention rate, while 37% transition to agricultural areas (20% non-irrigated, 12% irrigated, and 6% mixed). Additionally, 7% of pastures transition to mining areas, and 4% transition to discontinuous urban fabric. Complex cultivation patterns retain 40% of their land cover, with 34% transitioning to non-irrigated agricultural areas and 27% transitioning to built-up areas. Areas covered with natural vegetation retain 35% of their land cover, with 49% transitioning to other agricultural areas (40% non-irrigated and 9% mixed) and 14% transitioning to forest areas.

Broadleaf forests exhibit a high retention rate of 91%, while coniferous forests retain 82% of their land cover and transition 14% to forest-scrub transition areas. Mixed forests retain 44% of their forest character, with 44% transitioning to broadleaf forests and 10% transitioning to coniferous forests. Furthermore, 5% transition to non-irrigated agriculture, and 5% transition to industrial-commercial units. Natural grassland areas transition 45% to pastures, 40% to forest-scrub transition areas, and 5% to agriculture. Forest-scrub transition areas transition 55% to forests (36% broadleaf, 10% coniferous, and 10% mixed forests), 7% to pastures, 7% to agriculture, and 8% to built-up areas. These transformations highlight the dynamic nature of land use changes within the study area and provide valuable insights into the long-term trends and patterns of land use transformations.

In addition to the detailed analysis conducted at CLC Level-3, the LULC transformations occurring between the years 1990 and 2018 are investigated also at CLC Level-1, with a specific emphasis on the conversion of natural areas into artificial surfaces. The trends of urbanization-driven LULC transformations over the specified time period are presented graphically in Figure 4.13 providing insights into the long-term trends observed in the watershed over the specified time period.



Areas converted to "Artificial Surfaces" between 1990 and 2018 (Corine level 1)

Areas converted to "Artificial surfaces"	Area (ha)	(% of change)
Non-irrigated arable land	2250.46	68.1%
Discontinuous urban fabric	1113.76	
Complex cultivation patterns	338.07	10.2%
Transitional woodland-shrub	321.61	9.7%
Pastures	287.09	8.7%
Construction sites	195.25	
Mineral extraction sites	176.40	
Mixed forest	43.40	1.3%
Broad-leaved forest	34.23	1.0%
Industrial or commercial units	33.99	
Land princp. occupied by agriculture	31.02	0.9%
Total area of conversion (ha)	**3305.90**	**100.0%**

Figure 4.13 : Areas converted to artificial surfaces in Buyukcekmece Watershed between 1990-2018 (CLC-Level 1).

In summary, between 1990 and 2018, the following trends were observed in Buyukcekmece Watershed:

- Continuous urban fabric and forests remain stable at a rate of over 90%.
- Construction areas predominantly transformed to road infrastructure, accounting for 90% of the transformations (with 8% transitioning to industrial-commercial units).
- The highest loss of land cover occurs in non-irrigated arable land, complex cultivation patterns, transitional woodland scrubs, and pastures, which collectively contribute to 88% of the transitions to built-up areas. This is followed by transitions from areas covered with natural vegetation to built-up areas.
- Pastures experience a significant transition to other agricultural areas, accounting for 37% of the changes (with 11% transitioning to built-up areas).
- Within the agricultural areas, there are various transformations, including transitions from non-irrigated to complex cultivation patterns, permanently irrigated areas, and areas covered with natural vegetation, as well as transitions from complex cultivation patterns to non-irrigated areas.
- Notably, non-irrigated arable lands experience the highest rate of conversion to built-up areas, accounting for 68% of the transformations.

- Road and airport constructions primarily occur on non-irrigated agricultural lands, with a high conversion rate of 95-100%.

Furthermore, pastures transformed into discontinuous urban fabric, mining areas, construction areas, industrial-commercial units, and agricultural areas (particularly mining and agriculture). Mixed and broadleaf forests experience losses to industrial-commercial units, mining areas, and agricultural areas. Forest-scrub transition areas also undergo transformations, which could be attributed to forest management activities such as clear-cutting.

On a positive note, there are afforestation efforts within the area, contributing to the preservation of forests. Transitions to pastures are observed in non-irrigated agricultural areas and forest-scrub transition areas. The conversion of certain mining areas to pastures and agricultural lands is significant for post-usage rehabilitation. Additionally, there are instances of discontinuous urban fabric transitioning to agricultural areas, often associated with the demolition of illegal structures.

This initial phase of the study, encompassing the LULC change analysis, has been accomplished through the procurement, pre-processing, and analysis of LULC data related to the study area. The obtained results reveal the patterns of LULC change and transformation in the Buyukcekmece Watershed within the defined study period. These findings will be further evaluated in the subsequent phase of SoES change analysis, and the interactions of LULC and SoES changes will be examined in the Buyukcekmece Watershed case.

4.3 Quantification of the Spatio-Temporal Changes in SoES Provision

The overall aim of the thesis is to investigate the impacts of LULC change on SoES specifically in urban areas. In the previous section, LULC changes and conversions in the Buyukcekmece Watershed were analyzed and a preliminary idea was obtained regarding the spatial dynamics of the watershed in the selected time period (1990, 2000, 2006, 2012, 2018). Following the in-depth analysis of LULC change, the spatio-temporal dynamics of SoES provision in Buyukcekmece Watershed are studied within the designated time period.

In the context of the Buyukcekmece Watershed case, as previously indicated, three SoES were selected for the assessment: Surface water flow regulation; Storage of soil organic carbon; and biomass production. Following the selection of SoES to be analyzed, a comprehensive research effort was undertaken to acquire a deep understanding of the functionality and characteristics of each SoES. This research phase also facilitated the identification of the most suitable datasets, analytical tools, and methodologies required for the analysis of SoES provision. A detailed explanation of the methodological design and data preparation procedures can be found in the preceding chapters (sub-chapters 3.1 and 3.2).

In this chapter, the analysis of the change in each selected SoES is presented under three sub-chapters namely; “4.3.1 Surface water flow regulation”; “ 4.3.2 Carbon storage”; and “4.3.3 Biomass production”. For each SoES, the analyses conducted to assess the changes in SoES provision in the Buyukcekmece Watershed case are summarized in the following three stages: (i) Data acquisition; (ii) Dataset building and pre-processing; (iii) Analysis and validation.

4.3.1 Surface water flow regulation

This analysis aims to examine the potential changes in the conversion of precipitation into surface runoff in the Buyukcekmece Watershed.

Soil and vegetation play a critical role in the circular movement of water (hydrological cycle) by capturing, storing, and releasing water (FAO and ITPS, 2015). As soil filters the water and contributes to the recharge of groundwater, a portion of the infiltrated water is retained by the soil. This water contains dissolved organic and inorganic substances and transports dissolved nutrients, making it available for use by plants through root uptake. Besides its role in plant growth, aquifer recharge, regulating soil temperature, and erosion control by binding soil particles together, soil water is also used by the soil biota which plays important roles, in organic matter decomposition, and the progression of global biogeochemical cycles such as N, P, K, and water (McCauley et al, 2005). Therefore, soil and water are inherently connected and soil water availability is critical for the overall health of the terrestrial ecosystems. The disruption of the connection between soil and water due to various reasons poses significant risks to the sustainability of ecosystems from a holistic perspective.

The interactions between soil and water are subject to numerous interventions, particularly due to urbanization-induced LULC changes. The expansion of built-up areas leads to a decrease or complete loss of the soil's ability to allow rainfall to infiltrate, known as soil sealing. This, in turn, contributes to an increase in surface runoff, leading to the occurrence of flooding and pollution problems (FAO and ITPS, 2015; Marcotullio et al., 2008). In drinking water catchments experiencing the impact of urban growth and related LULC change, the increasing impermeable surfaces prevent the infiltration of rainfall by the soil and facilitate the transport of surface pollutants to the drinking water reservoir through surface runoff, ultimately deteriorating water quality (Schwilch et al., 2016; Stolte et al., 2015).

In the context of the Buyukcekmece Watershed, a significant drinking water source for Istanbul, the soil's capacity to regulate surface water flow assumes a pivotal role. Beyond its ecological implications, this service serves a critical function in mitigating potential flood risks within the area and safeguarding the quality of the drinking water supply.

The movement of water on the Earth's surface (precipitation, interception, infiltration, surface runoff, storage, percolation, evaporation/transpiration, and condensation) is studied in detail through a range of hydrological models. These models are designed to produce outcomes that closely approximate real-world data, albeit contingent upon specific assumptions and hypotheses. The tools for comprehensive modeling of surface water and groundwater (e.g., SWAT, MIKE SHE) are often used for long-term hydrological and water quality assessments, including predicting the impact of land use changes, climate change, and land management practices on watershed behavior. They are frequently applied in large, complex watersheds and require detailed technical knowledge and expertise. Therefore, in predicting the changes in surface flow in the Buyukcekmece Watershed a simplified empirical method known as the USDA (United States Department of Agriculture) SCS-CN method has been employed. This method, developed in 1975, provides an empirical approach for calculating infiltration and surface flow in watersheds, especially where data from streamflow observation stations are unavailable.

The SCS-CN method provides a simplified approach that relies on the CN to estimate runoff from precipitation data, taking into account factors such as LULC, HSG, and rainfall data. The CN value is determined by considering various combinations of LULC and HSG. It serves as a parameter that characterizes the hydrological properties of the watershed with values spanning from 0 (lowest value) to 100 (highest value). Generally, lower CN values indicate areas with high infiltration rates and low potential for runoff generation (such as forests and well-drained soils), while higher values represent areas with low infiltration rates and high potential for runoff (such as urban areas and compacted soils).

According to the method, the equation used to calculate surface runoff is shown in equation 4.1 (USDA, 1986):

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{4.1}$$

where, Q runoff (mm); P rainfall (mm); S potential maximum retention after runoff starts(mm); and I_a initial abstraction (mm).

Previous studies have demonstrated that the initial abstraction is associated with soil and cover parameters, and it can generally be determined using the empirical equation in equation 4.2.

$$I_a = 0.2S \tag{4.2}$$

By eliminating Ia as a separate parameter, this approximation enables the utilization of a combination of S (potential maximum retention) and P (precipitation) parameters to calculate the runoff through equation 4.3.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{4.3}$$

The potential maximum rainfall retention (S) is influenced by the soil and cover characteristics of the watershed and can be estimated using the CN value, as depicted in equation 4.4.

$$S = \frac{2540}{CN} - 25.4 \tag{4.4}$$

To calculate the amount of runoff (Q) for a specific area using equation 4.3, two parameters need to be known: rainfall (P) and potential maximum rainfall retention (S). To achieve this, it is imperative to obtain rainfall data that are specific to the area of interest. Subsequently, the S value can be computed by employing Equation 4.4, which uses the CN. This method underscores the necessity of commencing the analysis by calculating CN values tailored to the unique characteristics of the Buyukcekmece Watershed.

The CN value can be determined by referring to the "Runoff curve numbers" table provided by the SCS-CN method, which is separately prepared for urban areas, cultivated agricultural areas, and dry/semi-arid areas (USDA, 1986). The table assigns a specific CN value to each land class based on its combination with the HSG. However, two concerns have been identified regarding the utilization of this table within the scope of the research. The first issue is that the LULC classes determined by the SCS-CN method do not match the LULC classes in the CLC database used for the LULC change analysis of the Buyukcekmece Watershed. The second problem is the absence of HSG data specific to the watershed. Therefore, during the data preparation stage, it is necessary to first complete these two preliminary studies.

The approach followed to calculate the change in the total runoff amount in the Buyukcekmece Watershed in the years 1990, 2000, 2006, 2012, and 2018, is summarized under three stages: Data acquisition; Dataset building and pre-processing, and; Analysis and validation.

Data acquisition: The essential data required for this analysis comprises LULC, soil type (hydrologic soil groups), and rainfall data. The LULC data for the years 1990, 2000, 2006, 2012, and 2018 is obtained from the CLC database. The soil map is acquired from the 1:25,000 scaled National Soil Database, which is produced by the Ministry of Agriculture and Forestry (MoAF). Furthermore, the rainfall data, including monthly and daily total precipitation, is obtained from the State Meteorological Institute (MGM) covering the period from 1985 to 2018. Additionally, for validation purposes, real-time ground data from flow gauging stations (AGI) is obtained from the DSI.

Dataset building and pre-processing: To compute runoff values in the analysis, it is imperative to ascertain the CN values which depend on the LULC and HSG data. Given that the land classes in the SCS-CN method do not align with those in the CLC database the table developed by Guidice et al. (2012) was employed to establish the appropriate correspondences between these land classes (Table 4.3).

Table 4.3 : The CLC classes corresponding to the LULC classes in the SCS-CN table.

CLC CODE*	CORINE LAND COVER CLASSES (Level 3)	S.C.S LAND USE DESCRIPTION	CN FOR SOIL GROUP (SCS)			
			A	B	C	D
111	Continuous urban fabric	Urban districts (commercial and business)	89	92	94	95
112	Discontinuous urban fabric	Residential districts by average lot size (1/8 acre or less)	77	85	90	92
121	Industrial or commercial units	Industrial districts	81	88	91	93
122	Road and rail networks and associated land	Paved streets and roads; curbs and storm drains	98	98	98	98
124	Airports	Residential districts by average lot size (1/8 acre or less)	77	85	90	92
131	Mineral extraction sites	Herbaceous mixture of grass, weeds and low-growing brush (poor HC)	_	80	87	93
133	Construction sites	Developing urban areas	77	86	91	94
141	Green urban areas	Open space (poor HC)	68	79	86	89
142	Sport and leisure facilities	Open space (fair HC)	49	69	79	84
211	Non-irrigated arable land	Small grain	61	73	81	84
212	Permanently irrigated land	Close-seeded legumes or rotational meadows	60	72	81	84
222	Fruit trees and berry plantations	Woods-grass combination	43	65	76	82
231	Pastures	Herbaceous mixture of grass, weeds and low-growing brush (good HC)	_	62	74	85
242	Complex cultivation patterns	Close-seeded legumes or rotational meadows	60	72	81	84
243	Land principally occupied by agriculture with significant areas of natural vegetation.	Woods-grass combination	43	65	76	82
311	Broad-leaved forest	Woods	36	60	73	79
312	Coniferous forest	Woods	36	60	73	79
313	Mixed forest	Brush-brush-weed-grass mixture	35	56	70	77
321	Natural grasslands	Open space (good HC)	39	61	74	80
324	Transitional woodland-shrub	Sagebrush with grass understory (fair HC)	_	51	63	70
333	Sparsely vegetated areas	Saltbush, greasewood, creosote-bush,blackbrush, bursage, palo verde, cactus	55	72	81	86

Another important step in the data preparation process involves establishing HSG specific to the Buyukcekmece Watershed. HSG is a classification system that categorizes soils based on their hydrological characteristics, particularly their water infiltration capacities. The HSG system categorizes soils into four primary groups denoted as A, B, C, and D. These classifications are determined by various factors including soil texture, permeability, and depth. Group A comprises soils with high infiltration rates, Group B includes soils with moderate infiltration rates, Group C consists of soils with low infiltration rates, and Group D represents soils with very low infiltration rates (USDA, 1986). The soil map retrieved from the national soil database for the Buyukcekmece Watershed did not contain HSG. Consequently, it was intended to identify hydrological groups by collecting soil samples from the field and conducting laboratory investigations to assess their texture and infiltration rates. However, due to some administrative and technical constraints, the fieldwork could not be executed as intended. As an alternative approach, prior research on the subject was thoroughly examined, and the method used by Özer (1990) and Alturk (2017) for HSG determination was incorporated into the study. In these studies, HSG is determined based on the combination of major soil groups, soil properties, and land use capabilities within the national soil database. The relationship between infiltration rates (mm/hr), major soil groups, subcategories of land use capability, and soil properties are utilized to determine HSG, as presented in Appendix E.

Following the comprehensive analysis, the HSG map of the Buyukcekmece Watershed has been generated (Figure 4.14). According to the map, B group soils cover an area of 26.7%, C group soils cover 24.5%, and D group soils have a distribution of 48.6%. A-group soils were not identified in the area. After the matching of LULC classes and the preparation of HSG maps, the analysis stage was initiated to determine the CN values.

Analysis and validation: The overall aim of this analysis is to calculate the changes in runoff quantity in the Buyukcekmece Watershed for each study year (1990, 2000, 2006, 2012, 2018) by evaluating the associated changes in CN values. The analysis stage consists of four main steps: (i) Determination of CN values in the Watershed; (ii) Acquisition and preparation of rainfall data; (iii) Calculation of surface runoff (for each study year); (iv) Comparison of the outputs with actual measurement data (validation).

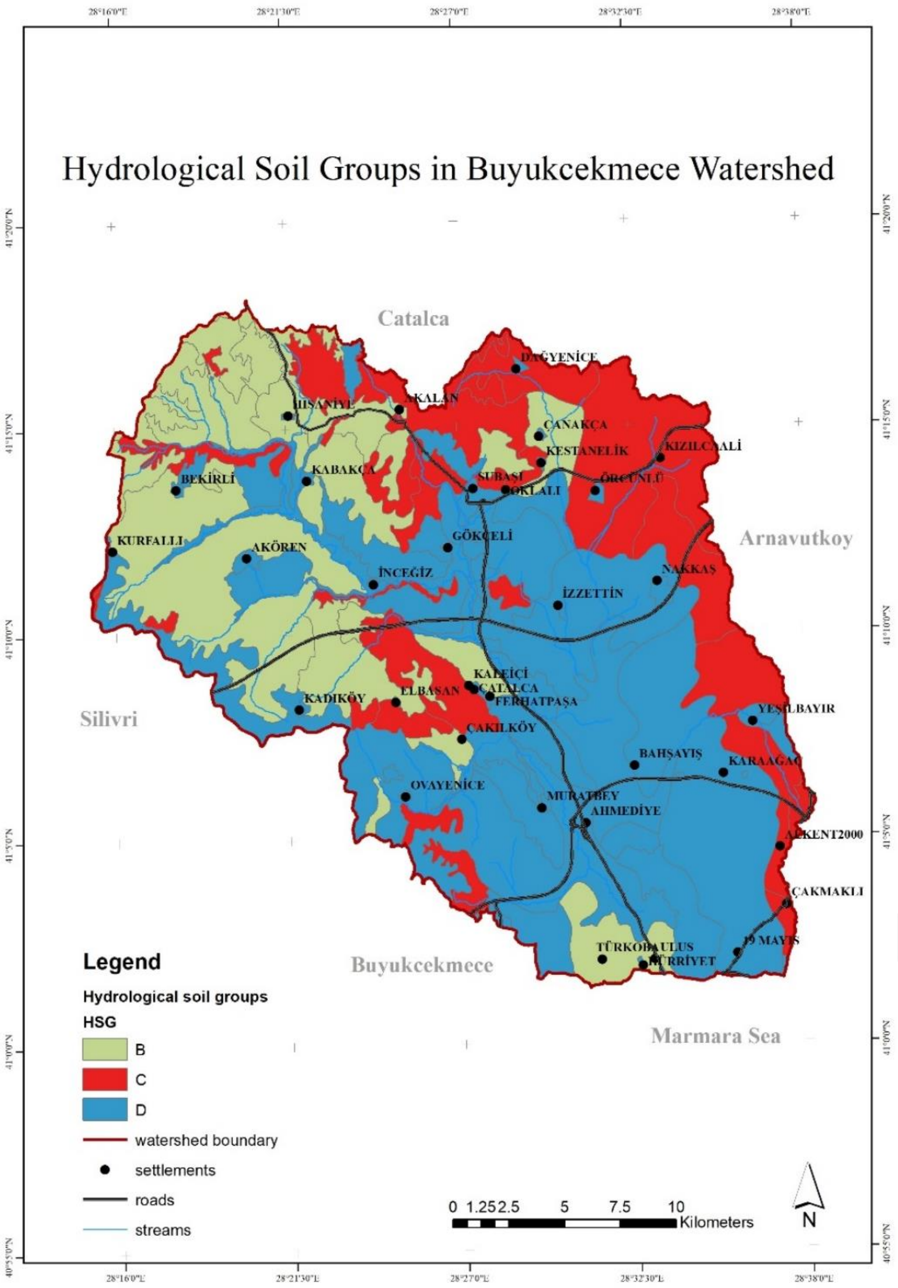


Figure 4.14 : HSG in Buyukcekmece Watershed.

In the first step of determining the CN values, the guidelines provided in Table 4.3 were followed, and the LULC data for the Watershed was matched with the corresponding HSG data for the same period by using the Microsoft Excel program. An example is presented to provide a clear understanding of this step:

If an area belongs to the land cover class "continuous urban fabric" with a CLC code of 111, and it corresponds to HSG group C on the HSG map, the CN value for this combination would be 94 according to Table 4.3. This matching process was repeated for each land cover class, and CN maps for the entire study years were prepared for the Watershed.

After the generation of CN maps, considering the validation process that involves comparing the calculated runoff values with the observed ground data, the Buyukcekmece Watershed has been divided into sub-catchments. These sub-catchments were created based on the drainage areas of AGI obtained from DSI, which measure streamflow within the Watershed. This division allows for the comparison of CN and runoff values calculated in the sub-catchments with the measured runoff values from the AGI stations on a spatial basis.

To achieve this, the drainage areas of the AGI stations in the watershed were calculated and mapped using the ArcGIS environment. Then, the obtained AGI drainage area maps were overlapped with the CN maps prepared for the Buyukcekmece Watershed in the previous step, resulting in the delineation of new sub-catchments (referred to as CA-1, CA-2, CA-3, CA-4, and CA-5) as shown in Figure 4.15.

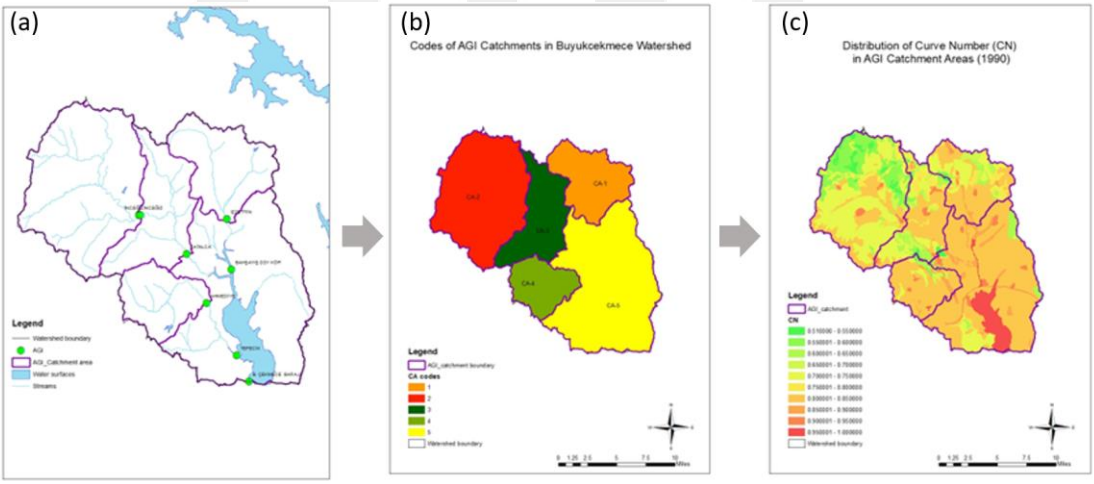


Figure 4.15 : (a) AGI drainage catchments (b) Codes of sun-catchments (c) Integrated map of CN and sub-catchment boundaries.

To calculate the CN-weighted average values for the sub-catchments, equation 4.5 has been used. This equation facilitates the computation of the average CN values by considering the CN values for each LULC class within the sub-catchment, weighted by their respective areas. The equation is as follows:

$$CN_w = \frac{\sum_i^N (CN_i * A_i)}{A_T} \tag{4.5}$$

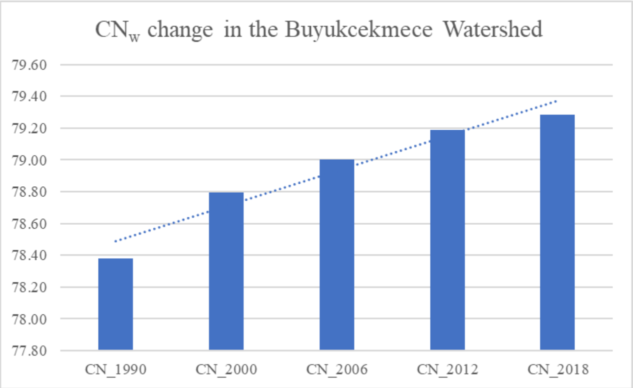
where, CN_w weighted curve number; CN_icurve number from 1to any number n; $A_i$area with curve number; and A_T total area of the watershed.

The CN values for the sub-catchments are shown in Table 4.4. According to the table, the sub-catchment CA-2 has the lowest CN value (71.4) for the year 1990, while the sub-catchment CA-5 has the highest CN value (85.3) for the year 2018. These CN values represent the hydrological characteristics of the respective sub-catchments, indicating their potential for runoff generation.

Table 4.4 : CN_w change in the sub-catchments of Buyukcekmece Watershed.

	Area (km^2)	1990	2000	2006	2012	2018
CA 1	81.26	77.42	77.73	77.92	77.99	77.99
CA 2	178.20	71.40	71.52	71.58	71.81	71.83
CA 3	84.41	76.14	76.49	76.73	77.09	77.20
CA 4	54.89	81.69	82.29	82.81	83.04	83.08
CA 5	229.71	84.17	84.82	85.07	85.19	85.39
Total watershed area	628.46					

The weighted average CN values obtained from the sub-catchments have been used to calculate the average CN value for the entire Buyukcekmece Watershed, following equation 4.5. It has been observed that the average CN value of the watershed shows a continuous increase from 1990 to 2018. This increase indicates an increasing potential for surface runoff generation in the watershed during the selected study years. From the SoES perspective, it can be inferred that the soil's capacity for regulating surface water in the Buyukcekmece Watershed has shown a decreasing trend over the study years. The change in the average CN value of the watershed between the study years is presented in Figure 4.16.



CN_w change in the Buyukcekmece Watershed	
CN_1990	78.38
CN_2000	78.79
CN_2006	79.00
CN_2012	79.19
CN_2018	79.29

Figure 4.16 : CN_w change in Buyukcekmece Waterhed.

In brief, as it was mentioned at the beginning of the analysis stage, two parameters needed to be known (according to Equation 4.3) to calculate the runoff in the area. The first parameter is the potential maximum rainfall retention (S), which can be calculated based on the CN values (according to Equation 4.4). The CN values determined for the sub-catchments and the entire Buyukcekmece Watershed can be used to calculate the S value of the watershed using this equation. Another parameter that needs to be known according to the equation is the rainfall data specific to the watershed. These rainfall data, along with the S value, determine the percentage of rainfall that turns into surface runoff in the watershed and enable the calculation of the runoff amount.

For the analysis of long-term rainfall data, daily rainfall data from all meteorological stations located in the European side of Istanbul were requested from the MGM for the period 1985-2018. To calculate the spatial distribution of rainfall more accurately, it was planned to determine the catchment areas of the measurement stations using the Thiessen Polygon method. However, it was observed that out of the 21 measurement stations provided by MGM, only three stations had complete data records covering the study period (1985-2018). Since the stations with missing data cannot be used in the study, the data from the three stations with complete records (170059-Sariyer/ Kumkoy/ Kilyos, 170061-Sariyer, and 17636-Florya) were included in the study. However, due to the low number of stations and their distant locations from the watershed, the Thiessen method could not provide sufficient and accurate information about the catchment areas of the measurement stations. Therefore, for the calculation of annual rainfall values in the area, the arithmetic mean of the measurement values from these three stations was used.

In calculating the total rainfall values (P) for the Buyukcekmece Watershed in the years 1990, 2000, 2006, 2012, and 2018, the "hydrological year" interval covering the measurements from 1 October to 30 September was considered. This time interval is also used in AGI measurements to calculate the annual total flow volume. Thus, the runoff values calculated using this rainfall data can be compared with the AGI measurement results during the validation stage. The total rainfall amount for each study period in the watershed is shown in Table 4.5.

In the first two steps of the application phase, the two parameters required to calculate the runoff amount according to equation 4.3, namely potential maximum rainfall retention (S) and rainfall (P), were obtained. In the third step of the application, the obtained values were substituted into the relevant equation to calculate the total runoff amount (Q). Using the relevant parameters, the total runoff values for both the sub-catchments and Buyukcekmece Watershed were calculated as shown in Table 4.6.

Table 4.5 : Total annual rainfall (mm) in 1990, 2000, 2006, 2012, and 2018 hydrological years*.

Code-Station	**1990**	**2000**	**2006**	**2012**	**2018**
17059-Sariyer/Kumkoy/Kilyos	607.9	875.2	963.5	705.1	902.5
17061-Sariyer	777	941	1053.1	846.4	979.9
17636-Florya	525.1	768.9	554.2	667.3	780.4
TOTAL RAINFALL (mm)	636.7	861.7	856.9	739.6	887.6

*(Between 1 October- 30 September)

Table 4.6 : Total runoff (mm/y) in the sub-catchments and Buyukcekmece Watershed.

Sub-catchments	**1990**	**2000**	**2006**	**2012**	**2018**
CA-1	277.84	390.07	388.11	330.01	403.51
CA-2	264.51	375.58	373.39	632.07	389.16
CA-3	275.10	387.31	385.48	328.08	401.76
CA-4	286.54	399.70	398.38	340.40	414.20
CA-5	291.36	404.73	402.82	344.56	418.75
TOTAL RUNOFF (mm/y)	1395.34	1957.39	1948.18	1975.12	2027.37

When examining the changes in surface runoff amount over the years, it is observed that except for the period between 2000 and 2006, the surface runoff has consistently increased in the entire watershed from 1990 to 2018 (Figure 4.17).

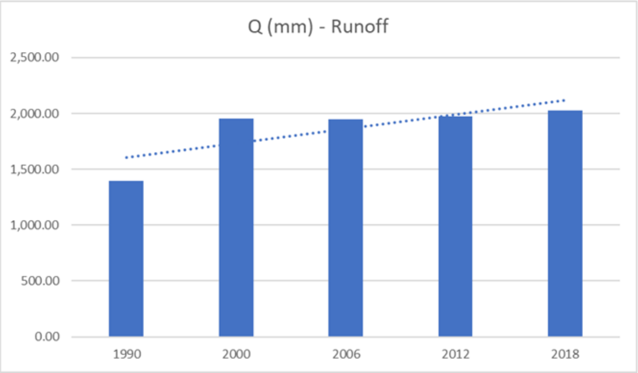


Figure 4.17 : Total surface runoff change in Buyukcekmece Watershed.

According to the methodology used, two key factors that influence the amount of surface runoff are CN and rainfall data. As shown in Figure 4.16, the CN in the Buyukcekmece Watershed has shown a continuous increase throughout the study periods. In order to understand the reason for the decrease in runoff amount between 2000 and 2006, a cumulative deviation graph of annual average rainfall was created using long-term annual average rainfall data to identify wet and dry periods (Figure 4.18).

According to the graph, it was determined that the region where the Buyukcekmece Watershed is located experienced a dry period in 2006. This finding explains why the Q (runoff) value decreased during this specific time interval despite the continuous increase in CN values in the watershed from 1990 to 2019.

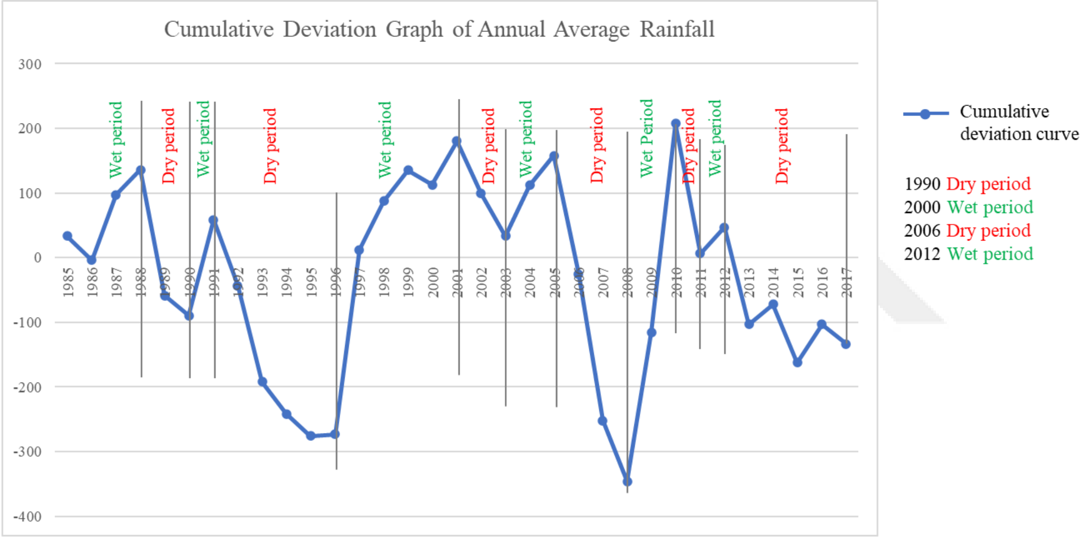


Figure 4.18 : Cumulative deviation graph of annual average rainfall.

When examining the long-term data, it was found that, on average, 48% of the rainfall in the watershed is converted to surface runoff. The variation of this value over the years has been analyzed, and it has been determined that the proportion of water that flows as runoff in all sub-catchments has shown a continuous increase between 1990 and 2018 (Table 4.7).

In the final step of the analysis, the computed runoff values for the sub-catchments, as previously given in Table 4.6, were multiplied by the respective surface areas of the catchments to calculate the annual total flow volume (m^3/year). Then, after making the necessary unit conversions, the annual total surface runoff amounts (million m^3/year, MCM) generated in the sub-catchments were determined. According to the average of the total runoff amounts generated by the sub-catchments for each year, the annual water flow produced in the Buyukcekmece Watershed is calculated as 158.2 MCM (Table 4.8).

Table 4.7 : Percentage of runoff to annual precipitation in the sub-catchments and Buyukcekmece Watershed.

Sub-catchments	**1990**	**2000**	**2006**	**2012**	**2018**
CA-1	43.64	45.27	45.29	44.62	45.46
CA-2	41.55	43.59	43.57	85.46	43.84
CA-3	43.21	44.95	44.98	44.36	45.26
CA-4	45.01	46.38	46.49	46.02	46.67
CA-5	45.76	46.97	47.01	46.59	47.18
AVERAGE (%)	43.83	45.43	45.47	53.41	54.82

Table 4.8 : Total runoff in (MCM) in the sub-catchments and Buyukcekmece Watershed.

Sub-catchments	**1990**	**2000**	**2006**	**2012**	**2018**
CA-1	15.05	21.13	21.02	17.88	21.86
CA-2	31.42	44.62	44.36	75.09	46.23
CA-3	15.48	21.79	21.69	18.46	22.61
CA-4	10.49	14.63	14.58	12.46	15.16
CA-5	44.62	61.98	61.69	52.77	64.13
AVERAGE (MCM)	**117.06**	**164.15**	**163.34**	**176.65**	**169.98**
WATERSHED AVE. (MCM)			**158.24**		

The obtained value has been compared with the results of the previous studies conducted in the Buyukcekmece Watershed. It has been observed that the total surface runoff value generated in the watershed using the SCS-CN method falls within the determined reference range (Figure 4.19).

Additionally, the total runoff amounts generated by the AGI obtained from DSI were compared with the results obtained from the analysis in terms of sub-basins (Table 4.9). Although the results at the sub-basin level did not show a significant similarity, considering the discrepancies that may arise from deviations and assumptions in hydrological modeling studies, it can be said that the results generated within the scope of the study are within the validity range, as indicated in Figure 4.19. The comparison of research findings with the results obtained from conducted studies provides consistent data related to the watershed.

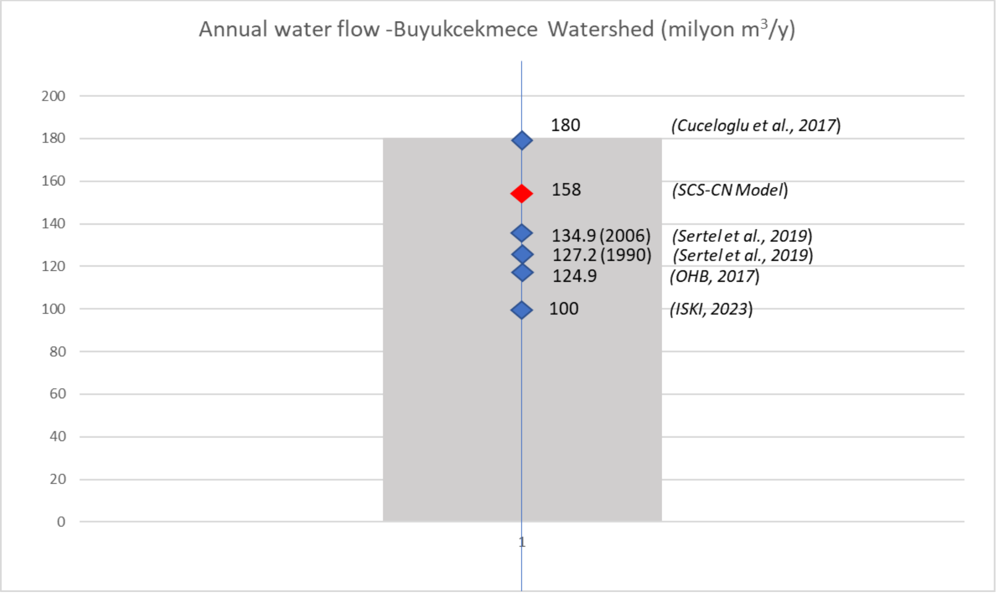


Figure 4.19 : Annual total water flow in Buyukcekmece Watershed in comparison with related literature findings.

4.3.2 Carbon storage

The second SoES chosen for this research is the carbon storage service provided by soil. As extensively discussed in Chapter 2.3.2, soil represents the second-largest carbon reservoir on the planet, following the oceans, and plays a critical role both in the global carbon cycle and climate change (Pereira et al., 2017).

The process of capturing carbon dioxide from the atmospheric environment (carbon sequestration) and storing it in the soil in both organic and inorganic forms (carbon storage) is highly significant for mitigating climate change by lowering GHG emissions. This overlooked importance of soil in climate change mitigation has been emphasized in recent global-scale studies (IPCC, 2019; IPBES, 2018; EPA, 2017).

The carbon storage service provided by soil is not only crucial for maintaining climate balance but also for soil health. SOC, a fundamental indicator of soil fertility, enhances water-holding capacity, strengthens soil structure, and increases resilience against extreme weather events (e.g., droughts) and erosion, particularly in topsoil. Moreover, SOC plays a vital role in soil biodiversity, microbial activities, nutrient availability, plant growth, agricultural productivity, and global biogeochemical cycles (FAO, 1995).

Table 4.9 : Annual total water flow in Buyukcekmece Watershed in comparison with AGI data.

Data				**Stream Flow Monitoring Yearbooks DSI (1990-2015) - EIE (1935-2011)**				**SCS-CN Method Results**				
Sub-catchments	Gauge station (AGI)	Stream	Area (km^2)	Annual (hydrological) Total Streamflow (MCM)				Annual (hydrological) Total Streamflow (MCM)				
				1990	2000	2006	2012	1990	2000	2006	2012	2018
CA-1	Izzettin	Sarısu (Hamza)	81	nd	21.07	45.74	26.27	15.05	21.13	21.02	17.88	21.86
CA-2	Incegiz	Karasu	178	5.88	26.42	77.67	nd	31.42	44.62	44.36	37.54	46.23
CA-3	Catalca	Karasu	84	6.84	37.9	116	nd	15.48	21.79	21.69	18.46	22.61
CA-4	Ahmediye	Cakil (Tahtakopru)	54	nd	7.05	18.43	9.57	10.49	14.63	14.58	12.46	15.16
CA-5	Buyukcekmece Dam	Gol Gozlem	628									

*nd: do data

The carbon storage service provided by soil has been selected as one of the SoES to be examined in the context of the Buyukcekmece Watershed, given its fundamental importance for soil health and the provisioning of other SoES, as well as its critical role in the context of climate change. Particularly in cities where GHG emissions make a critical contribution, supporting and enhancing the carbon sequestration capacity of urban soil can play a crucial role in combating climate change.

For the calculation and mapping of carbon storage in the watershed, the InVEST software developed within the Natural Capital Project framework has been employed. This open-source tool provides modules for the measurement and mapping of ES. One of the modules provided by the software is the "Carbon Storage and Sequestration" model, which focuses on estimating the amount of carbon stored in terrestrial ecosystems. In doing so, it takes into account the carbon stored in four different carbon pools: aboveground living biomass, belowground living biomass, soil (SOC), and dead organic matter and aggregates their respective biophysical quantities (Url-3).

The analysis process related to the calculation and assessment of soil carbon storage and its changes in the Buyukcekmece Watershed for the designated study years (1990, 2000, 2006, 2012, 2018) is summarized below in three stages: Data acquisition; Dataset building, and pre-processing, and; Analysis and validation.

Data acquisition: The InVEST Carbon Storage and Sequestration model requires two input datasets for estimating the carbon storage in a specific area. The first requirement is the LULC map specific to the study area. In the case of Buyukcekmece Watershed, this data has been obtained from the CLC-LULC dataset with a spatial resolution of 25 ha/100 m, as done in previous analyses. Another necessary dataset for the analysis is the biophysical carbon stocks held by each land class. The ideal method for obtaining this data is through fieldwork, including soil sampling from the area and laboratory analysis. However, due to certain administrative and technical constraints, soil analysis could not be conducted in the Buyukcekmece Watershed. Instead, literature data have been used to estimate the carbon stocks per unit area.

Upon reviewing the relevant studies, it has been observed that Pamukcu (2015) conducted a doctoral thesis in which unit carbon values were determined for Kagithane, Alibeykoy, and Sazlidere Watersheds located in Istanbul, Turkey, considering four different carbon pools. The study involved field and laboratory work to determine the unit carbon values held by different land classes. The rationale behind choosing this particular study was predicated on its similarity with the Buyukcekmece Watershed in terms of scale (watershed size) and shared physical attributes (location, climate, vegetation, etc.), along with the scientific validity of the study. However, the data used within the scope of the study provides unit carbon values only for a portion of the land cover classes. To estimate the carbon stocks for the remaining land classes, additional literature sources were needed. The selection of these studies was based on their scientific background (published theses, articles, official reports, etc.) and their relevance to the geographic and phenological characteristics of the study area resembling the Buyukcekmece Watershed. Other studies that were consulted for unit carbon data in the research are as follows:

- Ma et al. (2019): Assessment of SOC (Soil Organic Carbon) variations in the Schleswig-Holstein region of Northern Germany based on CLC (Corine Land Cover) LULC classes (article published in a peer-reviewed journal).

- Cruickshank et al. (2000): Estimation of unit carbon storage values associated with CLC-LULC classes identified in Northern Ireland (article published in a peer-reviewed journal).

- Molin (2010): Prediction of unit carbon storage values associated with CLC-LULC classes identified in Portugal (Ph.D. thesis).

- Muñoz-Rojas et al. (2011): Evaluation of the impacts of Land Use and Land Cover Change (LULCC) between 1956 and 2007 on SOC levels in Andalusia, Southern Spain (article published in a peer-reviewed journal).

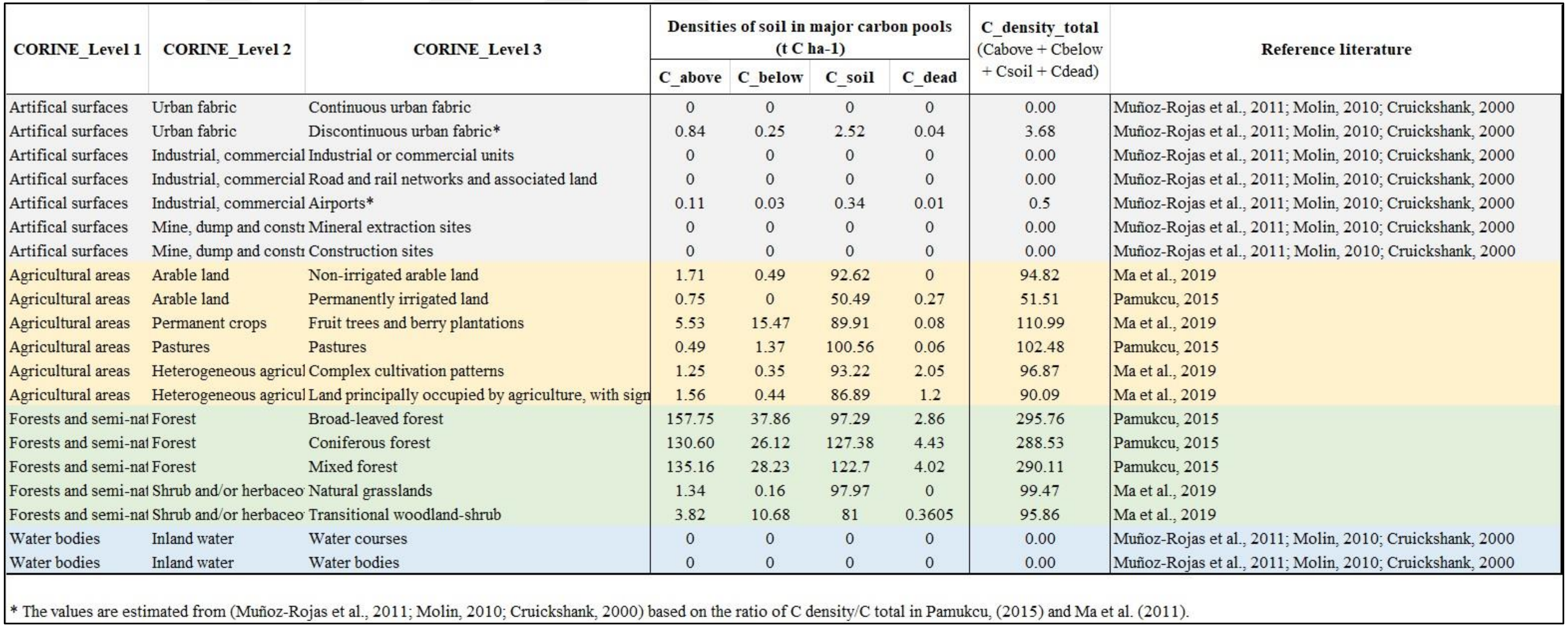
Dataset building and pre-processing: The required LULC data for running the model was obtained from the CLC dataset for each study year. Another essential dataset for the model is the biophysical carbon values associated with the identified land cover classes in the study area. For each land cover class, the unit carbon values for the four carbon pools needed to be determined separately, and the input data should be prepared in Excel (.csv) format before running the model.

While assessing the data from reference studies, discrepancies were identified concerning the unit carbon values for specific LULC classes. For instance, although both Pamukcu (2015) and Ma et al. (2000) provided unit carbon values for five LULC classes (permanently irrigated land, pastures, broad-leaved forest, coniferous forest, and mixed forest) they assigned different unit carbon values for the same class. To resolve these conflicts and establish the most appropriate unit carbon values for the LULC classes in the Buyukcekmece Watershed, obtained data were compiled in the table presented in Appendix F. The table identifies the reference work of the unit carbon values for each LULC class.

In the table, the conflicting LULC classes were treated separately, and when determining the carbon values for the land cover classes, priority was given to the study that exhibited the highest geographical and phenological similarity to the study area. Consequently, for the common LULC classes in Pamukcu (2015) and Ma et al. (2010), the data from Pamukcu (2015) were used as the reference. In the other three studies that included European examples, the unit carbon values for the conflicting LULC classes were based on the data from Ma et al. (2010) due to their geographical proximity. However, these two prioritized sources do not provide carbon data for two LULC classes (discontinuous urban fabric and airports). The total carbon values for these two classes were calculated by averaging the values presented by Cruickshank et al. (2000), Molin (2010), and Muñoz-Rojas et al. (2011). To determine the distribution of this total value among the carbon pools, the proportions of the total carbon amounts in Pamukcu (2015) and Ma et al. (2010) were utilized as the basis for allocating them among the carbon pools.

The total carbon values for these two classes were calculated by taking the average of the values presented by Cruickshank et al. (2000), Molin (2010), and Muñoz-Rojas et al. (2011). To determine the distribution of this total value among the carbon pools, the proportions of the total carbon amounts in Pamukcu (2015) and Ma et al. (2010) were used as the basis for distributing them among the carbon pools. As a result of these preliminary and preparatory works, the ultimate carbon values for the LULC classes in the Buyukcekmece Watershed were compiled in Figure 4.20. After obtaining the necessary data and completing the preparatory works, the analysis phase was initiated.

Analysis and validation: To prepare the model input, the LULC and biophysical carbon data were formatted appropriately in the ArcGIS environment. The model was then executed and run. The result files generated by the model were analyzed and mapped using Microsoft Excel and ArcGIS software.



CORINE_Level 1	CORINE_Level 2	CORINE_Level 3	Densities of soil in major carbon pools (t C ha-1)				C_density_total (Cabove + Cbelow + Csoil + Cdead)	Reference literature
			C_above	C_below	C_soil	C_dead		
Artifical surfaces	Urban fabric	Continuous urban fabric	0	0	0	0	0.00	Muñoz-Rojas et al., 2011; Molin, 2010; Cruickshank, 2000
Artifical surfaces	Urban fabric	Discontinuous urban fabric*	0.84	0.25	2.52	0.04	3.68	Muñoz-Rojas et al., 2011; Molin, 2010; Cruickshank, 2000
Artifical surfaces	Industrial, commercial	Industrial or commercial units	0	0	0	0	0.00	Muñoz-Rojas et al., 2011; Molin, 2010; Cruickshank, 2000
Artifical surfaces	Industrial, commercial	Road and rail networks and associated land	0	0	0	0	0.00	Muñoz-Rojas et al., 2011; Molin, 2010; Cruickshank, 2000
Artifical surfaces	Industrial, commercial	Airports*	0.11	0.03	0.34	0.01	0.5	Muñoz-Rojas et al., 2011; Molin, 2010; Cruickshank, 2000
Artifical surfaces	Mine, dump and const	Mineral extraction sites	0	0	0	0	0.00	Muñoz-Rojas et al., 2011; Molin, 2010; Cruickshank, 2000
Artifical surfaces	Mine, dump and const	Construction sites	0	0	0	0	0.00	Muñoz-Rojas et al., 2011; Molin, 2010; Cruickshank, 2000
Agricultural areas	Arable land	Non-irrigated arable land	1.71	0.49	92.62	0	94.82	Ma et al., 2019
Agricultural areas	Arable land	Permanently irrigated land	0.75	0	50.49	0.27	51.51	Pamukcu, 2015
Agricultural areas	Permanent crops	Fruit trees and berry plantations	5.53	15.47	89.91	0.08	110.99	Ma et al., 2019
Agricultural areas	Pastures	Pastures	0.49	1.37	100.56	0.06	102.48	Pamukcu, 2015
Agricultural areas	Heterogeneous agricul	Complex cultivation patterns	1.25	0.35	93.22	2.05	96.87	Ma et al., 2019
Agricultural areas	Heterogeneous agricul	Land principally occupied by agriculture, with sign	1.56	0.44	86.89	1.2	90.09	Ma et al., 2019
Forests and semi-na	Forest	Broad-leaved forest	157.75	37.86	97.29	2.86	295.76	Pamukcu, 2015
Forests and semi-na	Forest	Coniferous forest	130.60	26.12	127.38	4.43	288.53	Pamukcu, 2015
Forests and semi-na	Forest	Mixed forest	135.16	28.23	122.7	4.02	290.11	Pamukcu, 2015
Forests and semi-na	Shrub and/or herbaceo	Natural grasslands	1.34	0.16	97.97	0	99.47	Ma et al., 2019
Forests and semi-na	Shrub and/or herbaceo	Transitional woodland-shrub	3.82	10.68	81	0.3605	95.86	Ma et al., 2019
Water bodies	Inland water	Water courses	0	0	0	0	0.00	Muñoz-Rojas et al., 2011; Molin, 2010; Cruickshank, 2000
Water bodies	Inland water	Water bodies	0	0	0	0	0.00	Muñoz-Rojas et al., 2011; Molin, 2010; Cruickshank, 2000

* The values are estimated from (Muñoz-Rojas et al., 2011; Molin, 2010; Cruickshank, 2000) based on the ratio of C density/C total in Pamukcu, (2015) and Ma et al. (2011).

Figure 4.20 : Biophysical carbon values by CLC-LULC classes.

Consequently, the "carbon stored in the four carbon pools" in the Buyukcekmece Watershed and the "total carbon" were calculated separately for the years 1990, 2000, 2006, 2012, and 2018. According to the results, the carbon stored by aboveground biomass (C-above) and belowground biomass (C-below) in the Buyukcekmece Watershed continuously increased between 1990 and 2006, while both decreased between 2012 and 2018. The carbon stored by dead organic matter (C-dead) showed a continuously increasing trend between the study years, although it did not exhibit significant changes across the watershed.

The carbon stored by soil (C-soil) in the area consistently decreased between 1990 and 2018. In addition to these four carbon pools, the total stored carbon (Total C) in the Buyukcekmece Watershed followed a similar pattern as C-above and C-below, increasing between 1990 and 2012 and decreasing between 2012 and 2018. The carbon change values obtained from the analyses are presented in Figure 4.21, while the maps depicting the spatial distribution of stored carbon amounts are shared in Appendix G.

After calculating the total carbon stock in the Buyukcekmece Watershed, the findings were compared with the results of the "Soil Organic Carbon Project." This project (hereunder mentioned as “SOC Project”) aimed to estimate the overall SOC stock in Turkiye by conducting field observations and analyzing soil samples collected from 21,061 points with known coordinates. The project was conducted in collaboration with TUBITAK BILGEM YTE (Software Technologies Research Institute) and the General Directorate of Afforestation and Erosion Control (ÇEM), under the auspices of the Republic of Turkey Ministry of Agriculture and Forestry (MoAF). Within the scope of this project, total carbon stock in the 30 cm soil depth was calculated for different land cover classes (MoAF, 2018). According to the project's modeling studies, the unit carbon values for six LULC classes were estimated as follows:

- Artificial Areas: 16.12 tons C ha^{-1}
- Agricultural Areas: 35.96 tons C ha^{-1}
- Grazing Areas: 49.77 tons C ha^{-1}
- Forest Areas: 55.68 tons C ha^{-1}
- Wetlands and Water Surfaces: 49.71 tons C ha^{-1}
- Bare Areas: 12.78 tons C ha^{-1}

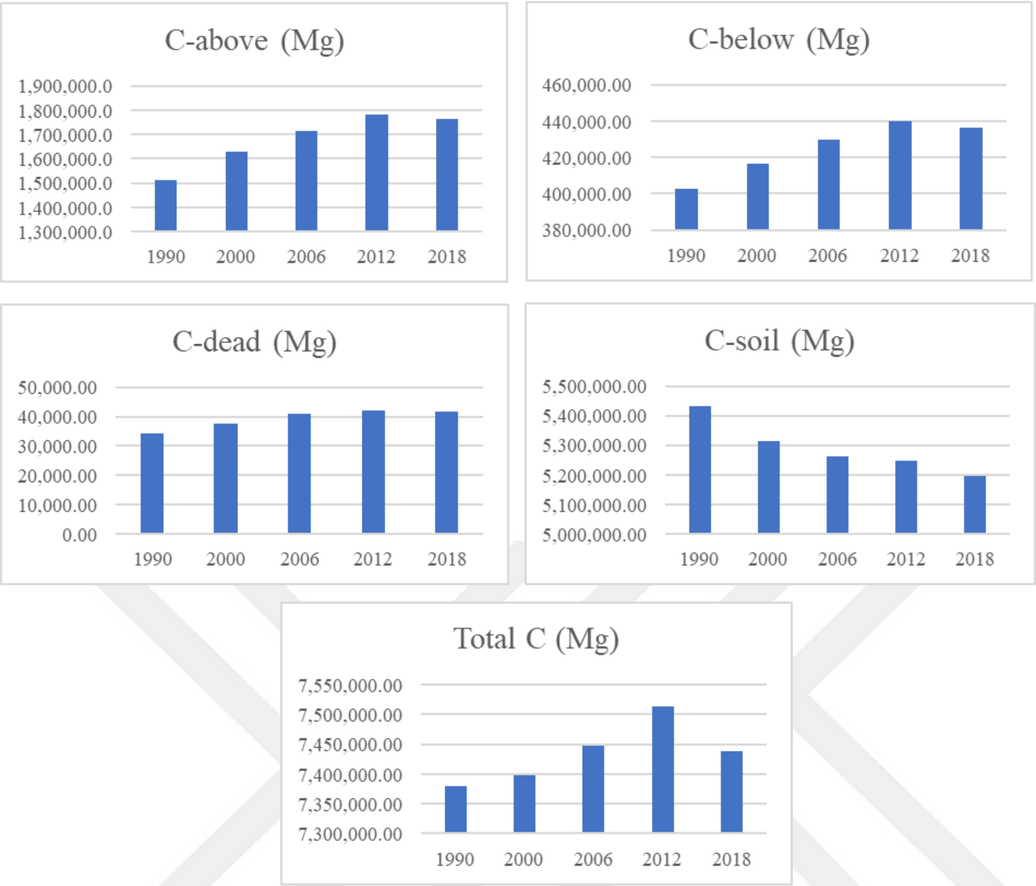


Figure 4.21 : Change in carbon storage in Buyukcekmece Watershed.

In order to compare the data generated within the project and the estimated total carbon storage calculated by the InVEST model in the Buyukcekmece Watershed, it was necessary to align the land cover classes used in both studies. Therefore, the LULC classes in the project were directly matched with the CLC Level-1 categories for artificial surfaces, agricultural areas, and forest areas. The category of wetlands and water surfaces used in the SOC project corresponds to the wetlands and water bodies categories in the CLC Level-1 classification. Unlike the CLC dataset, the project treated pastures as a separate class rather than including them within the agricultural areas category. Thus, the CLC Level-2 data were used only for this land cover class.

After aligning the LULC classes, the unit SOC stock values shared within the project were multiplied by the corresponding areas of the LULC classes in the Buyukcekmece Watershed. This calculation allowed the estimation of the total SOC amount stored by the LULC classes in the watershed based on the unit carbon stock values determined by the project.

According to the InVEST model results, it was found that the amount of carbon stored in the soil in the Buyukcekmece Watershed continuously decreased between 1990 and 2018. Similarly, the following calculations, which are based on the data produced by the MoAF also indicate a decline in the SOC amount in the watershed. The outcomes of the SOC project explicitly demonstrate that the SOC in the Buyukcekmece Watershed has consistently decreased between 1990 and 2018. This finding demonstrates that the results of the InVEST model analysis align with similar findings derived from land-based investigations of the SOC Project.

The amount of total SOC stored in Buyukcekmece Watershed is provided in Table 4.10 based on the data obtained from the SOC Project and the InVEST model results. Besides, the graph illustrating the changes in SOC based on the SOC Project and the InVEST model results is presented in Figure 4.22.

Table 4.10 : The amount of total SOC in Buyukcekmece Watershed (1990-2018).

	SOC (ton C ha-1)				
	1990	**2000**	**2006**	**2012**	**2018**
SOC Project	2,548,608.78	2,509,652.86	2,507,561.15	2,498,689.98	2,483,913.2
InVEST	5,431,905.25	5,312,540.12	5,262,207.83	5,247,827.39	5,194,691.8
Difference	2,883,296.47	2,802,887.26	2,754,646.68	2,749,137.41	2,710,778.5

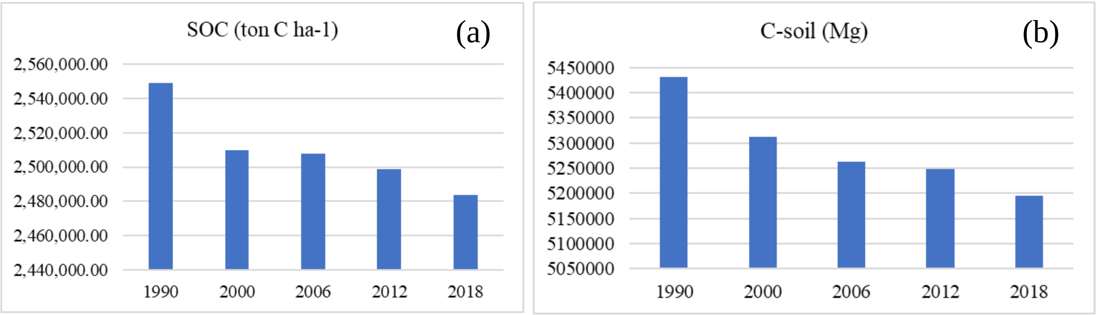


Figure 4.22 : SOC change in Buyukcekmece Watershed (1990-2018) according to the (a) SOC Project and (b) InVEST model results.

The total SOC amount and its changes in the Buyukcekmece Watershed were estimated based on the results of two different studies, and further analysis was conducted for five different time periods to examine the quantitative and proportional (%) changes of SOC during these periods. The comparison of the quantitative changes in SOC is presented in Table 4.11.

Table 4.11 : SOC change in Buyukcekmece Watershed (1990-2018).

	SOC (ton C ha-1)				
	1990-2000	**2000-2006**	**2006-2012**	**2012-2018**	**1990-2018**
SOC Project	-38,955.92	-2,091.71	-8,871.17	-14,776.70	-64,695.50
InVEST	-119,365.14	-50,332.29	-14,380.44	-53,135.53	-237,213.40
Difference	-80,409.22	-48,240.58	-5,509.27	-38,358.83	-172,517.90

According to the comparison table, it was observed that the total SOC amount yielded different results in the SOC Project and InVEST Model results, but the trajectory of SOC change between 1990 and 2018 exhibited a consistent parallel pattern. The variation in the total SOC quantities in the SOC Project and InVEST Model results can be attributed to the fact that the SOC Project is a large-scale study conducted in Turkey, not only for the Buyukcekmece Watershed. Besides, the biophysical unit carbon values are used as input data for the INVEST Model based on the literature findings instead of field data. Depending on these assumptions and limitations, the differences in SOC quantities can be considered scientifically acceptable, as long as the trend in SOC changes over the designated years present a similar pattern in both studies.

The comparison of the proportional changes (%) in SOC is presented in Table 4.12. According to this data, the relationship between the percentage change values was examined by using the "slope" function in Excel. This function is commonly used in linear regression analysis to determine the relationship between two sets of data. Herein, the calculated slope value of 0.58, which is the average SOC change rate from 1990 to 2018 for the SOC Project and the average change rate from InVEST, indicates a positive correlation between the variables.

Table 4.12 : Rate of change in SOC over time periods.

	SOC Change (% ton C ha-1)				
	1990-2000	**2000-2006**	**2006-2012**	**2012-2018**	**1990-2018**
SOC Project	-1.53	-0.08	-0.35	-0.59	-2.60
InVEST	-2.20	-0.95	-0.27	-1.01	-4.57
SLOPE:	0.586558784				

The relationship between the slope values was also illustrated graphically and R^2 values were calculated (Figure 4.23). It was found that the R^2 value is above 0.9 for both studies. This indicates that the variables produce compatible data and there is a close linear relationship between them.

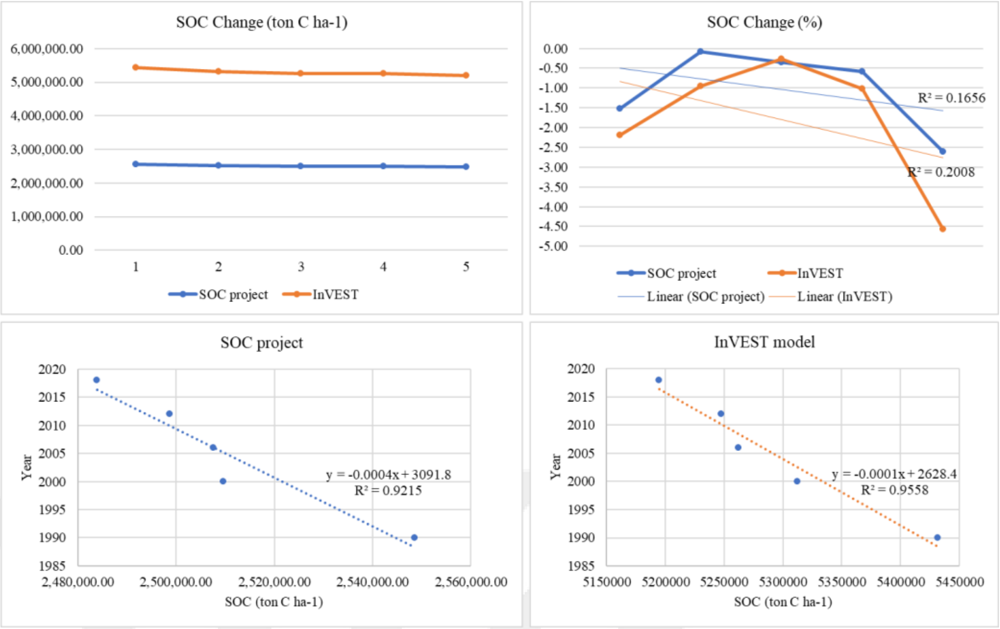


Figure 4.23 : Comparison of SOC project and InVEST model findings.

In conclusion, according to the InVEST model results for the Buyukcekmece Watershed, the total carbon stock in the area has continuously increased while the SOC amount has consistently decreased from 1990 to 2018. This finding indicates a loss of areas rich in SOC within the watershed. The SOC project has indicated that SOC is highest in forests, followed by pastures and agricultural areas. Also, according to Table 4.9, which includes unit carbon values compiled from literature data, pastures and grasslands, forests, and agricultural areas have the highest SOC ratios, respectively. When considered together with the LULC results, it is known that pastures and natural grasslands in the watershed have decreased between 1990 and 2018.

Therefore, it can be concluded that the decrease in SOC in the Buyukcekmece Watershed is related to the diminishing extent of pastures and natural grasslands. Furthermore, the continuous reduction in agricultural land within the watershed may also be regarded as a contributing factor to the decline in SOC content.

4.3.3 Biomass production

The third and final SoES examined within the scope of the study is soil's biomass production service. Biomass production involves the conversion of water, solar energy, and carbon dioxide into organic matter through photosynthesis, and it represents the total plant mass on Earth (Brady and Weil, 2017). Soil plays a crucial role in supporting plant growth by providing a medium for plants and facilitating their development. This essential function of soil is instrumental in the formation of primary producers in terrestrial ecosystems and ensures the continuity of the food chain (Box et al, 1989).

Soil provides a favorable environment for plant growth through the availability of essential nutrients, SOM, and soil water. Soil microorganisms also contribute to plant development in various ways within this complex system through global nutrient cycles. Herein, the vegetation supported by the soil constitutes the total biomass and is directly related to the net primary production (NPP) on Earth (Robinson et al., 2013). NPP represents the net energy gain and organic matter production by plants through photosynthesis, and it is a crucial measure of productivity and energy flow within an ecosystem (Brady and Weil, 2017).

Therefore, the vitality and growth of biomass in an area directly and positively affect the NPP in that region. This is crucial for supporting primary producers and ensuring the continuity of food chains and life on Earth (Robinson et al, 2013). As soil plays a significant role in supporting plant growth by providing a suitable environment and supplying nutrients to plants, this in turn directly influences the biomass and, consequently, the NPP in the area. The interconnected and multifaceted relationship among these three components (i.e., soil, total biomass and NPP) plays a vital role in ecosystem health and productivity.

Due to the vital significance of soil's biomass production service and its potential to directly influence other SoES through intricate relationships, this SoES has been included in this research for analysis. In this context, the change in vegetation cover in the Buyukcekmece Watershed was evaluated using the NDVI. This method is commonly used to analyze and monitor agricultural crop patterns as well as to assess changes in vegetation density and health in natural areas. Furthermore, according to Box et al. (1989), NDVI can be a reliable predictor in estimating total biomass production and NPP.

NDVI enables the seasonal analysis of vegetation in an area using remote sensing techniques with satellite images and aerial photographs. The method utilizes the "reflectance of near-infrared (NIR)" and "red light bands" in the electromagnetic spectrum to generate a vegetation index that provides information about the condition (health, density, robustness, and vigor) and quantity of vegetation. This index, also known as the greenness index, ranges from -1 to 1, where values approaching 1 indicate healthier and more abundant vegetation. This index is calculated using the formulation presented in equation 4.5 (Gandhi et al, 2015; Box et al., 1989).

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})} \tag{4.5}$$

This formulation is based on the reflection of chlorophyll, which enables plants to undergo photosynthesis, where it reflects NIR and green light while absorbing more red and blue light. NDVI utilizes this difference between NIR and red light to measure vegetation health and density. The generated NDVI values tend to approach +1 in areas with abundant green vegetation, while clouds, water, and snow exhibit low (negative) NDVI values. Bare soil and sparse vegetation show NDVI values close to zero. The approximate ranges of NDVI values determined according to LULC patterns are depicted in Figure 4.24. These values can vary based on vegetation density, stress conditions, LULC change, land conditions, and seasonal characteristics.

The analysis of NDVI used to determine the variation in vegetation quality in the Buyukcekmece Watershed over the selected study years (1990, 2000, 2006, 2012, and 2018) is summarized under three main headings, similar to previous analyses conducted within the study: Data acquisition; Dataset building and pre-processing, and; Analysis and validation.

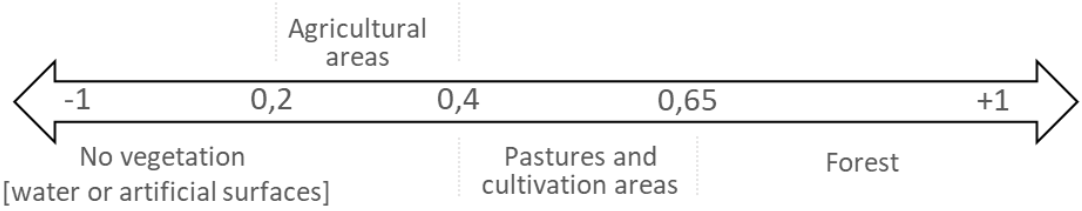


Figure 4.24 : The range of NDVI based on surface reflectance (adapted from Gandhi et al, 2015).

<u>Data acquisition:</u> In the implementation of the NDVI analysis, satellite imagery specific to the study area is required. For the NDVI analysis in the Buyukcekmece Watershed, satellite images of the area were obtained as open data from the official website of the Earth Explorer platform (https://earthexplorer.usgs.gov/). The main reasons for selecting these data are as follows:

- The comparability and updateability of the data
- The provision of high-quality and reliable data
- The delivery of standardized products with accuracy and consistency
- The data being openly accessible
- The calibration, validation, and quality control processes of the images being conducted by local experts

To access satellite images, the coordinates of the area and the desired time range (month and year) need to be specified first. The following steps involve selecting the desired satellite and dataset, specifying any additional criteria (e.g., cloud cover), and ultimately choosing suitable images that cover the entire area. Once the data is obtained, the data preparation process can be initiated.

Dataset building and pre-processing: This stage involves selecting the most suitable satellite images related to the area and preparing them for the analysis stage. One of the most important criteria to consider when selecting satellite images is the cloud cover percentage, which should generally be less than 10%. Lower cloud cover values will result in more precise analysis outcomes. In the case of the Buyukcekmece Watershed, the following criteria have been taken into account in the selection of satellite images, in addition to the land and scene clarity:

- The data should have been acquired during the designated study periods (1990, 2000, 2006, 2012, 2018) or in close proximity to those dates
- The images should correspond to the active vegetation period in the area, preferably in the summer (June, July, August)
- For comparability purposes, the images should be captured on dates that are close to each other for each study year

Furthermore, before the analysis, the obtained satellite images need to undergo necessary pre-processing steps using appropriate software and tools (e.g., MATLAB, ENVI). These steps, such as atmospheric correction and radiometric correction, require technical expertise and knowledge. Therefore, in the selection of observation satellite datasets, "Level 2" data that have already been pre-processed and corrected were used.

According to the aforementioned criteria, the Landsat 4-5 TM satellite data was utilized for the years 1990 and 2000 for the Buyukcekmece Watershed case, and specific cloud-free images from June 13, 1990, and June 8, 2000, were selected due to their proximity in date and scene clarity. Also, for the year 2006, the Landsat 4-5 TM data was utilized and the image from June 6, 2005, was preferred due to the high cloud cover (87%) of the images in 2006. Similar challenges were encountered for the 2012 images, and therefore an image from June 7, 2011, was chosen. Since the Landsat 4-5 satellite was deactivated in 2013, Landsat 7 ETM data were initially considered for the 2018 dataset. However, due to the technical errors (scan line errors) originating from the sensors in Landsat 7 ETM images, the Landsat 8 OLI/TIRS satellite data is utilized. For the 2018 dataset, an image from June 7, 2017, was selected due to the low cloud cover ratio. As a result, the selection of the satellite images did not exclusively rely on the years of investigation within the Corine CLC dataset. Instead, due to technical constraints and clarity problems, the images from the nearest available data years (1990, 2000, 2005, 2011, and 2017) were used. Table 4.13 provides the dates and technical specifications of the satellite images chosen for Buyukcekmece Watershed, based on the specific criteria and limitations.

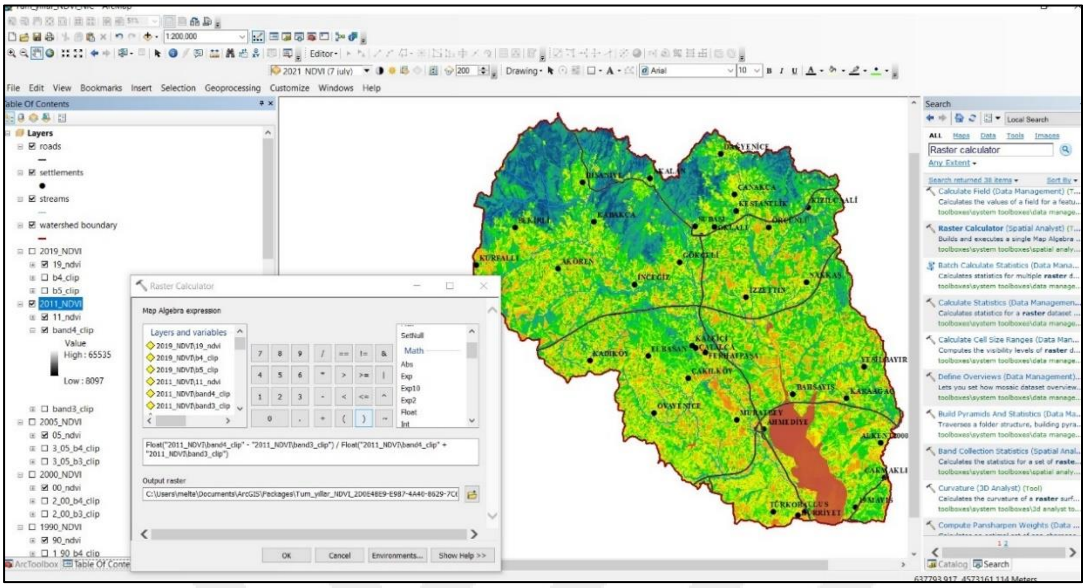
The NIR and red band combinations of satellite images are utilized for the NDVI analysis. Therefore, the acquired bands of each image are selected and clipped according to the boundaries of the study area utilizing the "clip" command in ArcGIS. Once the final satellite images for the Buyukcekmece Watershed are selected and their band combinations are adjusted to align with the study area boundaries, the analysis phase is carried out.

Table 4.13 : Satellite images selected for Buyukcekmece Watershed.

Year	Date	Dataset	Land Cloud Cover	Scene Cloud Cover	Band Combinations
1990	13 June	Landsat 4-5 TM	0	1	Band 4 NIR Band 3 Visible Red
2000	8 June	Landsat 4-5 TM	4	3	
2005 (alternative year for 2006)	6 June	Landsat 4-5 TM	1	1	
2011 (alternative year for 2012)	7 June	Landsat 4-5 TM	2	1	
2017 (alternative year for 2018)	7 June	Landsat 8 OLI/TIRS	0	10	Band 5 NIR Band 4 Visible Red

<u>Analysis and validation:</u> For the NDVI analysis, the "Raster calculator" function in ArcGIS is used, where the relevant band combinations are inserted according to equation 4.5 to calculate NDVI values and generate NDVI maps for the area (Figure

4.25). To obtain the mean NDVI values for each study year in the area, the "Zonal statistics as table" command is employed.



Map Algebra expression: Float("2011_NDVI\band4_clip" - "2011_NDVI\band3_clip") / Float("2011_NDVI\band4_clip" + "2011_NDVI\band3_clip")

Output raster: C:\Users\melte\Documents\ArcGIS\Packages\Tum_yiller_NDVI_2D0E4BE9-E987-4A40-8629-7C

Figure 4.25 : Application of NDVI analysis in ArcGIS environment.

According to the analysis results, the range of NDVI values and mean NDVI values detected in the Buyukcekmece Watershed on a yearly basis, are presented in Table 4.14.

Table 4.14 : NDVI values in Buyukcekmece Watershed (1990-2017).

Year	Date	Min	Max	Mean	STD
1990	13 June	-0.44	0.75	0.351	0.188
2000	8 June	-0.31	0.73	0.354	0.186
2005	6 June	-0.98	0.84	0.381	0.225
2011	7 June	-0.52	0.80	0.375	0.241
2017	7 June	-0.25	0.66	0.341	0.154

According to the results of NDVI analysis conducted for the years 1990, 2000, 2005, 2011, and 2017 in the Buyukcekmece Watershed, the mean NDVI value of the area remained almost constant between 1990 and 2000 but increased between 2000 and 2005. However, the mean NDVI value consistently decreased between 2005, 2011, and 2017 (Figure 4.26).

This pattern can be primarily attributed to the changes in the LULC pattern of the watershed, especially between 2006 and 2018. During this period, there was an increase in the continuous urban fabric in the watershed, while reductions were observed in the non-irrigated arable land and transitional woodland shrubland classes.

The decrease in natural land cover likely contributed to the decline in the mean NDVI value, which can have adverse effects on the soil's biomass production services and potentially lead to a decrease in NPP in the area.

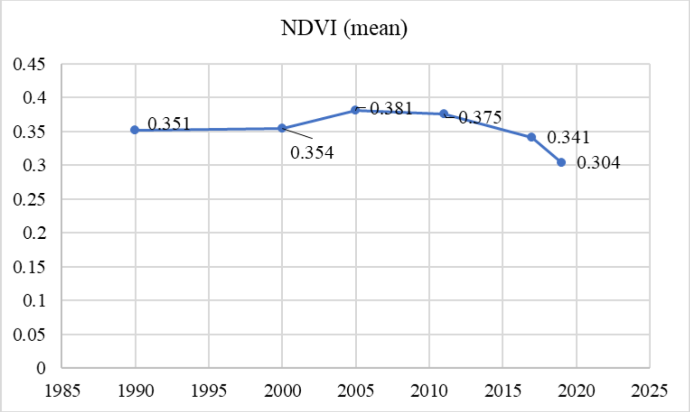


Figure 4.26 : Mean NDVI value change in Buyukcekmece Watershed.

Yet, in light of the prevailing urbanization trends, anticipated infrastructure projects, and the trajectory of LULC changes, it is foreseen that the pressures on the vegetation integrity within the Buyukcekmece Watershed will persist and likely intensify in the forthcoming years. The confluence of these factors suggests a sustained challenge to the ecological balance of the watershed, posing potential threats to its biodiversity, ES, and overall environmental health. The NDVI maps prepared for the Buyukcekmece Watershed, covering the study years, are shown in Figure 4.27.

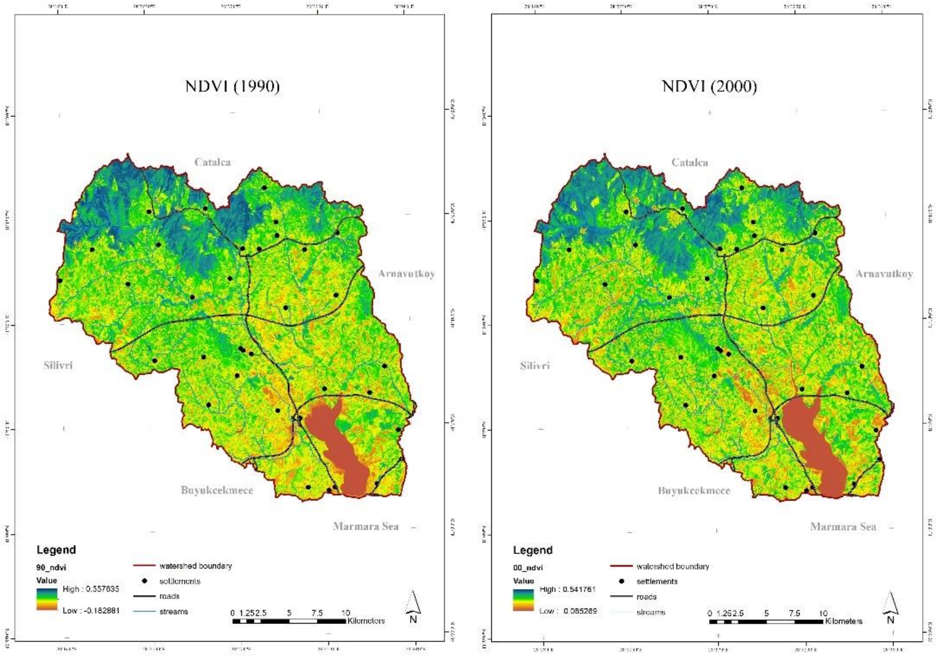
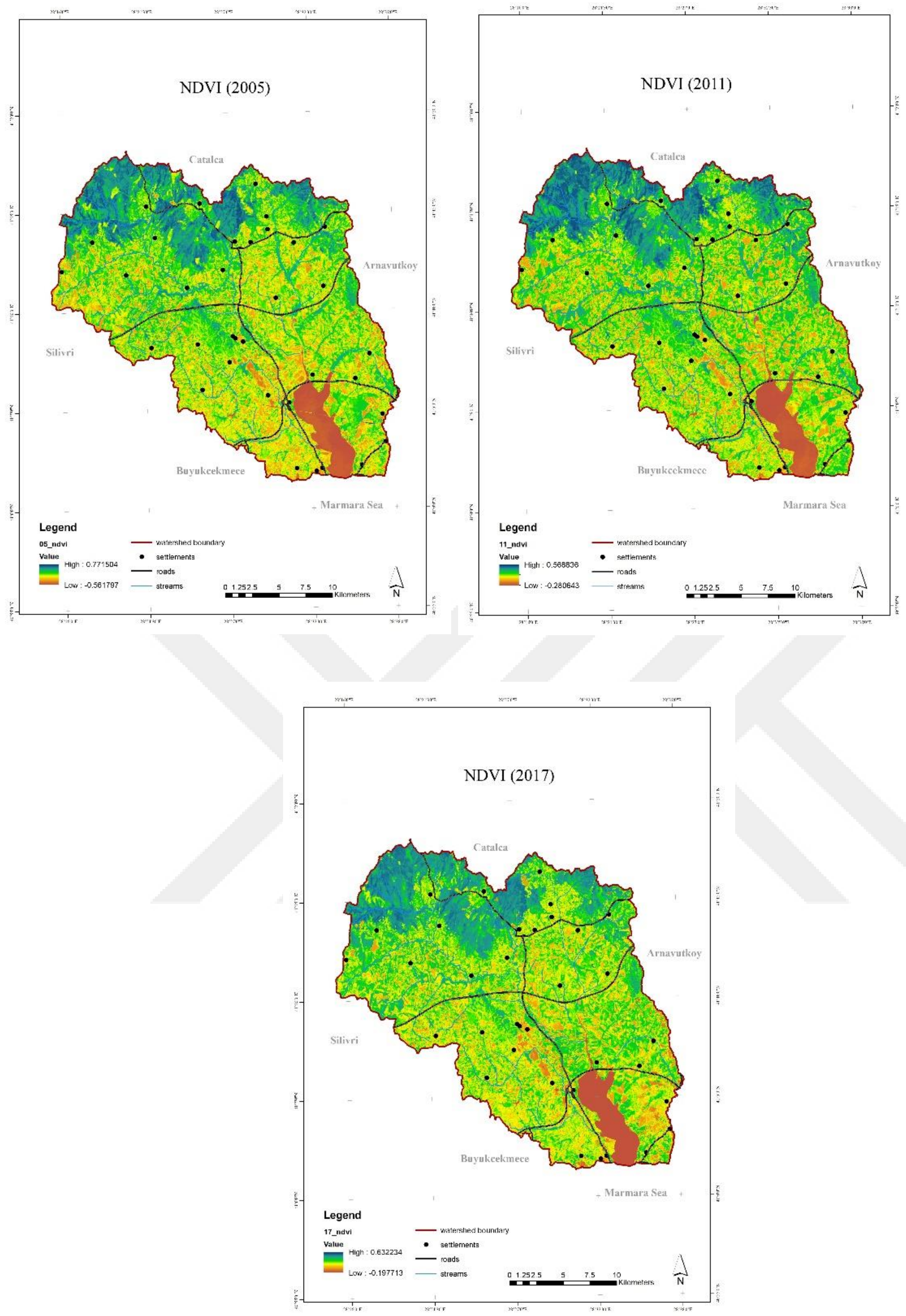


Figure 4.27 : NDVI maps of Buyukcekmece Watershed.


NDVI (2005)

NDVI (2011)

NDVI (2017)

Figure 4.27 (continued) : NDVI maps of Buyukcekmece Watershed.

5. RESULTS AND DISCUSSIONS

This chapter entails a thorough analysis of the research outcomes and presents recommendations regarding the integration of SoES into urban spatial planning, based on the results derived from the Buyukcekmece Watershed case.

The chapter comprises two sub-chapters namely the "5.1 Evaluation of the Case Study Findings", which assesses the empirical research findings specific to the selected study area, and the "5.2 Suggestions on Integrating SoES into Urban Spatial Planning Framework", which evaluates the ultimate research outputs in the context of the legislative and spatial planning framework.

5.1 Evaluation of the Case Study Findings

In the context of the research, the Buyukcekmece Watershed in Istanbul has been selected as the study case due to its ecological significance, its role as a crucial reservoir providing drinking water to the city, and the anthropogenic pressures it experiences as an urban watershed. The potentials and challenges inherent in the watershed have been thoroughly discussed in the preceding chapter together with the analyses conducted on LULC and SoES changes in the area.

As described previously in Chapter 4, a total of four distinct quantitative analyses were conducted in the Buyukcekmece Watershed case. The first analysis involves assessing the condition, changes, and transformations of the LULC patterns in the watershed. For this purpose, LULC data for the years 1990, 2000, 2006, 2012, and 2018 were acquired from the CLC database and examined in detail at all levels (CLC levels 1, 2, and 3). Subsequently, the changes and transformations of LULC patterns were analyzed for five different periods: (1990-2000), (2000-2006), (2006-2012), (2012-2018), and (1990-2018).

The remaining three analyses focus on analyzing and mapping the changes in the SoES (surface water flow regulation, carbon storage, and biomass production) within the selected study years (1990, 2000, 2006, 2012, and 2018). The first analysis aimed to determine the changes in the surface flow regulation service (SoES-1) of the soil. For this purpose, the SCS-CN method was employed to calculate the CN values representing the potential for rainfall-to-runoff conversion and to determine the changes in surface runoff within the area. The second analysis focused on the soil's carbon storage service (SoES-2). Using the InVEST model, the total carbon stored in the Buyukcekmece Watershed and its change between the specified study years were examined. Lastly, in consideration of the significant role of soil in biomass production, the changes in vegetation status across the watershed were assessed using NDVI analysis (SoES-3).

While these analyses delved into calculating the changes in LULC and SoES over the study years, the interconnectedness between these two variables was not explored in Chapter 4. Therefore, this chapter is predominantly dedicated to the synthesis of the research findings and, notably, the exploration of the relationship between LULC transformations and SoES changes in the designated area.

To facilitate a clear evaluation and interpretation of the long-term spatial changes in the watershed, the correlation between LULC and SoES changes is assessed in the period between 1990 and 2018. The relationship between LULC transformations and SoES alterations in Buyukcekmece Watershed between these years are examined initially on the LULC classes basis and the following observations were made:

Urban Fabric: The urban fabric in the area showed an increase of 731 ha between 1990 and 2018. Of this increase, 609 ha occurred in the form of discontinuous urban fabric. The greatest increase in both categories was observed between 2006 and 2012. The expansion and increase in urban fabric resulted in the conversion of open areas into impervious surfaces, leading to an overall increase in the CN runoff coefficient in the watershed. When examining the spatial distribution of CN changes in the watershed, it can be observed that the increase occurred in the settlement areas (Tepekent and Alkent 2000) and transportation routes in the eastern and western parts of Lake Buyukcekmece. These areas also caused a significant decrease in SOC levels between 1990 and 2000 and a decrease in NDVI values in the northern and western parts of the lake. On the other hand, the increase in forest areas in the northern part of the watershed positively affected the SOC, NDVI, and CN values in the watershed during this period.

Industrial-Commercial-Transportation units: The areas classified as impervious surfaces mostly showed an increasing trend between 1990 and 2018. This increase was associated with a decrease in SOC levels and NDVI values, particularly in the northwestern and northeastern regions of the area. The distribution of fragmented NDVI change values in these areas concentrated in the industrial and commercial zones in the northwestern parts of the lake, overlapping directly with certain regions. Similarly, the areas where SOC values decreased generally exhibited fragmented characteristics close to the eastern border of the area. However, the largest decrease in SOC was observed in areas converted from pastures, forests, shrublands, and transitional areas.

Mine, Dump, and Construction Sites: Mining areas, which are mainly concentrated in the northern, northwestern, and western parts of the Watershed, showed an increasing trend throughout the years except for the period between 2006 and 2012. Construction sites, on the other hand, showed a continuous increase from 1990 to 2000-2006, followed by a sudden decrease between 2006 and 2012, and a rapid increase between 2012 and 2018. From satellite images, it can be inferred that these activities are associated with construction projects, including new transportation projects.

Arable Land: A continuous decrease was observed in this category between 1990 and 2018. Non-irrigated arable land in this category experienced the highest loss among all LULC classes in the Watershed. A decrease in SOC levels was observed in areas where non-irrigated arable land was converted into continuously irrigated agricultural land. This decrease is believed to be associated with certain agricultural practices such as excessive irrigation and cropping patterns. SOC exhibits high sensitivity to changes in land management and practices. Non-irrigated arable land, which is the dominant LULC class in the Watershed, continuously decreased between 1990 and 2018. This situation has laid the foundation for the negative impact on CN runoff coefficient values and, consequently, the water regulation service provided by the soil. Restricting or preventing soil-water connections can not only increase surface runoff and related flood risks but also have negative effects on vital activities performed by soil microorganisms (such as nutrient cycling and synthesis processes) and associated functions and services.

Permanent crops: This category, which did not exist in the area before 2000, increased between 2000 and 2006 and remained stable in subsequent years (2006-2012-2018), contributing positively to the increase in SOC.

Pastures: Pastures are the most important land group in terms of SOC. In pastures, there was a decrease in the entire watershed between 1990 and 2000, followed by an increase between 2000-2006-2012. However, a decline was observed between 2012 and 2018. It has been observed that the conversion of grassland-pasture areas into urban and agricultural land causes significant SOC loss in the area.

Forests and natural grasslands: Forest areas are prioritized for their role in retaining and regulating water flow, as well as for increasing the amount of SOC stored in both aboveground and belowground biomass. While broad-leaved forests remained stable between 1990 and 2000, there was a significant increase in the period of 2000-2006, which continued between 2006 and 2012, and 2012 and 2018.

Coniferous forests, on the other hand, experienced an increase during the 1990-2000 period and a similar rapid increase during 2000-2006, similar to broad-leaved forests. It is thought that plantation efforts carried out by ISKI contributed to this increase. The conservation and development of forest areas, which cover approximately 17% of the area, are critical for the sustainability of SoES. Another category that is important in terms of SOC is natural grasslands, which showed stability between 1990 and 2000, an increase between 2000 and 2006, and a decrease between 2006 and 2012.

In addition to the comparison based on LULC classes, the correlation between LULC transformations and changes in SoES in the Buyukcekmece Watershed was also investigated spatially. For this purpose, mapping studies were conducted, and initially, LULC transformations were systematically categorized into three classes: Areas converted to artificial surfaces; Areas converted to agricultural areas; and Areas converted to forest and semi-natural areas (Figure 5.1). Subsequent to this categorization, SoES change maps were prepared and compared with the LULC transformation maps classified into three categories. This comparative analysis aims to provide an in-depth understanding of the spatial relationships and interconnected dynamics between LULC alterations and the corresponding shifts in SoES in the case study area.

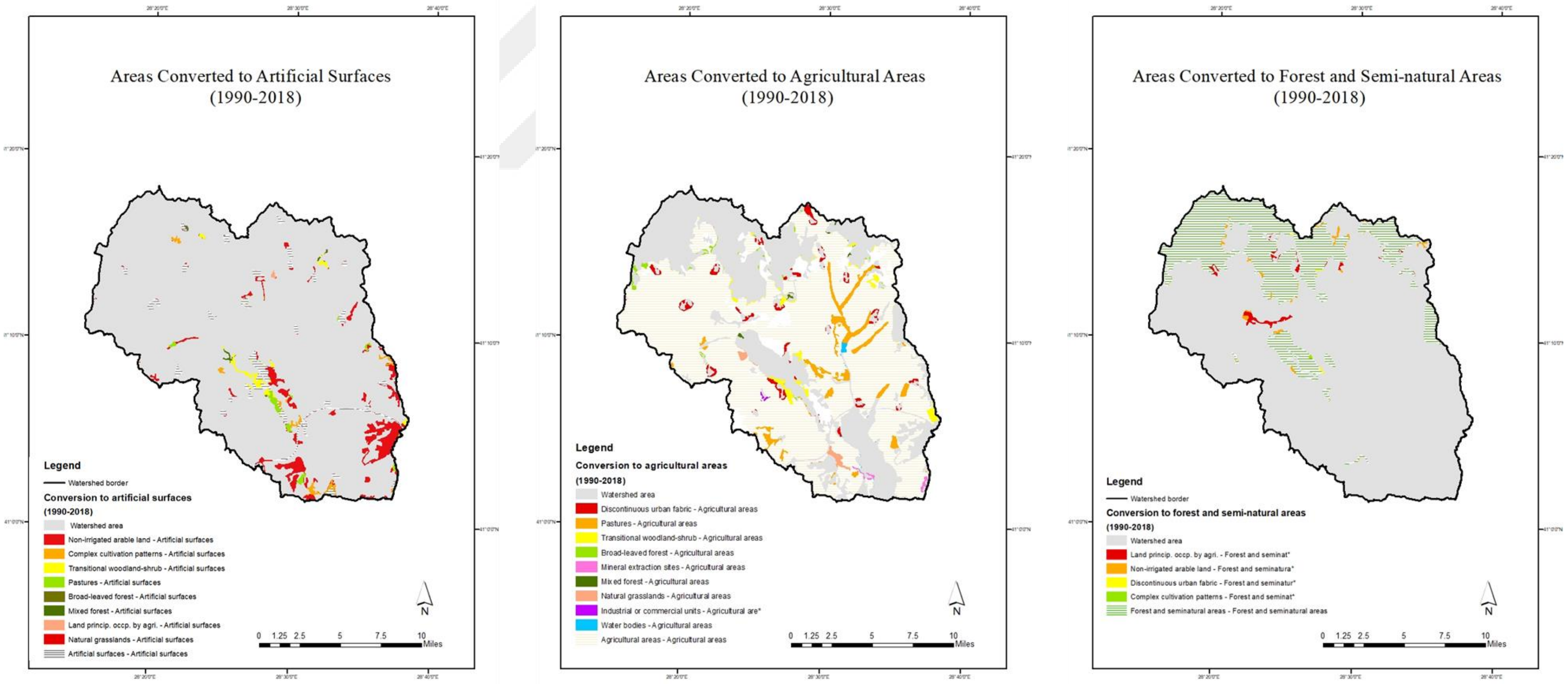


Figure 5.1 : LULC transformations in Buyukcekmece Watershed (1990-2018).

Initially, the LULC transformations were examined in relation to the changes in "SoES-1: Surface water flow regulation” and it was observed that the surface water flow regulation capacity of the soil in areas where natural land cover (e.g., non-irrigated arable land, complex cultivation patterns, transitional woodland-shrub, pastures, forest, natural grasslands) has been converted into artificial surfaces has decreased (Figure 5.2).

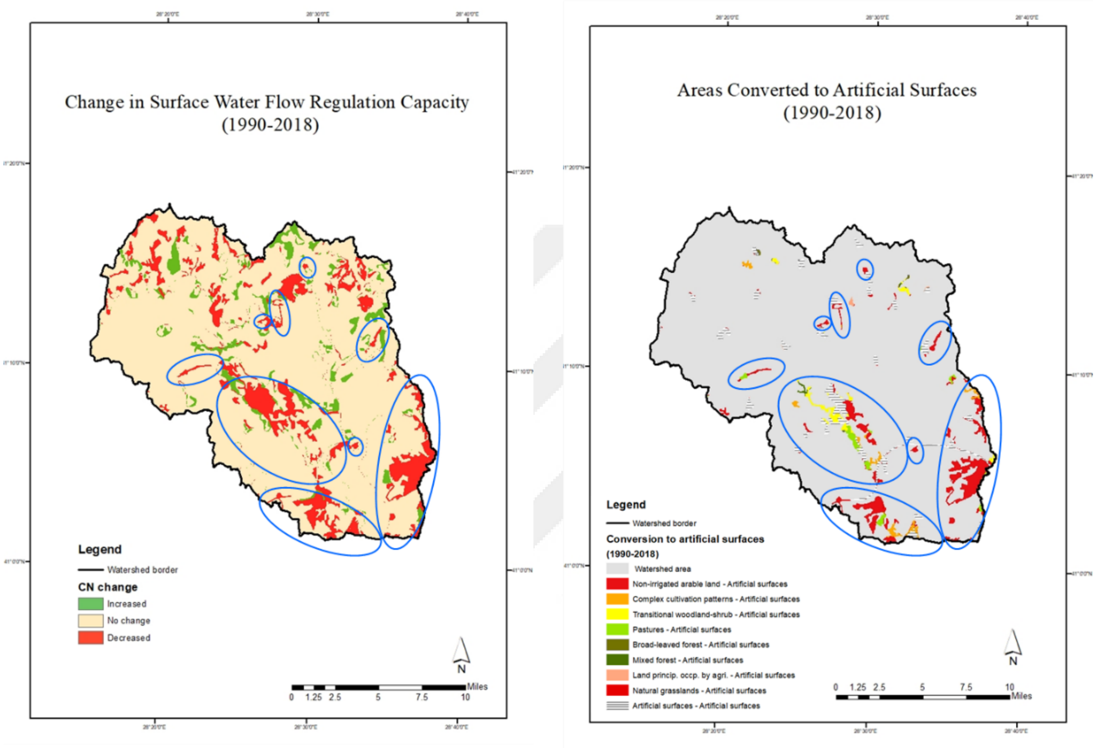


Figure 5.2 : Spatial comparison between SoES-1 change and LULC conversions (areas converted to artificial surfaces).

Similarly, a decrease in surface water flow regulation capacity can be observed in areas where broad-leaved forests, natural grasslands, and transitional woodland shrubs transformed into agricultural areas (Figure 5.3).

On the other hand, in areas where mineral extraction sites transformed into agricultural areas as well as the areas where the land principally occupied by agriculture and non-irrigated arable land converted to forest and semi-natural areas, a decrease in runoff and a higher regulation of surface flow by the soil were observed (Figure 5.4).

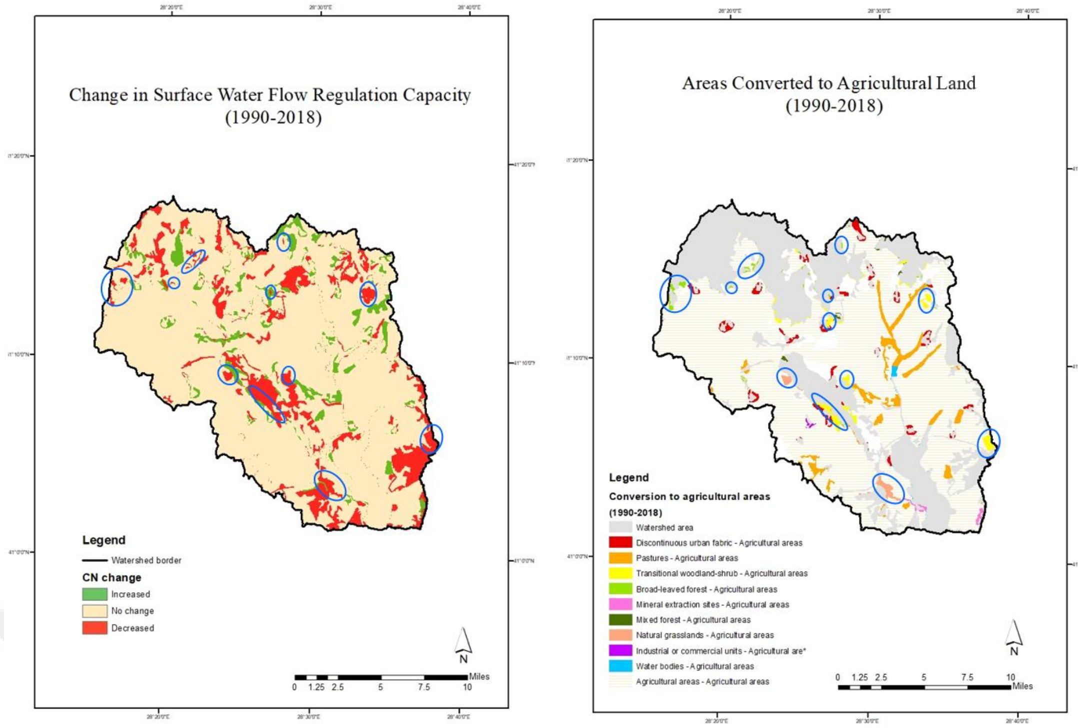


Figure 5.3 : Spatial comparison between SoES-1 change and LULC conversions (areas converted to agricultural land).

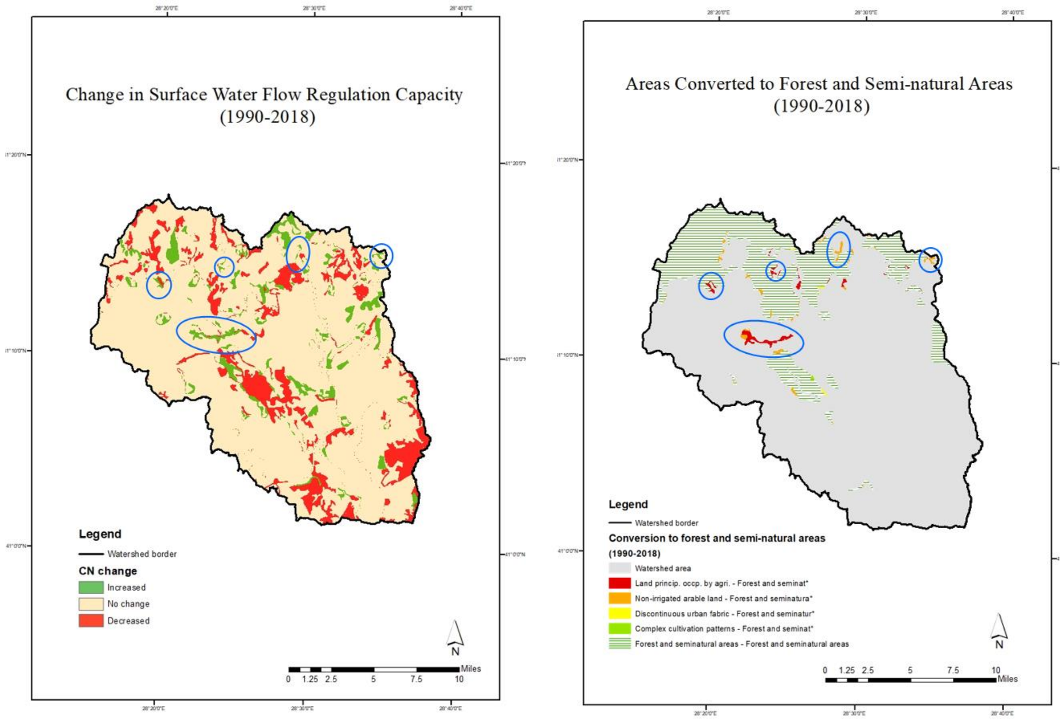


Figure 5.4 : Spatial comparison between SoES-1 change and LULC conversions (areas converted to forest and semi-natural areas).

When the relationship between LULC transformations and "SoES-2: SOC storage" was examined, it was found that carbon storage decreased in areas where natural areas (e.g., non-irrigated arable land, complex cultivation patterns, transitional woodland-shrub, pastures, forest, natural grasslands) transformed into artificial surfaces (Figure 5.5), while an increase in SOC was observed in areas where mineral extraction sites transformed to agricultural areas.

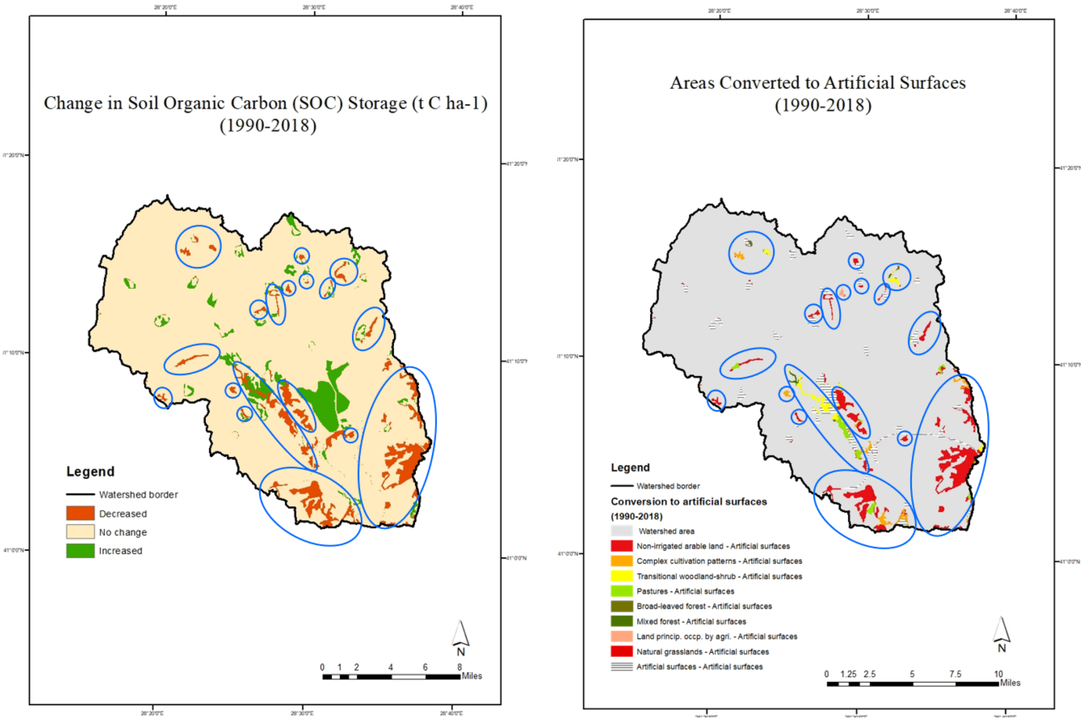


Figure 5.5 : Spatial comparison between SoES-2 change and LULC conversions (areas converted to artificial surfaces).

In the LULC transformation analyses conducted in Chapter 4.2, it was indicated that non-irrigated arable land, in a fragmented manner, underwent the most significant transformation among LULC types (refer to Figure 4.12 for change rates).

As part of an additional analysis conducted for this purpose, the SOC storage capacity was evaluated within the scope of "Areas converted from Non-irrigated Arable Land," revealing an increase in SOC in areas where non-irrigated arable land converted to permanently irrigated land between 2000 and 2006. However, it was observed that in areas where non-irrigated arable land transformed into artificial surfaces (construction sites, industrial and commercial units) and water bodies, there was a decrease in the carbon storage capacity of soil (Figure 5.6).

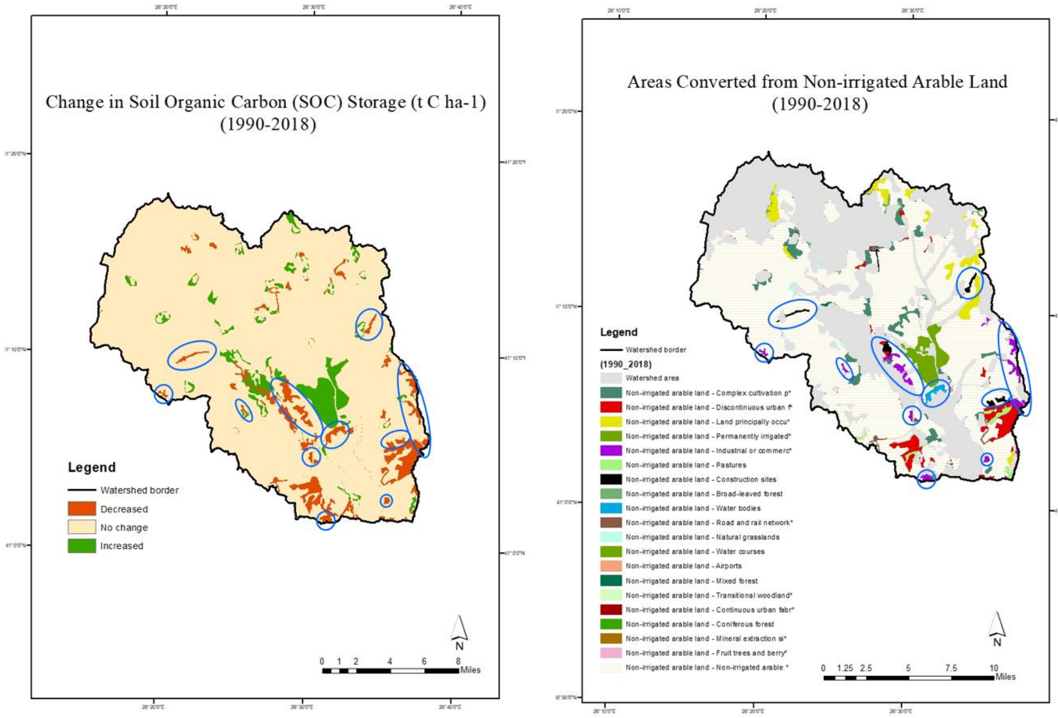


Figure 5.6 : Spatial comparison between SoES-2 change and LULC conversions (areas converted from non-irrigated arable land).

Unlike the SoES-1 and SoES-2 change maps, the mapping of the change in "SoES-3: Biomass production" did not yield meaningful results in terms of capturing the spatial changes and fragmented NDVI patterns of agricultural land use. Instead, a comparative analysis was conducted between the mean NDVI values of vegetated areas contributing to NPP and biomass production in the Buyukcekmece Watershed, along with the LULC change trends within the specific periods.

As shown in Figure 5.7, it can be observed that the mean NDVI value in the watershed increased between 2000 and 2006, indicating an enhancement in vegetation density. During the same period, an increase was also observed in broad-leaved forests, pastures, complex cultivation patterns, and permanently irrigated lands within the watershed. However, between 2005 and 2017, a decrease in mean NDVI value was observed. When compared with LULC transformations, it was determined that discontinuous urban fabric increased while natural grasslands and transitional woodland -shrubs decreased during the same time period (Figure 5.8).

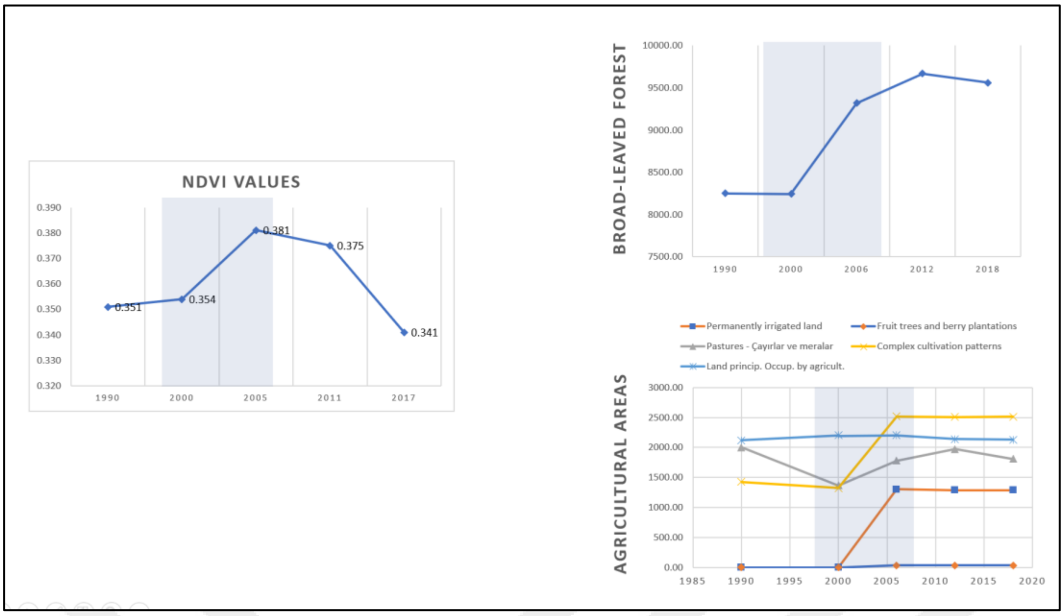


Figure 5.7 : Comparison between SoES-3 change and LULC conversions (2000-2005).

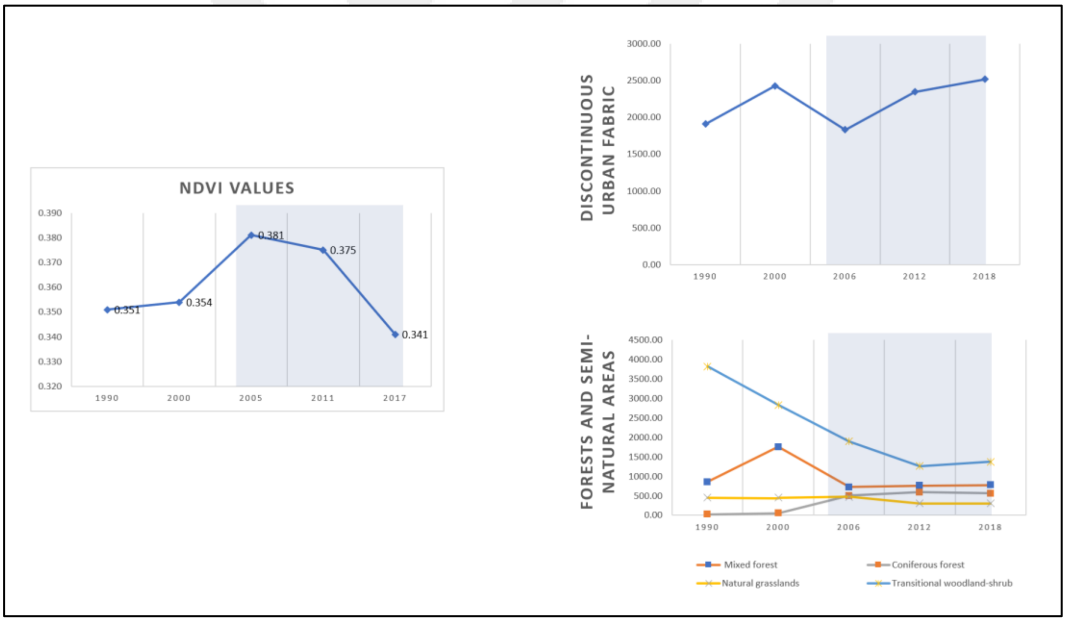


Figure 5.8 : Comparison between SoES-3 change and LULC conversions (2005-2017).

As NDVI is indicative of healthier and more abundant vegetation and is closely associated with total biomass, a decrease in NDVI values may imply a reduction in both the quantity and health of vegetation, potentially leading to diminished biomass production. In the case of the Buyukcekmece Watershed, under the assumption of constancy in other factors (e.g., agricultural land-use and cropping patterns, climatic conditions) and considering NDVI value as the sole proxy for vegetation productivity, it can be asserted that between the years 2005, 2011, and 2017 there is an evident trend of declining total biomass production and, consequently, NPP. This trend is attributed to diminished natural vegetation and decreased photosynthetic activity in the watershed.

The observed trend in NDVI decrease can have negative effects on the overall health and productivity of the ecosystem, potentially resulting in disruptions to energy and nutrient flows and impacts on other SoES. In the context of cumulative effects, it may adversely impact the food chain as well. Therefore, monitoring both the quantity and health of vegetation through NDVI changes becomes crucial for understanding and maintaining the overall state and health of the watershed ecosystem and its services.

The results of the analysis and comparative assessments indicate that the alterations in the LULC pattern in Buyukcekmece Watershed between 1990 and 2018 have either positive or negative effects on the three examined SoES. Indeed, the transformation of natural areas into artificial surfaces or the decrease in forests and pastures has led to a decline in all three SoES. Conversely, a trend of LULC change in the opposite direction has resulted in an increase in all examined SoES. In these evaluations, it is noted that the ES provided by the soil are directly connected to the LULC changes in the area. In other words, as mentioned in the literature review in the 2nd chapter of the study, LULC changes not only lead to alterations in the physical, chemical, and biological characteristics of the soil but also have significant effects on the capacity of providing SoES provision. Therefore, it can be concluded that the protection and enhancement of SoES are possible through the proper management of LULC changes in the area. Otherwise, it is envisaged that the fragmented LULC decisions neglecting soil functions and services could result in irreversible damage and losses in SoES in the long term.

Especially in densely populated cities characterized by rapid and unplanned urbanization trends, urban watersheds, such as Buyukcekmece Watershed, are directly affected by the consequences of LULC decisions, similar to other urban ecosystems that are ecologically sensitive (e.g., wetlands, riverine ecosystems, and riparian zones). At this point, unsustainable anthropogenic interventions can lead to cumulative and complex impacts on these fragile ecosystems, affecting both overall ecosystem health and human welfare. As one of these vulnerable ecosystems, considering the soil ecosystem within the scope of land use decisions in drinking water basins is crucial not only for the health of the soil and related ecosystems but also for the preservation of the quantity and quality of the drinking water reservoir provided by the watershed.

The incorporation of SoES into spatial planning decision-making processes and the prevention/ reduction of the pressures and threats on them require, first and foremost, the identification of areas critical for SoES. From this point of view, SoES in Buyukcekmece Watershed have been analyzed and mapped. In the maps, areas with high, medium, and low SoES provisioning capacities have been identified for each SoES (SoES-1: Surface water flow regulation, SoES-2: Carbon storage, SoES-3: Biomass production). In the analysis, SoES-2 has been categorized into two groups: ‘SOC storage’ and ‘Total carbon storage,’ representing the total carbon stored in aboveground biomass, belowground biomass, SOC, and dead organic matter.

These synthesis maps include:

- "Surface runoff regulation zones" define areas with high capability to control surface water flow based on HSG and the CN values
- The "zones with high carbon storage (total)" map shows areas with high total carbon stock in the watershed according to the results of the InVEST model
- The "zones with high carbon storage (SOC)" map displays areas with high SOC retained by the soil in the watershed according to the results of the InVEST model
- "Biomass production zones" represent densely vegetated areas with the highest mean NDVI value and are influential in biomass production

According to the "SoES-1: Surface runoff regulation zones" map shown in Figure 5.9, it is observed that the potential for regulating surface runoff is particularly low in the northern and eastern parts of the Buyukcekmece Lake. It can be stated that in these areas, the increased potential for surface runoff also corresponds to an increased risk of flooding and erosion.

The increased surface runoff in the watershed also implies a rise in diffuse pollution sources reaching the Buyukcekmece Lake. This includes the increase in pollution sources such as pesticides, artificial fertilizers, and pharmaceuticals, leading to potential degradation to water quality.

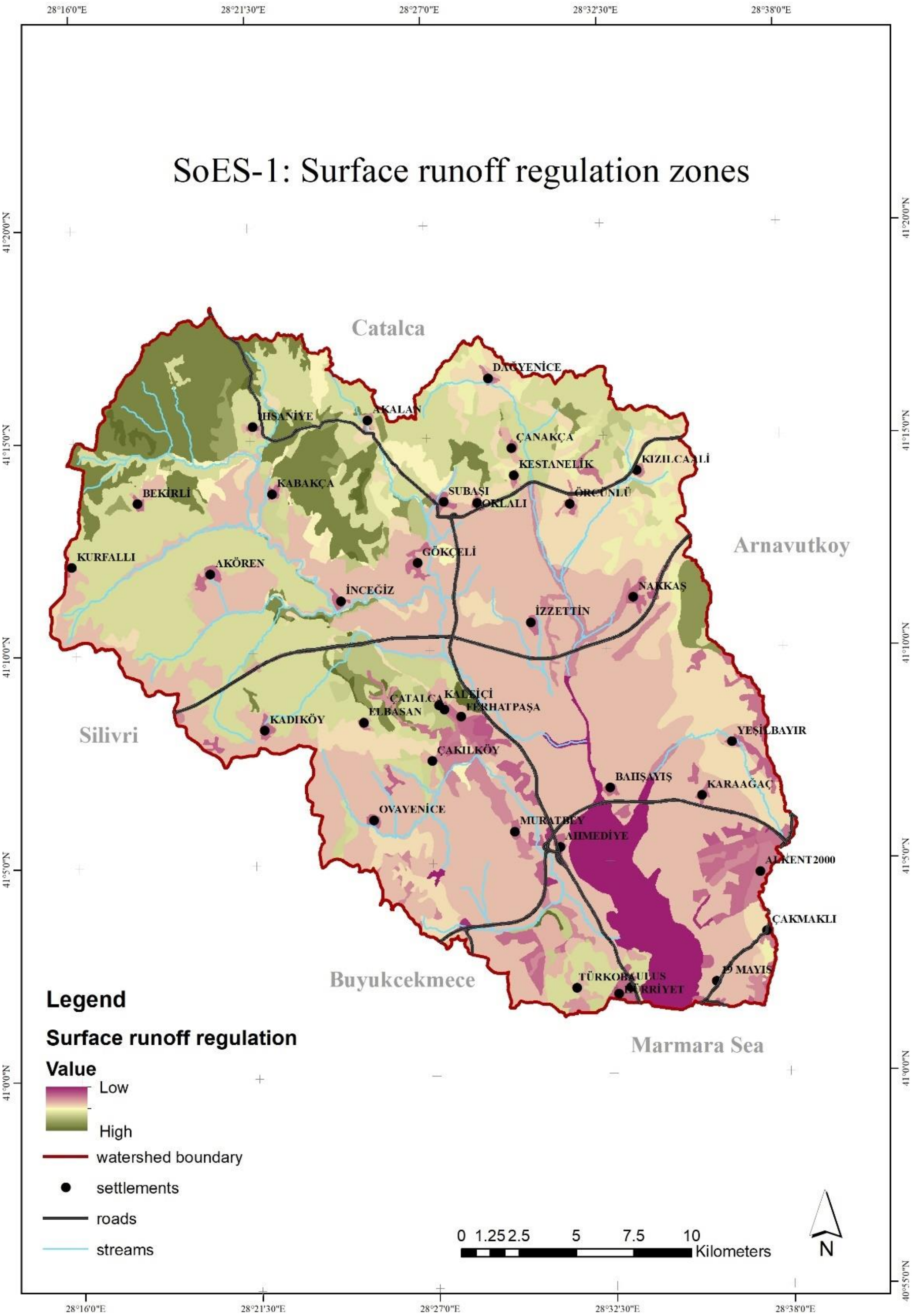


Figure 5.9 : Synthesis map on SoES-1 provision in Buyukcekmece Watershed.

On the other hand, in the forested northern part of the watershed and the western and northwestern parts of the Buyukcekmece Lake, it is observed that the surface flow regulation capacity of the watershed is at a moderate to high level, depending on the soil and land use characteristics. In these areas, the retention and infiltration of surface water by the soil are vital for soil fertility, food supply, and the continuity of chemical reactions carried out by soil microorganisms. Likewise, the storage of water in the soil and/or its percolation down to underground layers is of paramount importance for the continuity of significant functions and SoES such as the global water cycle and groundwater recharge.

It is observed that areas with low population density are generally concentrated in the central and northern parts of the watershed (see Figure 4.2). Herein, the careful consideration of land-use decisions would contribute to the protection and enhancement of critical zones with high SoES-1 provision capacity in these areas. On the other hand, it is observed that the section of the Northern Marmara Highway located to the west of the watershed (covering the settlements of Incegiz, Kadikoy, Elbasan, and Catalca Merkez) and the densely populated residential areas on the west side of the lake (Turkoba, Ulus, Hurriyet neighborhoods) have high capacity for regulating surface runoff.

Therefore, in the development of both macro and micro-scale spatial plans within these areas, it is recommended to consider zones of critical importance for SoES-1 as "priority protection zones". In these designated zones, the incorporation of natural water flow into urban design and planning is encouraged, by utilizing practical applications such as water-sensitive urban planning and design solutions (e.g., rain gardens, bioretention systems, porous pavements, constructed wetlands, and stormwater harvesting systems). Consequently, a myriad of advantages can be derived, encompassing proper management of stormwater and groundwater, preservation of water and soil quality, and the mitigation of potential hazards related to floods and erosion.

Upon reviewing the maps for "SoES-2: Zones with high total carbon storage" and "SoES-2: Zones with high soil carbon storage (SOC)" (Figure 5.10), it is observed that across the watershed, areas except the urban settlements exhibit a moderate level of both total carbon and SOC storage capacity. On the contrary, in built-up areas, where impervious surfaces are concentrated, both total carbon and SOC storage capacities are observed to be at their lowest levels. Yet, it is observed that the northwest of Buyukcekmece Lake (the area between the settlements of Incegiz, Elbasan, Cakil, Kaleici, and Ferhatpasa), has a very high capacity in terms of both total carbon storage and SOC storage. In the northern part of the watershed covered with forests, it is understood that the total storage capacity is high. These zones, identified as having critical importance for SoES-2, contribute significantly to soil and water quality, along with climate regulation. In fact, the soil serves as both the source and sink for GHG emissions that contribute to climate change. The emission flux rates of important climate change-related trace gases (e.g., CO_2, methane, and nitrous oxide) produced through physicochemical reactions by the soil ecosystem (e.g., microbial activity, root respiration, chemical decay processes) are dependent on meteorological and climatological parameters as well as land-use management practices. In other words, soil, depending on LULC, can function as a GHG source, contributing to climate change, or it can transform into a source that contributes to the reduction of GHG emissions and climate change impacts. This dual nature of soil in terms of climate regulation places soil and LULC in a critical position (for detailed information about the role of soil in climate change, please refer to section 2.3.2).

The carbon sequestrated and stored in soil is not only important for climate regulation. SOC is also essential for most of the vital soil functions, by supporting microbial activities and establishing a robust soil structure. Yet, the continuity of biogeochemical cycles, such as the water cycle, nitrogen cycle, and phosphorus cycle, which is carried out by soil microorganisms is dependent also on the presence of SOC. On the other hand, SOC, especially in watersheds crucial for drinking water such as the Buyukcekmece Watershed, holds great importance for both preserving the quantity and quality of water. It acts as a natural filter, trapping and immobilizing pollutants, such as nutrients, pesticides, and heavy metals, and helps to maintain the quality of water sources and reduces the risk of contaminants entering drinking water sources. Additionally, since SOC enhances soil structure and stability, it helps to prevent rapid runoff during intense rainfall, thereby reducing the risk of flooding and soil erosion.

When considering the multifaceted benefits of SOC, areas critical for SoES-2 provision in Buyukcekmece Watershed should be considered as “priority protection zones” in spatial planning decisions and the crucial role of soil in combating climate change should be highlighted. Especially in the area where Elbasan, Catalca Merkez, Kaleici, and Ferhatpasa settlements are located (in the sections near the road to the west of the Northern Marmara Motorway), developing LULC decisions in the scope of climate-sensitive urban planning and design measures would be beneficial for preventing SOC losses and aiming to increase SOC levels.

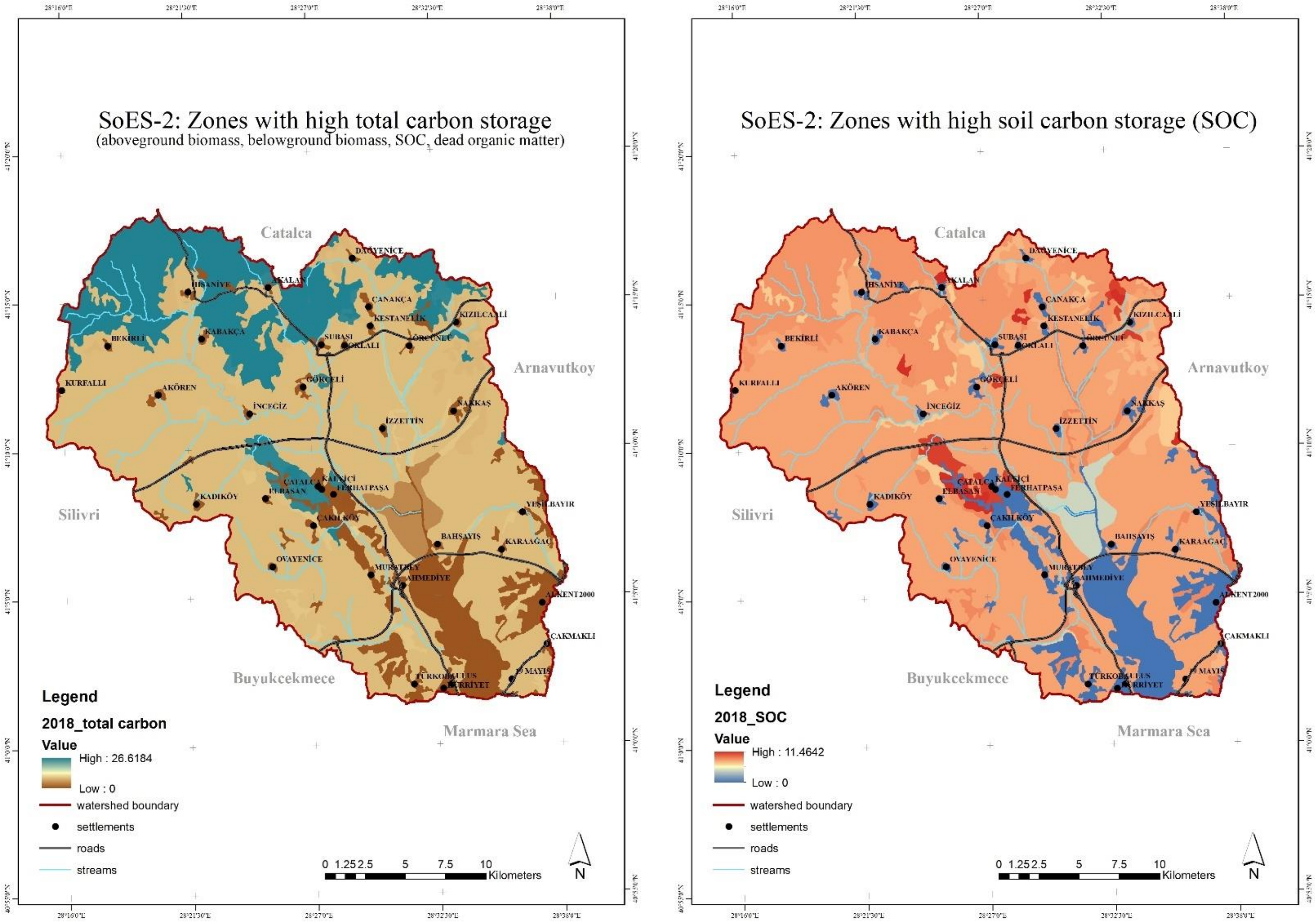


Figure 5.10 : Synthesis maps on SoES-2 provision in Buyukcekmece Watershed.

The predominant role of soil in combatting climate change is largely contingent upon LULC decisions. This underscores, once again, the significance of the land use decisions to be formulated carefully across the watershed area.

Lastly, critical areas for "SoES-3: Biomass production," representing another pivotal service offered by the soil, have been analyzed and mapped (Figure 5.11). The results derived from NDVI analyses suggest that the northern section of the watershed, characterized by forest cover, and the area encompassing Elbasan, Catalca Merkez, and Kaleici settlements, along with a segment of the Catalca Wind Energy Plant, demonstrate a significant capacity for providing SoES-3. These areas are also characterized by dense vegetation cover, that further contributes to increasing the capacity of soil for surface water regulation (SoES-1) and carbon storage (SoES-2).

As previously mentioned, soil plays a key role in the health and vigor of vegetation by offering the medium, soil water, SOM, and other nutrients necessary for plant growth. The total vegetation in an area represents the total plant mass, known as 'biomass,' and the vitality and growth of biomass are directly linked to NPP. NPP forms the basis for energy flow within the ecosystems and it serves as a critical link between primary producers and higher trophic levels. In this regard, both NPP and biomass hold critical importance for the global food chain and the continuity of life on Earth.

Given the crucial function of biomass production in enhancing both the quantity and quality of water, along with its contribution to other SoES and overall ecosystem health in Buyukcekmece Watershed, the areas critical for SoES-3 provision should be assessed as “priority protection zones”. Herein, it is recommended that LULC decisions, especially in the settlements located to the north of the watershed, the eastern and northern parts of Buyukcekmece Lake, and the zone spanning Elbasan, Catalca Merkez, and Kaleici settlements, should be developed within the context of low impact urban design and development (LIUDD), encompassing urban design practices that are sensitive to water and climate considerations. As a result, this approach aims to minimize the adverse effects on SoES resulting from LULC changes in the watershed, with the overarching goal of establishing comprehensive, SoES-based, and sustainable living environments.

The synthesis maps, generated through the analyses using local datasets such as soil, climate, and LULC characteristics, are expected to provide essential evaluation and analytical inputs for planners, decision-makers, and practitioners involved in formulating land use plans and practices, that take into account critical zones associated with "SoES-1: Surface water flow regulation," "SoES-2: Carbon storage," and "SoES-3: Biomass production."

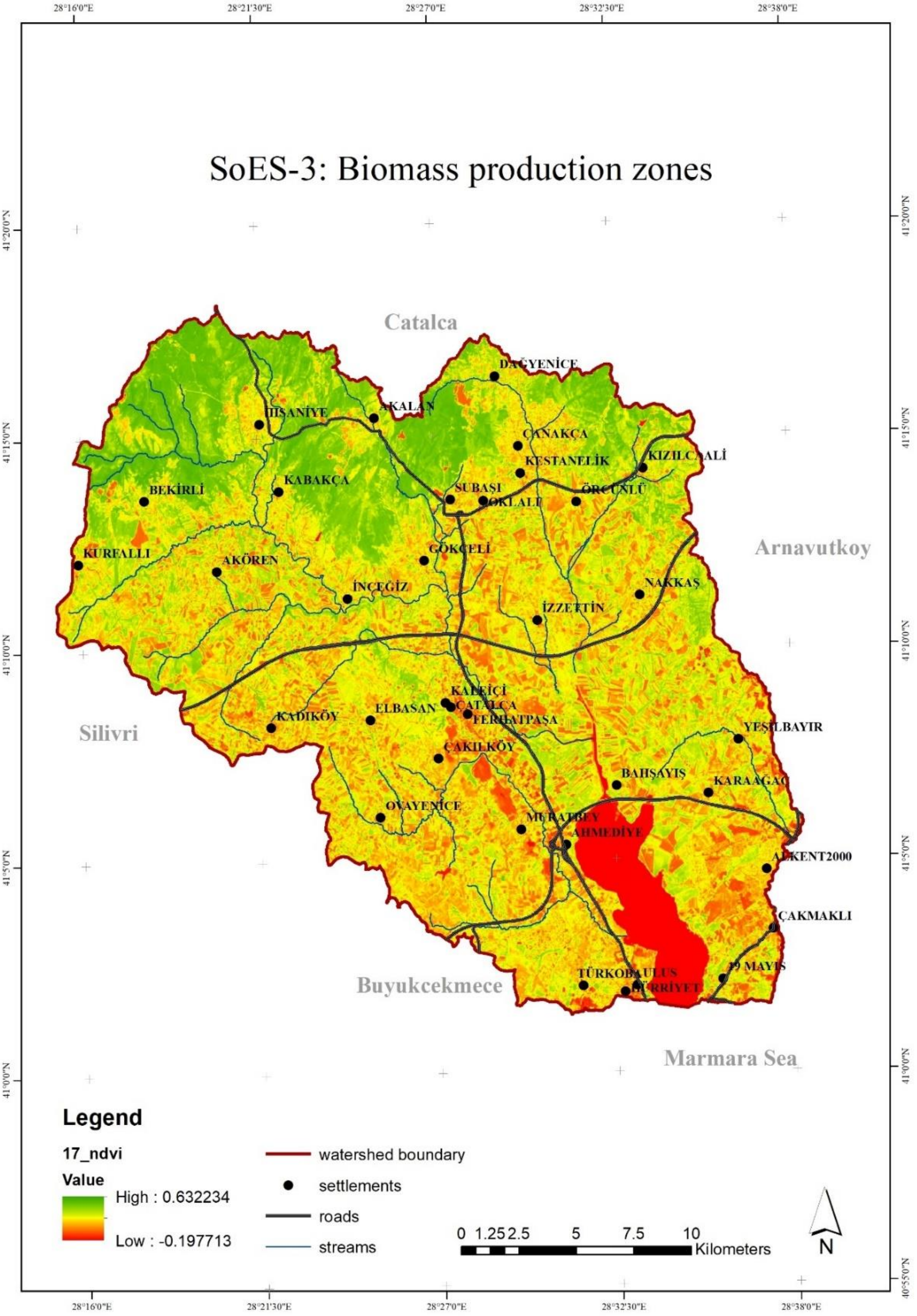


Figure 5.11 : Synthesis map on SoES-3 provision in Buyukcekmece Watershed.

As indicated by comparative analyses assessing the impacts of LULC transformations on the SoES, LULC decisions have direct and indirect effects on the improvement or degradation of the SoES. Therefore, it is crucial to develop comprehensive spatial planning approaches that aim to preserve and enhance SoES, while ensuring the protection of the quantity and quality of water in the watershed.

For a more comprehensive understanding of critical zones for SoES provision, a final synthesis map has been prepared in addition to the three synthesis maps mentioned above, to reveal the integrated SoES capacity in Buyukcekmece Watershed. This map was prepared using the synthesis maps shared in the previous section, which indicate critical zones for SoES-1, SoES-2 (SOC carbon), and SoES-3. The maps were integrated using overlay analysis (weighted sum) within the ArcGIS environment, considering specific measures and assumptions (Figure 5.12).

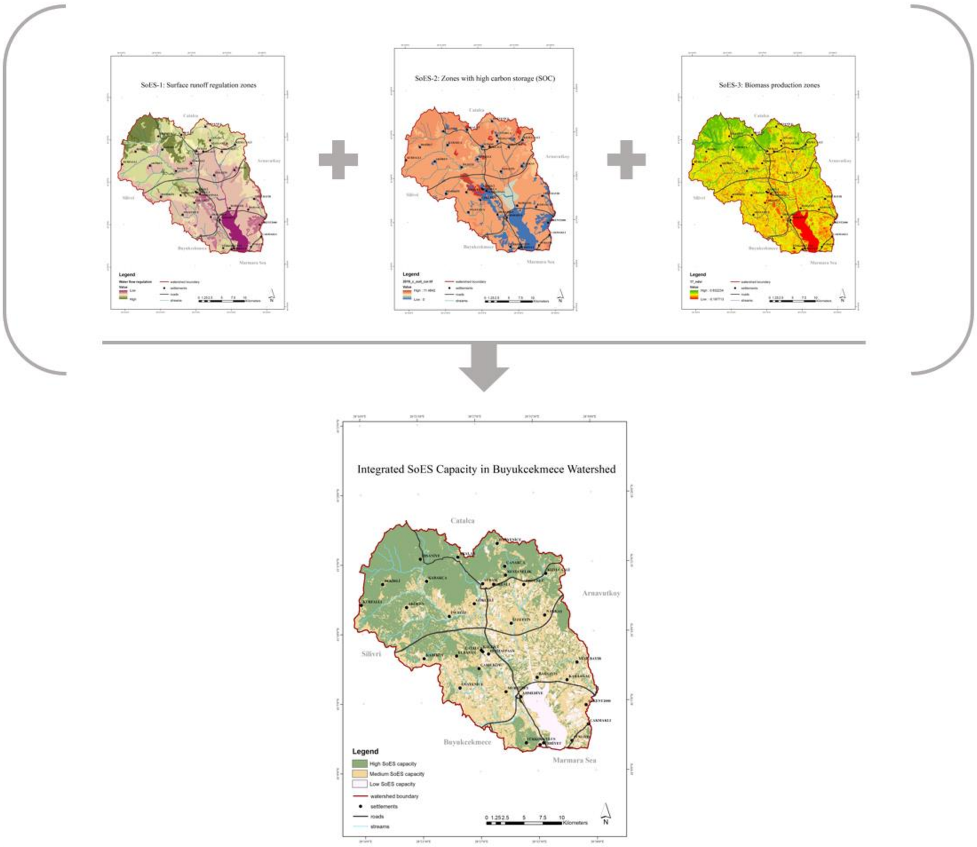


Figure 5.12 : Mapping In-SoES provision zones in Buyukcekmece Watershed.

Indeed, the scope, purpose, and priority of the SoES synthesis maps in overlay analyses may vary depending on the study area, necessitating adjustments to their significance and weighting accordingly. However, within the scope of this study, all three SoES components were considered to have equal weight of importance for the watershed and consequently, the "Integrated SoES Capacity in Buyukcekmece Watershed" map was developed (Figure 5.13). The map depicts areas with high, moderate, and low potential for providing integrated SoES (In-SoES) provisioning capacity.

Accordingly, the areas in the watershed with different LULC patterns and high In-SoES provision capacity are shown in Figure 5.14, including the area (1) the northern part of the watershed that includes mostly forests and agricultural lands; area (2) areas close to the eastern border of the watershed near the Nakkas settlement and characterized by forests; area (3) agricultural lands located around the Northern Marmara Motorway in the northwest of Buyukcekmece Lake; and area (4) the western part of the lake, which is currently covered by agricultural lands and built-up areas.

The continuity of the protection status of the forested areas in the northern part of the watershed is of great importance for preserving the In-SoES obtained from this area. On the other hand, when the In-SoES zones in Buyukcekmece Watershed are examined within the context of the urban development dynamics mentioned in section 4.1, it is considered that the opening of the 3rd Bosphorus Bridge (Yavuz Sultan Selim Bridge) in 2016 and the completion of the construction of the 3rd Airport (Istanbul Airport) in 2018, along with the Northern Marmara Motorway, could exert significant urbanization pressures on the watershed’s LULC pattern and In-SoES zones.

Indeed, the Northern Marmara Motorway, connected to the 3rd Bosphorus Bridge and the 3rd Airport, cuts across the watershed area horizontally, similar to other major transportation arteries in Istanbul, such as the TEM and E-5 Motorways. This situation also brings along the potential for possible LULC changes along the route of the road. Therefore, the central parts of the watershed (areas indicated as (2) and (3) on the map) may face various risks such as the expansion of urban areas, increase in impervious surfaces, soil sealing, soil compaction, and habitat fragmentation due to the impacts of transportation connections.

Another area of concern in terms of In-SoES is the western part of Buyukcekmece Lake, particularly the areas of Ulus, Hurriyet, and (including Tepekent) Turkoba, which are currently largely urbanized (indicated as area (4) on the map).

Figure 5.13 : Synthesis map on In-SoES provision in Buyukcekmece Watershed.

These residential areas (approximately a total of 55,000 population) are located within the boundaries of the "absolute protection zone (0–300 m)," "short-distance protection zone (300–1000 m)," "middle-distance protection zone (1000–2000 m)," and "long-distance protection zone (beyond 2000 m from the watershed boundary)," which require high restrictions for LULC changes due to ISKI's Regulation on Drinking Water Basins, are also situated in an area with high potential for In-SoES provision capacity (areas denoted as (4) in Figure 5.14) in the watershed, (Figure 5.15).

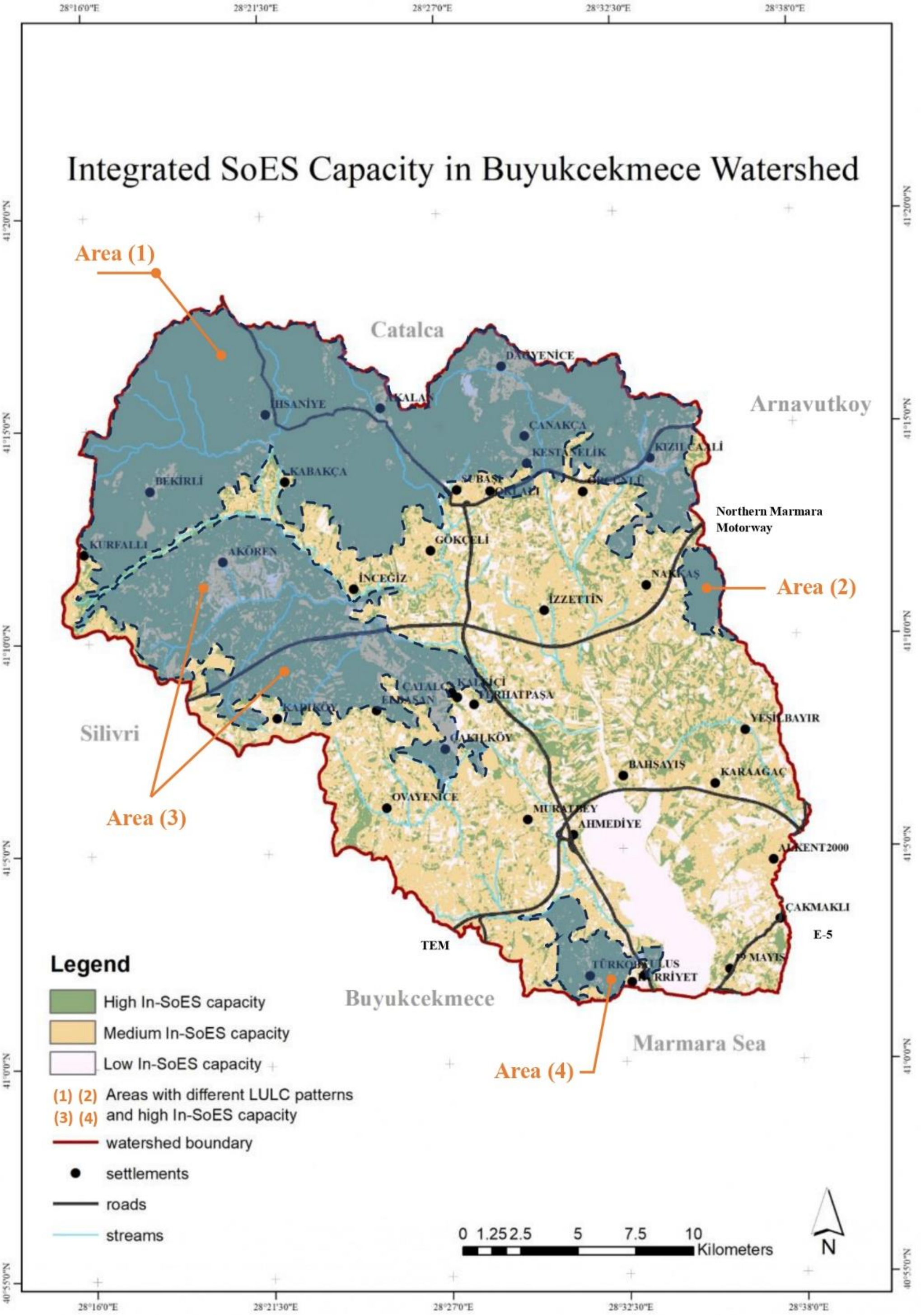


Figure 5.14 : Areas with high In-SoES capacity in Buyukcekmece Watershed.

The expansion of these areas towards the natural land cover in the area, which currently violates the restrictions of protection zones, poses a risk in terms of potential damage/loss to critical In-SoES zones, as well as deterioration of the watershed's water quantity and quality, and disruption of ecological integrity due to LULC transformation.

Figure 5.15 : In-SoES zones within the delineated watershed protection zones.

As a result, the research findings indicate that the zones with the highest In-SoES capacity in the watershed are currently under the pressure of major motorways and existing settlement dynamics. Therefore, land-use decisions developed in these areas must be restrictive and/or preventive against LULC changes that may adversely affect the SoES. In this context, taking into account the existing and potential anthropogenic pressures in the watershed, it is considered of great importance to consider the zones identified as critically important for In-SoES provision around the Northern Marmara Motorway (indicated in the map as areas (2) and (3)) and the partially urbanized area on the western shore of Buyukcekmece Lake (indicated in the map as area (4)) as "priority protected areas for preserving the quality and quantity of water in the watershed" in watershed protection and land-use plans.

When examining one of the most recent large-scale planning studies for the area, namely the Buyukcekmece Lake Watershed Special Provisions Project (2018) and the associated Buyukcekmece Dam Lake Protection Plan (2019), it is observed that the northern forest areas of the watershed, the area between the settlements of Incegiz, Elbasan, Cakil, Kaleici, and Ferhatpasa, including the area where the Catalca Wind Power Plant is located, and the area within the boundaries of Ulus and Hürriyet Neighborhoods, including the Tepecik sub-basin, have been designated as "Critical Protection Areas in terms of Water-Related Ecosystem Services (ES) Capacity". It has been determined that these areas, which prioritize the preservation of existing forest areas and prohibit excavation, dumping, and mining activities, bear a significant resemblance to the In-SoES zones identified within the scope of this research. Although the plan represents notable progress by incorporating the "ES" approach and providing analysis and recommendations for "Regulatory ES", it does not establish a direct link to SoES within its scope. In this regard, the failure to consider the connection between soil and water in the watershed protection plan prepared to preserve the quantity and quality of drinking water in a watershed is regarded as a significant deficiency. Furthermore, among the notable strengths of the plan for Buyukcekmece Watershed, which exhibits a distinct agricultural character, is the encouragement of biological control and biotechnical methods in place of agricultural pesticides that could contribute to water pollution. Supporting erosion-reducing techniques, endorsing good agricultural practices, and proposing green belt areas are also highlighted as strong points of the plan.

Another overarching plan guiding the land use decisions in the watershed is the 1:100,000 scaled Istanbul Metropolitan Area Environmental Master Plan, prepared in 2009.

In the plan, the area is defined as a vital watershed crucial for ensuring environmental sustainability. The decisions taken in the plan regarding the watershed include areas assigned for rehabilitation within the watershed, areas to preserve agricultural qualities, ecological farming zones, forested areas, critical areas for environmental sustainability, and areas designated for preserving natural and rural character, as illustrated in Figure 5.16. According to the plan, settlements except the residential areas in the south of the watershed mostly exhibit a "Rural Settlement (KY)" character. Furthermore, the area where the Catalca Wind Power Plant is located today (the area between Elbasan, Kaleici, Catalca Merkez, and Ferhatpasa settlements) is defined in the plan as a "Critical Area for Environmental Sustainability (CS)" and the area near the Akoren settlement in the northeast of the watershed is designated as an "Ecological Farming Zone (ETA)."

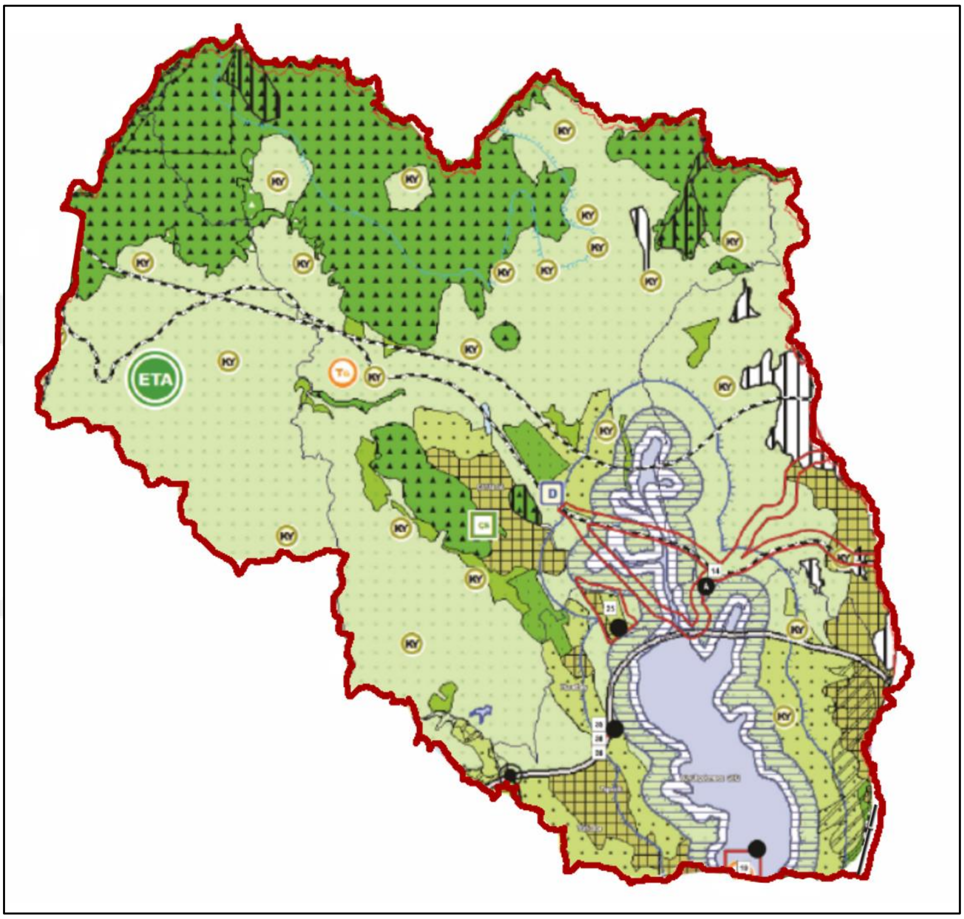


Figure 5.16 : Planning decisions for Buyukcekmece Watershed in the 1:100,000 scaled Istanbul Metropolitan Area Environmental Master Plan.

When compared with the current land use status, among the plan decisions taken for Buyukcekmece Watershed in the Metropolitan Area Environmental Master Plan, the most notable areas in terms of proposed LULC decisions and the current LULC pattern are the ones located to the east and west of the Buyukcekmece Lake, highlighted with red frames in Figure 5.17. According to the map:

- The entire area located in the short-distance protection zone in the east and west of Buyukcekmece Lake is designated as "Area to Preserve Agricultural

Qualities" in the plan. However, it is observed that a significant portion of the settlements of Ahmediye and Bahsayis, as well as the neighborhoods of Hurriyet and Ulus, are currently located within the short-distance protection zone. Yet, a built-up portion of the Tepecik sub-basin within the boundaries of Ulus and Hurriyet neighborhoods is situated in the absolute protection zone defined as "Area with Prohibited Construction within the Watershed" within the scope of the plan.

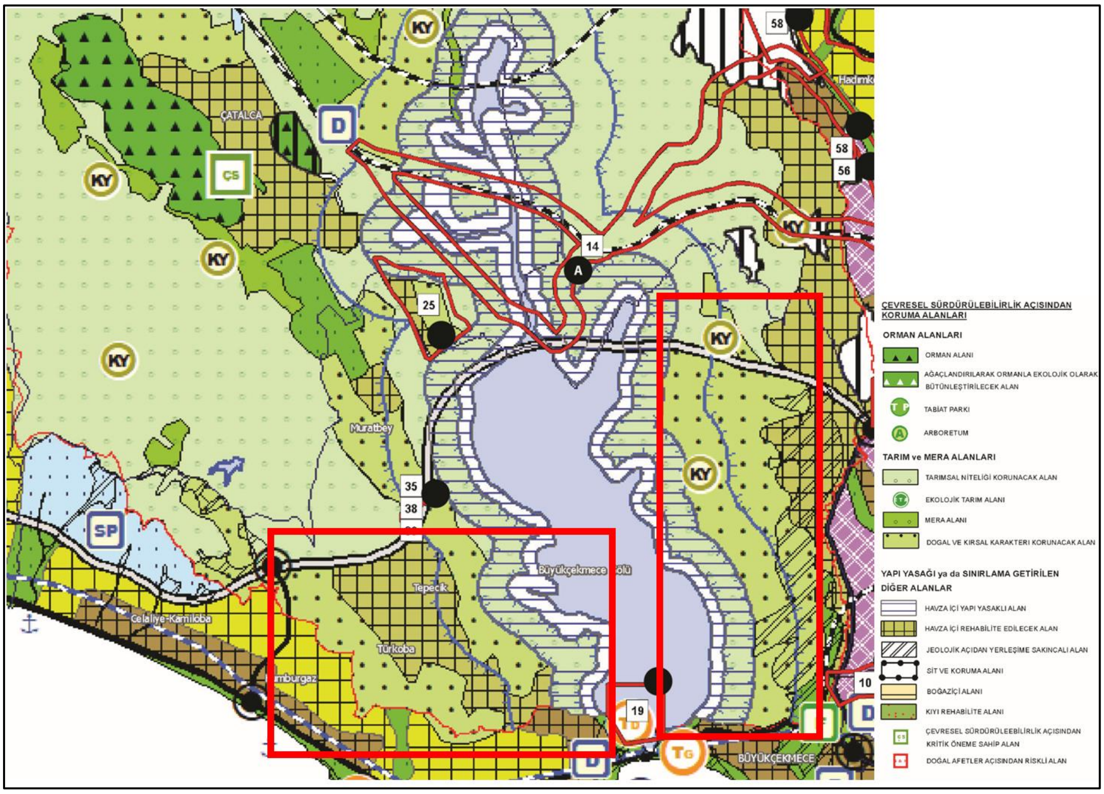


Figure 5.17 : Planning decisions for the eastern and western parts of the Buyukcekmece Lake.

- The entire area in the medium-distance protection zone to the east of the lake, and a portion of the long-distance protection zone, are described in the plan as "Area to Preserve Natural and Rural Qualities." However, it is observed that the densely built Alkent 2000 neighborhood extends beyond the designated settlement boundaries in the plan, spreading into both protection zones today.
- According to the plan, the areas encompassing Ulus, Hurriyet, Turkoba, Alkent 2000, Cakmakli, Yesilbayir, Cakilkoy, Ferhatpasa, Kaleici, Catalca Merkez, Muratbey, and Ahmediye settlements are designated as "Areas to be Rehabilitated within the Watershed." Notably, Alkent 2000 and Cakmakli fall

within the boundaries of areas marked as "geologically constrained for settlement."

The zones to the west of Buyukcekmece Lake were identified as "Areas to Preserve Natural and Rural Qualities," as well as "Areas to Preserve Agricultural Qualities," and the zones containing the neighborhoods of Hurriyet, Ulus, and Turkoba were designated as "Areas to be Rehabilitated within the Watershed," concurrently serve as crucial zones with a high capacity to provide In-SoES.

Certain areas where residential areas are presently located (e.g., Alkent 2000 Neighborhood to the east of the Buyukcekmece Lake) are identified in the plan as "Areas Requiring Absolute Protection for Agriculture" (highlighted with a black frame in Figure 5.18).

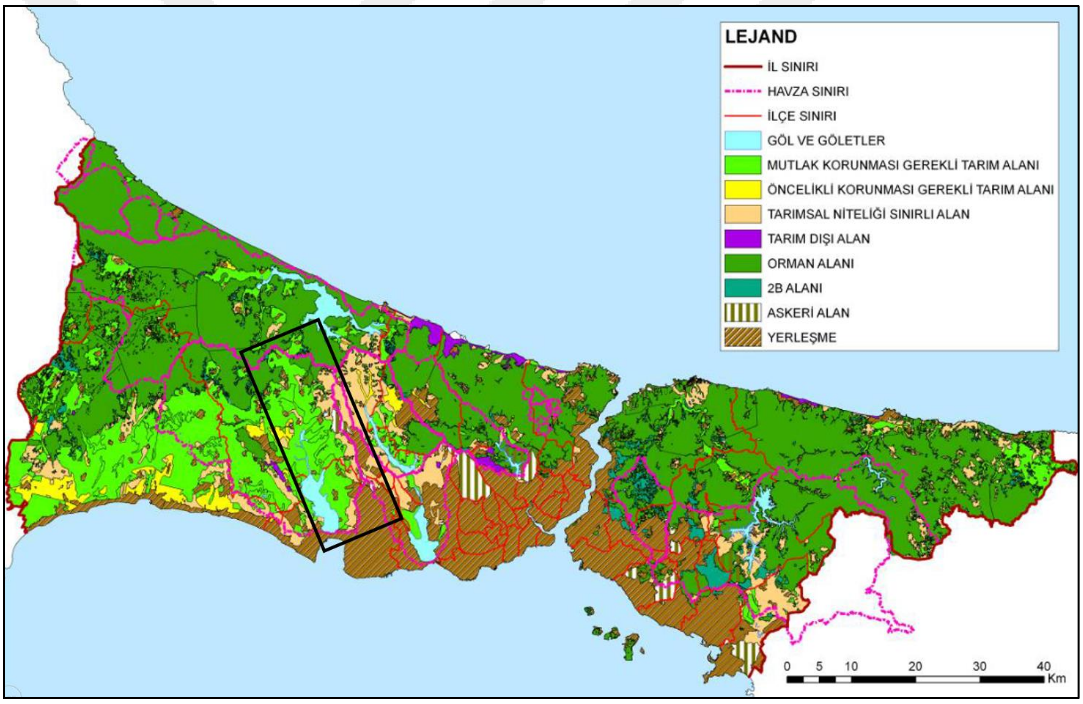


Figure 5.18 : Synthesis map on agricultural areas of the Istanbul Metropolitan Area Environmental Master Plan.

Furthermore, two of the four critical areas identified with high In-SoES capacity in Figure 5.14 (the area to the west of the Buyukcekmece Lake where Ulus, Hurriyet, and Turkoba settlements are located, depicted as area (4) and the east of Nakkas settlement, indicated as area (2) on the map) are defined as "Existing and irregular residential areas developed on natural thresholds" within the scope of the plan (highlighted with a black frame in Figure 5.19). The threshold value mentioned here is residential areas built on the stream beds in the watershed.

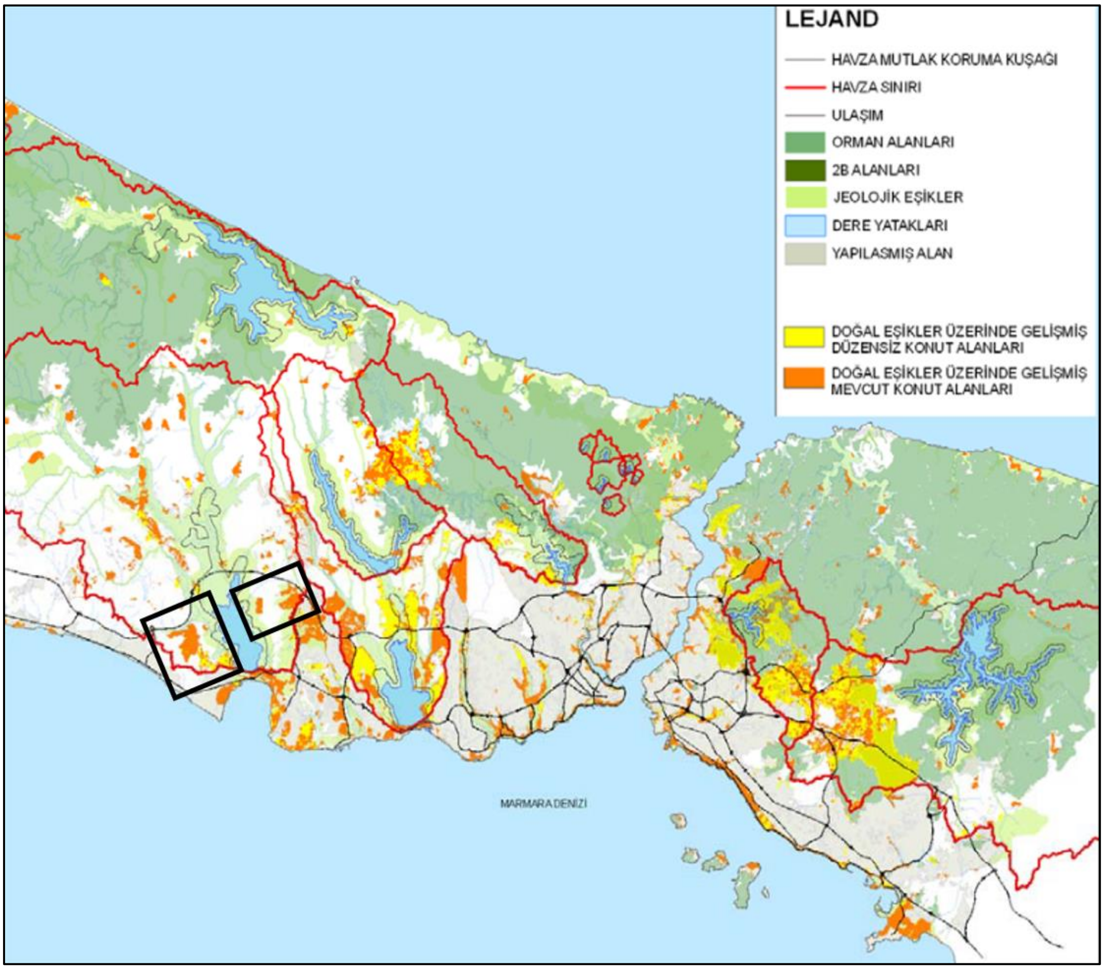


Figure 5.19 : Map of existing and irregular residential areas developed on natural thresholds in the Istanbul Metropolitan Area Environmental Master Plan.

Upon examining the plan decisions and the current land use in the watershed, it is evident that the decisions of the 1:100,000 scaled Istanbul Metropolitan Area Environmental Master Plan in the Buyukcekmece Watershed and the protection zones in the watershed have been violated in certain areas. Particularly, it is observed that the area defined as "Area Requiring Absolute Protection for Agriculture" to the east of the watershed and the areas within the protection zones to the east and west of the lake in the southern part of the watershed (areas with high In-SoES capacity), are under significant urbanization pressure.

At this point, one of the most significant reasons for the disruption of the holistic structure of the plan is the numerous parcel plan decision changes made since the plan approval in 2009 by the initiation of mega projects (such as the 3rd Airport, 3rd Bridge, and the Canal Istanbul Project), and the subsequent opening up of urban development, leading to an increase in anthropogenic pressure on natural areas. This situation, which directly accelerates the transformation of the LULC pattern against the sustainability of SoES in the watershed, not only poses a threat to critical urban watersheds but also undermines the "gradual integration principle" of the existing planning hierarchy that aims to balance the conservation and use of natural, historical, and cultural values. To sum up, the key gaps and challenges encountered in the comprehensive understanding and preservation of water-soil relationships in Buyukcekmece Watershed include:

(i) The absence of a shared scientific methodology and approach for analyzing the SoES in the watershed and identifying the critical zones for SoES provisioning capacity

(ii) The lack of emphasis on the importance of SoES in the plans aimed at preserving the quantity and quality of drinking water in drinking water basins, as well as in relevant legal regulations (e.g., Regulation on Drinking Water Basins)

(iii) The neglect of urban soils and the ES approach, especially that of SoES, within the current planning hierarchy, influences LULC decisions.

In this context, the next section (5.2: Suggestions on Integrating SoES into Urban Spatial Planning Framework) presents recommendations for incorporating the SoES provided by urban soils into the spatial planning framework related to watershed protection, using the Buyukcekmece Watershed Case as a reference.

5.2 Suggestions on Integrating SoES into Legislative Framework and Spatial Planning

Literature and research findings highlight the direct influences of LULC changes on the provisioning of SoES. Therefore, the proper management of LULC at multiple scales plays a central role in ensuring the integrity of the soil ecosystem.

In the preceding section, an emphasis was placed on the significance of identifying and mapping areas of critical importance for the provision of the SoES, serving as a guide for LULC decisions. Therefore, in the synthesis maps, areas characterized by varying levels of SoES provision capacity (high, medium, and low) in Buyukcekmece Watershed were identified, and planning decisions within these areas were assessed. It is evident that the zones of critical importance in terms of SoES provision in Buyukcekmece Watershed are experiencing considerable urbanization pressure. In the watershed, the expansion of built-up areas, coupled with anthropogenic activities (e.g., mining, and industrial expansion), is giving rise to various environmental problems such as water and soil pollution, elevated erosion, and landslide risks. It is anticipated that recent and prospective large-scale (mega) projects, lacking necessary measures, may intensify this pressure in the watershed, thereby jeopardizing its status as a drinking water source and posing threats to its ecological integrity and health.

At this point, it is apparent that the generation of SoES synthesis maps alone will not be adequate for the effective management of LULC decisions. To facilitate the development of necessary measures, it is important to ensure that the outputs obtained within the scope of this research serve as inputs to spatial plans and the relevant legal framework, guiding LULC decisions. Henceforth, as an initial step, developing a shared approach for SoES assessment is considered.

5.2.1 A new approach for watershed management: In-SoES Model

Presently, there is no common framework or scientific methodology in place for the analysis and mapping of the SoES. In response to this gap, the "In-SoES Model” has been developed in the context of this research.

The model aims to provide decision-makers and practitioners with a comprehensive foundation and content for quantifying, mapping, and analyzing SoES, either individually or in an integrated manner, within a specified area. At its core, the model is prepared by compiling the studies conducted in the Buyukcekmece Watershed Case, considering encountered challenges, proposed solutions, and lessons learned. In the model, the application steps to be followed for the SoES analysis are categorized into four stages (Figure 5.20). These stages include S.1: Preparation; S.2: Dataset Building; S.3: Analysis/Validation; S.4: Synthesis Maps.

The initial stage of preparatory work is crucial as it serves to establish both a foundation and a framework for the subsequent stages. In the preparatory stage of the SoES analysis, it is essential to initially define the scope and boundaries of the study area. The research can be conducted at the urban scale, or smaller, more localized scales such as ecological units like watersheds or urban parks. Following the determination of the study area, it is essential to comprehensively outline the potentials, risks, threats, and problems of the area to guide the study effectively. One of the subsequent and pivotal steps in the preparatory stage is the selection of the Nexus connection pool to be incorporated into the analysis. The 'SoES-Climate change-LULC-Spatial Planning Nexus Framework,' detailed in Chapter 2.5, emphasizes the importance of evaluating variables collectively instead of focusing on an individual component.

In this context, the connection pool to be analyzed within the scope and objectives of the research is important for a better understanding of the interdependencies among pillars in the study area. Determining the scope, objectives, and limitations of the research, selecting the SoES to be included in the study, and choosing the time frame for the work are other components of the preparatory stage.

The next stage in the SoES analysis involves dataset building. This stage encompasses the identification of suitable analysis methods and tools based on the identified connection pool, selected SoES, and the scope and objectives of the research. Accordingly, if multiple SoES are chosen to be assessed, and different methods are included for analyzing each SoES, a multi-tiered approach that provides a combination of different techniques could be adopted. Within the analytical framework, it is critical to specify the assessment criteria and the indicators for each SoES (refer to Table 3.1 for detailed information). Following the determination of the method and evaluation criteria, ensuring data acquisition and preparing the data for analysis through preprocessing is imperative. The documentation of metadata contributes to a better understanding of the method and the scope of the analysis while serving as a guiding reference for future studies.

The third stage of the model involves analysis and validation studies. In this phase, the data obtained in the dataset-building stage, which has been prepared for analysis through preprocessing, is analyzed according to the specified method.

One of the most critical applications in this stage is the validation of the obtained analysis results by comparing them with real-time data or ground-based measurements.

IN-SoES MODEL STAGES

S.1 Preparation	S.2 Dataset building	S.3 Analysis/Validation	S.4 Synthesis Maps
▪ Determination of the geographic extent of the study (i.e., city scale or watershed scale, assessment)	▪ Selection of the appropriate method(s) and tool(s) for the analysis of selected SoES	▪ Analysis of the SoES provision by using the selected methodology and tools	▪ Identifying and mapping the critical zones for SoES provision for each SoES analyzed
▪ Identification of the potentials, risks and problems of the area	▪ Definition of the assessment criteria and indicators (representative variables for each SoES)	▪ (if needed) Analysis of the changes in SoES provision over the designated study period	▪ Identifying and mapping the zones with critical importance for In-SoES provision
▪ Selection of the Nexus connection pool(s) to be studied (based upon the context and purpose of the project)	▪ Collection of the required (qualitative/quantitative) data via field surveys, sampling, open data, expert surveys, etc.	▪ (if needed) Analysis of the relationship between SoES changes and observed alterations in other variables (e.g., LULC)	▪ (if needed) Identifying and mapping the spatio-temporal changes in SoES provision over the study period
▪ Determination of the scope, goal(s) and limitations of the study	▪ Compilation and pre-processing of the acquired data	▪ Validation of the research findings with real-time data and/or ground data	▪ (if needed) Identifying and mapping other variables effecting SoES (e.g., LULC)
▪ Selection of the SoES to be analyzed ▪ Selection of the time period to be studied	▪ (if applicable) Documentation of the metadata to provide contextual information about the dataset	▪ (if needed) Scenario analysis to assess the possible future impacts (e.g., LULC change, climate variations) on SoES	▪ (if needed) Mapping the endangered zones (under natural and anthropogenic threats) with high SoES potential

IN-SoES MODEL OUTPUTS

Status	Description
Zones with high In-SoES provision capacity	These zones are areas with the highest provision capacity in terms of all SoES analyzed in the study area. These areas, which can be distributed and vary in size, are the most critical zones that should be primarily considered for the protection and development of SoES. Except for waste water treatment facilities to be constructed or commissioned by the administration, no construction or waste disposal of any kind is allowed in these areas, regardless of the purpose.
Zones with medium In-SoES provision capacity	These zones are areas with a moderate provision capacity in terms of all SoES analyzed in the study area. In these areas, which can be distributed and vary in size, establishment of new road routes, mining activities, new industrial establishments, service stations, fuel filling stations, storage facilities for chemical substances, fuels, toxic, harmful, and hazardous materials, as well as industrial and domestic solid waste storage and disposal centres are not allowed. Limited livestock activities are permitted in the area, while promoting good agricultural practices, water-sensitive, and climate-sensitive urban design solutions.
Zones with low In-SoES provision capacity	These zones are areas with a low provision capacity in terms of all SoES analyzed in the study area. In these areas, which can be distributed and vary in size, establishment of new industrial establishments, service stations, and fuel stations are not allowed. New road constructions and maintenance are permitted under the condition of protecting areas with 'high' and 'medium' In-SoES provision capacity near the highway (if any). Mining activities are permitted with the approval of the authorized institution in accordance with the Mining Law No. 3213.

Figure 5.20 : Stages of In-SoES Model.

Additionally, if required by the scope of the study, scenario studies can be developed to explore possible future impacts on SoES and associated variables (e.g., LULC and climate patterns). Sharing constraints, technical challenges, and assumptions encountered during the dataset-building and analysis stages can be beneficial for guiding future studies.

The final stage of the In-SoES Model is the synthesis maps stage. As implied by its name, this stage focuses on representing the spatial distribution and cartography of the analysis results. By utilizing the research findings obtained during the analysis stage, zones with SoES provision potential are mapped for each examined SoES. When dealing with multiple SoES, the initial step involves determining the importance and priority levels of the selected SoES within the working area and research scope. Subsequently, an integrated SoES map representing the overall SoES potential of the area is prepared using the weighted overlay technique. In addition to these maps, if deemed necessary, spatial mapping studies on SoES/In-SoES changes can be conducted. These change maps can be compared with the change maps of other components affecting SoES (e.g., LULC, climate variations, topography) and interpret the relationships between them. Furthermore, detailed maps highlighting endangered SoES zones can be prepared enabling more intricate examinations of these vulnerable areas at the local scale. In terms of sharing experiences, elucidating lessons learned, and discussing challenges faced during the stages of data acquisition, analysis, interpretation of outputs, and mapping, as well as articulating the limitations (both conceptual and technical constraints) of the research, is valuable for shedding light on implications for future research.

Clearly, the most significant outputs of the model are the final synthesis maps. These outputs are essential for determining zones with varying provision capacities in terms of SoES in the area and spatially visualizing them. As a result of the four-staged model framework, areas of critical importance for In-SoES (or SoES if a single one is being analyzed) are identified. These areas are classified based on In-SoES provision capacities as high, medium, and low capacity. Particularly, zones with high and medium In-SoES capacities are identified as the most crucial for the protection and development of soil quality, functions, and (studied) services in the area. Therefore, as seen in Figure 5.20, specific restrictions have been imposed on human activities in these areas.

A similar methodology is also found in the Regulation on Drinking Water Watersheds presented by ISKI. The current protection approach involves the classification of protection zones based on their proximity to water reservoirs (i.e., absolute protection zone, short-distance protection zone, middle-distance protection zone, and long-distance protection), with the overarching goal of protecting both the water quantity and quality in drinking water basins. However, as highlighted by Turer Baskaya and Tekeli (2016), this approach, which relies solely on metric distances, does not take into account the ecological characteristics of the watershed and needs additional protection measures to address the ecological significance of the watershed.

At this point, the close connection between soil and water, which is independent of both inherent and administrative boundaries, should be prioritized. Indeed, soil plays pivotal roles in ensuring the continuity of the water cycle, preserving the quantity and quality of surface and groundwater, and facilitating the efficient progress of other fundamental ecological processes in the watershed, such as biogeochemical cycles, carbon storage and sequestration, and food provision. Hence, expanding the current protection zone approach to consider the soil and the ES it provides would make a significant contribution to the health and ecological integrity of the watershed.

In this context, it is recommended to integrate the synthesized maps generated by the model into the traditional watershed protection zone approach used by ISKI (Figure 5.21). In the approach explained through the example of Buyukcekmece Watershed, zones with high, medium, and low In-SoES capacities presented in the synthesis maps are integrated with the categories in the current protection approach (absolute protection zone, short-distance protection zone, medium-distance protection zone, and long-distance protection zone). As a result, four different protection categories are established, under the proposed 'SoES-based Watershed Protection Zones' approach:

(i) Absolute protection zone: The area designated as the absolute protection zone encompasses areas identified as having a "high" SoES provision capacity in the SoES synthesis map of the watershed.

(ii) Primary protection zone: The area designated as the primary priority protection zone encompasses areas identified as having a “medium" SoES provision capacity in the SoES synthesis map of the watershed.

(iii) Secondary protection zone: The area designated as the secondary priority protection zone encompasses areas identified with a “low" SoES provision capacity in the SoES synthesis map of the watershed.

(iv) Tertiary protection zone: The area designated as the tertiary priority protection zone encompasses the entire land extending from the upper limit of the secondary priority protection zone to the ultimate boundary of the watershed (the area referred to as the “long-distance protection zone” in the current regulation).

This newly developed approach aims to establish a comprehensive and SoES-based understanding of watershed protection zones that considers both the safeguarding and enhancement of SoES, while also addressing the ecological sensitivities of the watershed.

Consequently, the 'priority protection area' approach for preserving the quality and quantity of drinking water in the watershed goes beyond a distance-based perspective and offers comprehensive content that takes into account the intricate and inseparable relationship between urban soils and water in the watershed.

In areas where In-SoES capacity is moderate to high within the identified protection zones, the promotion of ‘water-sensitive, climate-sensitive, and/or low-impact urban planning and design’ solutions that integrate nature into urban areas will contribute practically to the development of a SoES-based watershed planning approach. Furthermore, it is anticipated that the Blue Infrastructure (based on SoES-1 zones), Brown Infrastructure (based on SoES-2 zones), and Green Infrastructure (based on SoES-3 zones) patterns which will be examined on a macro-scale, will serve as complementary initiatives to the proposed applications at the local level.

Herein, the Blue-Brown-Green Network to be established in Buyukcekmece Watershed will encompass all three SoES components (surface flow regulation, climate change precautions, and biomass production), providing a connected and comprehensive ecological system that ensures soil, water, and vegetation connectivity across the entire watershed.

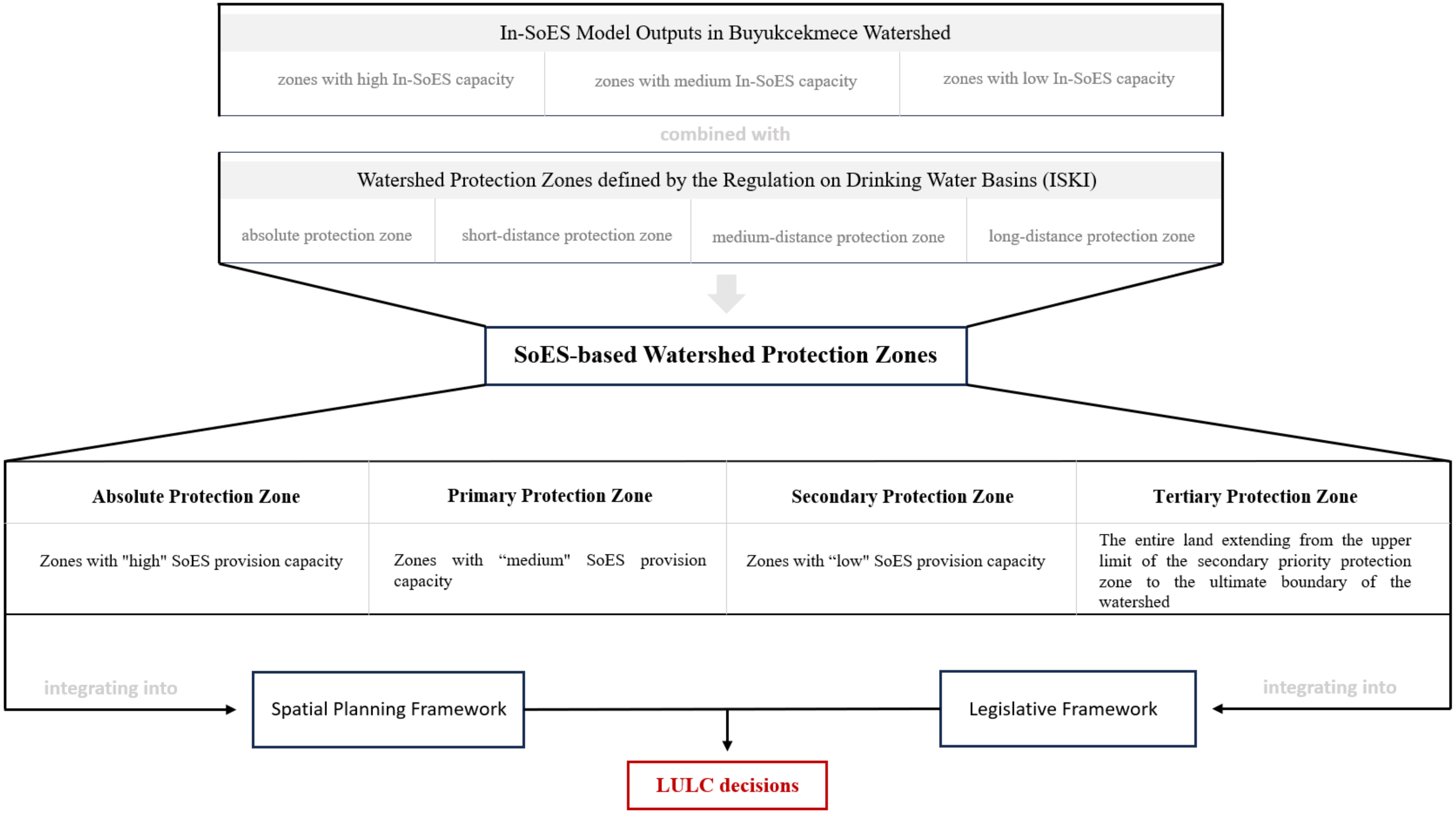


Figure 5.21 : Proposed framework for “SoES-based Watershed Protection Zones”.

The idea of considering Blue-Brown-Green Infrastructure as part of 'grey infrastructure' (built-up, engineered, physical infrastructure) will contribute to establishing a watershed protection approach that takes into account the following priorities;

- Providing multiple benefits beyond the area, as required by the Nexus approach (e.g., maintaining food security, promoting biodiversity, reducing flood risk, protecting water and soil quality, mitigating the urban heat island effect, increasing SOC, supporting sustainable urban development)
- SoES-based protection approach supported by spatial planning and relevant legal framework
- The ultimate aim of safeguarding and enhancing SoES, while considering the multifaceted interactions in the SoES-Climate Change-Spatial Planning Nexus approach.

For the widespread adoption, enforcement, and systematic implementation of this approach (as shown in Figure 5.21), the SoES context and the proposed protection zone approach need to be considered not only within the framework of the Regulation on Drinking Water Basins but also within the scope of other relevant legislation (e.g., Soil Conservation and Land Use Law, Regulation on Water Pollution Control, Regulation on Spatial Plans Making, Environment Law) and should be incorporated into the spatial planning processes influencing for LULC decisions.

5.2.2 In-SoES Model in legal framework and spatial planning

As mentioned in the previous section, in order to prevent or minimize the negative effects of LULC changes on urban soils and to enhance the SoES, approaches that take SoES into account need to be integrated into the relevant legislative framework and spatial planning decision-making processes. In this context, firstly, the legislative framework to be examined within the scope of the research was determined, and a contextual assessment of laws and regulations was carried out in relation to their relevance to SoES. The selected laws and regulations in Turkiye were listed in four categories depending on their contexts: (i) soil-related legislation; (ii) water-related legislation; (iii) spatial planning-related legislation; and (iv) other related legislation. These legal instruments included in the scope of the research are as follows:

A. Soil-related legislation

- Soil Conservation and Land Use Law (No. 5403) (in Turkish: 5403 Sayılı Toprak Koruma ve Arazi Kullanımı Kanunu, 2005)
- Regulation on Soil Pollution Control and Point Source Polluted Areas (in Turkish: Toprak Kirliliğinin Kontrolü ve Noktasal Kaynaklı Kirlenmiş Sahalara Dair Yönetmelik, 2010)

B. Water-related legislation

- Regulation on the Protection of Groundwater against Pollution and Deterioration (in Turkish: Yeraltı Sularının Kirlenmeye ve Bozulmaya Karşı Korunması Hakkında Yönetmelik, 2007)
- Regulation on Drinking Water Basins (in Turkish: İçmesuyu Havzalari Yönetmeliği, 2011)
- Regulation on Water Pollution Control (in Turkish: Su Kirliliği Kontrolü Yönetmeliği, 2004)

C. Spatial planning-related legislation (including two spatial plans)

- The Law of Development (No. 3194) (in Turkish: 3194 Sayılı İmar Kanunu, 1985)
- Regulation on Spatial Plans Making (in Turkish: Mekansal Planlar Yapım Yönetmeliği, 2014)
- Special Provisions and Watershed Protection Plan of Buyukcekmece Dam Lake (in Turkish: Büyükçekmece Baraj Gölü Özel Hükümleri ve Havza Koruma Planı, 2019)
- Turkey’s National Climate Change Adaptation Strategy and Action Plan (NCCAP) (2011-2023) (in Turkish: Türkiye'nin İklim Değişikliği Uyum Stratejisi ve Eylem Planı, 2012)

D. Other related legislation

- Environment Law (No. 2872) (in Turkish: 2872 Sayılı Cevre Kanunu, 1983)
- Forest Law (No. 6831) (in Turkish: 6831 Sayılı Orman Kanunu, 1956)
- Law on pastures (No. 4342) (in Turkish: 4342 Sayılı Mera Kanunu, 1998)

- Mining Law (No. 3213) (in Turkish: 3212 Sayılı Maden Kanunu,1985)

The contents of the selected laws and regulations were comprehensively examined under six key themes to investigate their interactions with ES/SoES, Urban Soils, Spatial Planning, and Climate Change. The legislations were analyzed under these themes to understand the current state of the ES/SoES approach within the existing legal framework and consequently, to identify the potential gaps and areas for improvement for each legal tool. The themes defined in the context of the research are as follows:

- Incorporation of definitions for ES/SoES/Urban soils
- Reference to ES/SoES/Urban soils in the scope and objectives
- Reference to the pressures/threats on soil, land and soil degradation, soil quality, and protection
- Reference to the utilization of ES/SoES/Urban soils in identifying critical zones (e.g., areas under disaster risk, watershed protection zones, special conservation areas)
- Reference to multifaceted interactions within the SoES-Climate Change-Spatial Planning Nexus Framework
- Proposal for data collection, analysis, and database building related to ES/SoES/Urban soils

The assessment matrix prepared for the contextual analysis of the laws/regulations under these themes is presented in Tables 5.1 and 5.2. In the tables, the relevance of themes to the respective law/regulation is analyzed in different contexts namely: (D) directly mentioned, (I) indirectly mentioned, (P) partially mentioned, and (-) not mentioned. Consequently, it is noted that certain laws and regulations explicitly incorporate the examined themes, whereas others do not address these themes at all. The overall assessment of the legislation under key themes and the core outcomes of the assessment are summarized based on their contextual categories.

<u>Evaluation of the soil-related legislation:</u>

In the preliminary examination of legislation related to soil, it is noted that the Soil Conservation and Land Use Law (No. 5403) provides comprehensive content concerning the protection, classification, analysis, mapping, and development of soils.

The law clarifies the effects of natural and anthropogenic threats, including climate change, on the soil ecosystem, but it primarily addresses this topic from an agricultural perspective. In other words, soils in urban areas are considered within the legal framework as built-up areas, excluding them from the scope of soil analysis and mapping studies. However, the soil ecosystem, like all other ecosystems, provides its functions and SoES independently of administrative boundaries. Not addressing soil as a natural resource in a holistic manner is identified as one of the most significant shortcomings of the Soil Conservation and Land Use Law (No. 5403). Another recognized and considered significant shortcoming in the law is that the protection and development of soils are defined solely through soil functions, neglecting the SoES (Article 12). The inclusion of the SoES approach within the legal framework providing the basis for soil resources in this law would serve as a guiding principle for other relevant legal tools. Similarly, in the Regulation on Soil Pollution Control and Point Source Polluted Areas, it is observed that the SoES is not considered within the scope of the regulation. However, soil quality is a factor of primary importance in the continuity of soil functions and services.

Evaluation of the water-related legislation:

According to the examination of water-related legislation, none of the preliminary regulations prepared for the preservation of the quantity and quality of surface and groundwater address the inherent connection between soil and water. Only within the scope of the Regulation on the Protection of Groundwater against Pollution and Deterioration, the importance of certain soil characteristics for groundwater recharge and quality has been mentioned, albeit partially. In the Regulation on Drinking Water Basins, no ecological sensitivity, including soil, has been taken into account in the determination of protection zones within watersheds. The currently used watershed protection approach consists of distance-based protection zones. Moreover, in the legislation related to water, a direct and detailed analysis of the relationship between pressures originating from human activities and water quality is carried out.

However, there is no clear identification of these adverse effects in terms of soil characteristics and SoES, with regards to water and soil quality. An emerging point of potential development in water-related legislation is the ‘watershed protection plans’ proposed in the Regulation on Water Pollution Control, to preserve the water quantity and quality.

Table 5.1 : Contextual analysis of soil-, water- and spatial planning-related legislation.

CONTEXT	**LAW NO. & TITLE**	**THEMES**					(D) directly mentioned (I) indirectly mentioned (P) partially mentioned (-) not mentioned
		Defining urban soils /ES /SoES	Reference to incorporating urban soils/ SoES within its goals and scope	Reference to soil threats/ land and soil degradation/ soil quality/SoES protection	Reference to the significance of urban soils/ SoES in designating critical zones	Indicating the interdependencies within the “SoES-Climate Change-Spatial Planning Nexus”	Data collection and dataset building for urban soils/ SoES
SOIL-RELATED LEGISLATION	Soil Conservation and Land Use Law (No. 5403)	(-)	(P) The law considers agricultural soils, while ignoring the soils within the areas with zoning plans (imar planı) (I) The law mentions protecting, analyzing, mapping and developing soil. However, there is no direct/specific reference to SoES	(D) Natural and anthropogenic threats to soil (D) Monitoring and preventing soil pollution (D) Land and soil degradation (I) Land use plans and projects are encouraged for protecting soil functions, while SoES was not mentioned	(I) Land capability classification considers some fundamental soil characteristics, without a direct reference to SoES capabilities. (I) Identification and protection of erosion-sensitive zones are mentioned without a direct reference to SoES	(P) The impacts of climate change on soil is partially considered in the context of soil loss and degradation. However, the effects of SoES to climate change was not included (I) The importance of spatial planning in soil protection is emphasized, without directly mentioning SoES	(P) Soil Database (National Soil Information System) includes some data about SoES (e.g., SOC) without a direct reference to SoES (I) Determination and classification of soil and preparation of maps and databases are encouraged, without a direct reference to urban soils/SoES
	Regulation on Soil Pollution Control and Point Source Polluted Areas	(-)	(-) The regulation focuses on prevention of soil pollution, without a direct reference to urban soils and SoES	(P) Human activities (e.g., agricultural and industrial activities, waste disposals) are considered in terms of soil quality	(I) In the characterization of contaminated soil, the risks on environmental health is considered without a reference to SoES	(-)	(I) Contaminated Sites Information System provides an input for the national soil database without a direct reference to the relationship between soil pollution and SoES

Table 5.1 (continued) : Contextual analysis of soil-, water- and spatial planning-related legislation.

WATER-RELATED LEGISLATION	Regulation on the Protection of Groundwater against Pollution and Deterioration	(-)	(-) The regulation focuses on preservation of the current status of groundwater in good quality and prevention of its pollution without a direct reference to urban soils and SoES	(P) The pressures resulting from human activities and deteriorations in groundwater and soil quality were addressed without referring their close relationship	(I) Soil characteristics were taken into consideration in the designation of groundwater conservation zones, but SoES were not directly mentioned	(I) The links between LULC and the protection of groundwater is assessed within the framework of protection zones determined by DSI without mentioning the interactions with SoES and climate change	(I) The characterization and mapping of groundwaters and data on the changes in groundwater levels are regularly submitted to the relevant ministry, without a direct reference to urban soils/SoES
	Regulation on Drinking Water Basins	(-)	(-) The regulation focuses on water quality in the drinking water basins of Istanbul without a direct reference to urban soils/SoES	(I) The impacts of human activities (e.g., changes in LULC, waste disposals industry) on water quality were mentioned without referring its direct linkages with SoES	(-) In the delineation of Watershed Protection Zones, ecological sensitivities, including SoES have not been considered	(I) The strong link between water quality and spatial plans are clearly emphasized, but there is an absence of consideration for interactions with climate change and SoES	(-)
	Regulation on Water Pollution Control	(-)	(-) The regulation encompasses the preservation of the surface and groundwater resources, as well as the prevention of water pollution, without a direct reference to urban soils/SoES	(P) The preservation of soil quality is mentioned without linking it to water quality/quantity (I) Anthropogenic activities are discussed in terms of their impacts on water quality, but its connections with SoES was not referred directly	(-) In the distance-based watershed protection zones and special environmental protection areas where high water quality parameters are prioritized, urban soils/ SoES zones were not considered	(I) The connection between LULC land use planning and water quality was mentioned, emphasizing the need for the preparation of Watershed Protection Plans.	(I) Water quality data and information derived from wastewater treatment facilities are regularly updated in the wastewater information system, without a direct reference to urban soils/SoES

Table 5.1 (continued) : Contextual analysis of soil-, water- and spatial planning-related legislation.

SPATIAL PLANNING-RELATED LEGISLATION	The Law of Development (No. 3194)	(-)	(P) The law encompass provisions related to the planning, development, and regulation of urban and rural areas. Herein, agricultural soils are partially included into the law's context, while there is no direct reference to urban soils/ SoES	(I) The impacts of land use decisions on environment are considered in the context of spatial plans (Environmental master plans), without a direct reference to urban soils/SoES	(I) Although, soil characteristics and SoES play significant role in disaster risks, the law does not provide a direct indication to SoES, unlike the geologically hazardous areas	(P) The link between soil and spatial planning was established through agricultural lands while the soils in built-up areas are completely overlooked in the spatial plans (P) Although not directly related to the SoES, energy-efficient, climate-sensitive, and ecologically distinctive plans and projects have been encouraged	(-) The data related to the land and the zoning plans archived through the GIS database do not contain data relevant to urban soils/SoES
	Regulation on Spatial Plans Making	(-)	(I) The purpose of the regulation is to establish the procedures and principles related to the plans prepared to create the sustainable and healthy environments However, there is no direct reference to urban soils/SoES	(I) Environmental problems and the protection of ecological balance, and continuity of ecosystems are considered in the context of the regulation without a direct reference to urban soils/SoES (-) While air quality is directly specified, soil quality was not mentioned	(I) In the context of natural or urban risk analyses, threshold and suitability analysis or conservation plans, urban soils/SoES zones were not directly considered (P) In zoning plans, soil features and agricultural land use are utilized but SoES were not mentioned	(I) The hierarchical system of spatial plans at different levels have been elucidated considering their influence on the environment, without a direct reference to SoES (P) Climate characteristics and the impacts of climate change is considered partially in some spatial plans	(-) In the planning process, a updatable and accessible digital database is created using geographic information systems and remote sensing methods. However, SoES are not directly included within this database.

Table 5.1 (continued) : Contextual analysis of soil-, water- and spatial planning-related legislation.

SPATIAL PLANNING-RELATED LEGISLATION	The Law of Development (No. 3194)	(D)The term 'ES' and its subset, ‘Regulating ES’, are explicitly defined in the regulation (-) SoES were not clearly defined	(I) The scope of the regulation is directly aimed at preserving the water quality of Buyukcekmece Lake and ensuring its sustainable use. However, no direct reference has been made to urban soils/SoES	(I) The influence of human activities (e.g., agricultural and industrial activities, waste disposals) on water quality was considered without a direct reference to its relationship with SoES (P) The green zoning initiative, mandatory implementation of erosion reduction methods, and the encouragement of good agricultural practices partially contribute to soil/ SoES protection	(I) In the regulation, ‘Protection areas of critical importance in terms of water-related ES capacity’ is defined.Although there is no direct reference to SoES, the content refers to the water storage and surface water flow regulation services of soil (-) In the delineation of watershed protection zones, areas with SoES provision capacity were not taken into account	(P) In the regulation, land use decisions aim to preserve water quality and the important areas in terms of water-related ES capacity. Although there is no explicit reference to SoES, the connection between ‘spatial planning & SoES’ is thereby partially established (-) The connection between climate change, SoES and spatial planning is not explicitly addressed within the scope of the regulation	(-)
	Turkey’s National Climate Change Adaptation Strategy and Action Plan (NCCAP) (2011-2023)	(-)	(I) The plan prepared within the framework of integrating climate change adaptation into Turkey's development goals has included both soil resources and ES individually, within its scope	(D) The document discusses soil degradation and the impacts of climate change on ES, soil resources, soil biodiversity and food security (P) SoES is partially mentioned (e.g., SOC, water flow regulation service)	(I) Although the role of SoES in identifying critical zones are not explicitly and referenced, the document discusses the establishment of key biodiversity zones including areas with rich soil biodiversity	(D)The multifaceted interactions between climate change, LULC and spatial planning is identified (P) The interactions between SoES and climate change is mentioned through soil biodiversity & soil degradation & food production	(I) The plan suggests conducting soil surveys, inventory and mapping studies as well as building "Soil and Land Database and Land Information System," considering the effects of climate change.

Particularly in urban watersheds, vulnerable to the effects of urbanization, LULC changes, and climate change, the formulation of recommended watershed plans holds significant importance for the ecological integrity, sustainability, and protection of SoES.

Evaluation of the spatial planning-related legislation:

Findings in the examination of spatial planning-based legislation and the two spatial plans indicate that fundamental legislative tools guiding LULC patterns and land use decisions (e.g., the Law of Development (No. 3194), Regulation on Spatial Plans Making) depict soil only within the scope of agricultural purposes, similar to the Soil Conservation and Land Use Law (No. 5403). In these plans, soil quality and protection are mostly defined through agricultural soils, while urban soils are often disregarded even in the national soil database and maps, being classified under 'built-up areas.' However, despite being modified compared to their counterparts in natural areas, urban soils retain the capacity to deliver noteworthy functionalities and services when subjected to effective management practices. Therefore, for a comprehensive understanding and management of urban soils and the associated threats on SoES, the presence, challenges, and significance of 'urban soils' and 'SoES' should be initially acknowledged by the leading institutions, legislations, and planning systems.

Furthermore, in disaster risk analyses, threshold analyses, and suitability analyses conducted in the context of land use plans, soil characteristics (e.g., porosity, permeability, and soil structure) are widely used. However, there is no reference indicating the utilization of SoES in determining these critical zones. Additionally, in suitability analyses for settlements, the identification of areas with geological risks and micro-zoning studies offers a protection approach based on ecological sensitivities and provides direct inputs into spatial plans. Nevertheless, a comparable approach for urban soils and the SoES is presently lacking.

The Special Provisions and Watershed Protection Plan for Buyukcekmece Dam Lake has explicitly defined and mapped areas critical for water-related ES. This comprehensive delineation involves identifying and highlighting zones essential for regulating and providing these services within the designated watershed. The plan, in this regard, distinguishes itself from other legislative and spatial planning tools and presents content specifically directed towards SoES in Buyukcekmece Watershed. Furthermore, the plan incorporates a green zoning proposal that entails implementing erosion prevention measures and the promotion of good agricultural practices, albeit not explicitly referenced, with a focus on preserving soil quality. However, in safeguarding the watershed, the distance-based protection zones defined in the

Regulation on Water Pollution Control are modified according to the surface and groundwater qualifications.

Turkey’s National Climate Change Adaptation Strategy and Action Plan (NCCAP) (2011-2023) aims to integrate the climate change adaptation approach into Turkey's development goals. The plan is crucial in explicitly highlighting the potential impacts of climate change on water and soil resources, emphasizing the connections with land and soil degradation, soil biodiversity, and food security. Moreover, it has been observed that the plan is the sole legislative tool, although partially, referring to the Nexus connections between soil-climate change and spatial planning. However, within the scope of this plan, direct references to the SoES or urban soils are absent, and the pivotal role of soil as a carbon sink in climate change precautions (adaptation and mitigation) remains inadequately clarified.

Evaluation of other related legislation:

According to the analyses of other related legislation that have an influence on LULC change and SoES provision, the most notable deficiency in the Environment Law (No. 2872), which provides comprehensive content on environmental protection, is the lack of a clear definition of soil quality and pollution (Table 5.2). The law provides recommendations for ecosystems, the establishment of special environmental protection zones, and measures to combat climate change. However, it does not make direct references to urban soils or SoES.

In the Forest Law (No. 6831), no references to soil and SoES have been identified. However, it is worth noting that forest soils are rich in SOM, exhibit a sound structure, and possess high potential in terms of SoES. Therefore, the conservation of forests indirectly ensures the protection and enhancement of the soil ecosystem and SoES.

Pastures play another significant role in the provision of important SoES such as erosion control and carbon sequestration and storage. However, the Law on Pastures (No. 4342) only partially addresses the impacts of factors like overgrazing and LULC changes on the soil. It does not provide comprehensive and direct content related to soil protection or the SoES.

Despite its direct relevance to soil, the Mining Law (No. 3213) does not encompass content directed towards soil protection and the SoES. Particularly in the context of mandatory restoration and rehabilitation efforts stipulated by the law during and after mining activities, it is essential to develop strategies focusing not only on the characteristics of the area, such as vegetation structure and land use but also on soil properties and the preservation of SoES.

Overall evaluation:

In the assessments, it was noted that the definitions of ES, SoES, or urban soils are not included in the legislative tools except the Special Provisions and Watershed Protection Plan of Buyukcekmece Dam Lake. This situation indicates that the examined concepts suggest a new approach to the existing legal framework.

Furthermore, upon assessing the relevant legislation in terms of data analysis, data collection, and dataset building for urban soils/SoES, it has been observed that there are ongoing initiatives for data storage systems/database building, such as the National Soil Database and Contaminated Sites Information System. However, it is apparent that the databases currently in use are prepared based on the relevant context, resulting in a fragmented structure. Also, while some of these datasets may contain partial information related to the SoES, such as SOC, they do not comprehensively address SoES.

Finally, it has been observed that the SoES, Climate Change, and Spatial Planning Nexus Framework, crucial for presenting a holistic approach, is not thoroughly addressed in any of the examined legislations. While some partial explanations of two-way interactions between pillars (e.g., climate change and spatial planning or climate change and SoES) exist in this legislation, none of the examined legislation comprehensively elucidates their multifaceted interactions.

Based on the findings of the content analysis, contextual gaps and potential developmental points in the existing legislation have been identified. Accordingly, recommendations for incorporating the SoES-based approach and the methodology proposed in the In-SoES framework into the scope of each examined law/regulation/plan have been developed. The table presenting these recommendations is provided in Appendix H (the recommendations are highlighted in red), and the key topic headings included in the table, along with their explanations, are summarized below:

1. Preparation of Watershed Protection Plans

The explicit articulation of preparing watershed protection plans for the protection of water quantity and quality in watersheds is explicitly stated in the Regulation on Water Pollution Control. In this context, particularly in urbanized watersheds facing the pressures of urbanization, the preparation of watershed protection plans is recommended to safeguard the ecological integrity, water quantity and quality, and SoES within the watershed.

These plans should be developed with a comprehensive, multidisciplinary approach, taking into account the multifaceted interactions within the Nexus Framework.

Notably, decisions regarding land use in the watershed should consider the SoES-based watershed protection zones and restrictions outlined in these plans. Ensuring the enforceability of plan decisions holds significance in this regard.

(Specifically related to: Soil Conservation and Land Use Law (No. 5403); Regulation on Drinking Water Basins; The Law of Development (No. 3194); Regulation on Spatial Plans Making; Special Provisions and Watershed Protection Plan of Buyukcekmece Dam Lake)

2. Data Analysis, Mapping, and Database Building

To protect and enhance SoES, it's crucial to promote the acquisition, analysis, and mapping of data related to SoES provision, which needs a comprehensive effort and a systematic approach. The proposed In-SoES Model framework, introduced within this study, aims to provide a robust methodological foundation for future research on SoES analysis. Specifically, integrating model results with existing databases, such as the National Soil Information System and Contaminated Sites Information System, is recommended to construct a comprehensive SoES database.

This integrated approach facilitates the quantitative assessment, spatial delineation, and examination of changes within SoES, concurrently exploring their connections with additional variables like LULC changes and climate parameters. The gathered information could be effectively stored in a database ensuring comparability, adaptability, and upgradability. This developed database will present both quantitative and spatial data related to SoES, serving as a valuable resource for decision-making processes in spatial planning.

(Specifically related to Soil Conservation and Land Use Law (No. 5403); Regulation on Drinking Water Basins; Special Provisions and Watershed Protection Plan of Buyukcekmece Dam Lake; Turkey's National Climate Change Adaptation Strategy and Action Plan)

3. Clarifying Definitions and Inclusion in Legislation

In light of relevant legislation, it is proposed to undertake a comprehensive evaluation of the soil ecosystem. This entails extending legislative considerations beyond agricultural soils to include urban soils in built-up areas as well.

As previously emphasized, the soils in these areas are not only subjected to increased anthropogenic pressures but are also overlooked in current spatial plans and the supporting legislative framework.

Table 5.2 : Contextual analysis of other related legislation.

CONTEXT	**LAW NO. & TITLE**	**THEMES**				(D) directly mentioned (I) indirectly mentioned (P) partially mentioned (-) not mentioned	
		Defining urban soils /ES /SoES	Reference to incorporating urban soils/ SoES within its goals and scope	Reference to soil threats/ land and soil degradation/ soil quality/SoES protection	Reference to the significance of urban soils/ SoES in designating critical zones	Indicating the interdependencies within the "SoES-Climate Change-Spatial Planning Nexus"	Data collection and dataset building for urban soils/ SoES
OTHER RELATED LEGISLATION	Environment Law (No. 2872)	(-) The law defines the ecosystem but does not include ES/ SoES	(I) The purpose of the law is to ensure the protection of the environment (including soil ecosystem) in line with the principles of sustainable development	(P) The importance of soil quality was emphasized within the scope of monitoring wastewater treatment facilities (-) The law defines air pollution, however, it does not provide a definition for soil pollution	(I) According to the law, soils with ecological significance, sensitive to environmental pollution and degradation, can be designated as Special Environmental Protection Zones (-) There is no reference to urban soils in the scope of the law	(P) The law partially addresses efforts to combat climate change yet fails to elucidate its connection with spatial planning and SoES (I) Although not directly referencing SoES, the law does acknowledge the link btw spatial planning and environmental protection	(-) Within the scope of the law, the monitoring systems mentioned do not include direct information about urban soils/ SoES
	Forest Law (No. 6831)	(-)	(I) In the context of preserving the integrity of forests and preventing potential damages, the law indirectly encompasses the forest soil ecosystem and the SoES it provides	(I) The law addresses activities such as watershed-based afforestation, erosion and flood control, landslides and protection of ecosystems, which contributes SoES protection	(P) In forest areas, exploration and exploitation of minerals are restricted in areas containing endemic and rare ecosystems, that may include rich soil biodiversity	(-) The law does not explicitly include climate change, as well as its interactions with spatial planning and SoES	(-)

Table 5.2 (continued) : Contextual analysis of other related legislation.

		THEMES					(D) directly mentioned (I) indirectly mentioned (P) partially mentioned (-) not mentioned
	LAW NO. & TITLE	Defining urban soils /ES /SoES	Reference to incorporating urban soils/ SoES within its goals and scope	Reference to soil threats/ land and soil degradation/ soil quality/SoES protection	Reference to the significance of urban soils/ SoES in designating critical zones	Indicating the interdependencies within the "SoES-Climate Change-Spatial Planning Nexus"	Data collection and dataset building for urban soils/ SoES
OTHER RELATED LEGISLATION	Law on pastures (No. 4342)	(-)	(I) The legislation incorporates provisions for the identification, maintenance, and sustainable use of pastures. In doing so, it actively contributes to the preservation of soil and SoES	(P) The law addresses the negative impacts of overgrazing and LULC changes on soils in pastures	(I) Soil characteristics serve as a determinant factor in the identification of pastures, along with other factors such as climate features and land use	(P) The link between urban plans in rural areas and soil conservation has been partially explained, but the law does not explicitly address climate change within its scope	(-)
	Mining Law (No. 3213)	(-)	(-) The context and objectives of the law does not explicitly encompass urban soils/SoES since it regulates the principles and procedures related to the exploration, operation, and abandonment of mines	(-) The law, within its scope does not explicitly address the significance of soils, their quality, or the threats and problems they may face during or after mining operations	(I) In special environmental protection zones (including soil ecosystem) mining exploration and operation activities are permitted based on the provisions defined in the environmental impact assessment report	(-) The law does not explicitly include climate change, as well as its interactions with spatial planning and SoES	(-)

Additionally, it is recommended that ES/SoES be clearly defined in the examined legislation while articulating the relationship of these concepts with the scope of the law/regulation (e.g., soil quality, surface and groundwater quality, climate change). Herein, the most crucial point is that this assessment should be established within the framework of the SoES-Climate Change-Spatial Planning Nexus. Consequently, this approach will ensure a more comprehensive perspective within the legal framework, revealing the interrelationships among the pillars. Therefore, the integration of the Nexus Framework into the relevant legislative framework will not only enable the assessment of SoES but also facilitate the comprehensive evaluation of all ecosystems involved in its multifaceted interactions. Indeed, there is a notable absence of a comprehensive approach to safeguarding natural resources and the environment.

(Specifically related to: Soil Conservation and Land Use Law (No. 5403); Regulation on Soil Pollution Control and Point Source Polluted Areas; Regulation on the Protection of Groundwater against Pollution and Deterioration; and Regulation on Water Pollution Control; The Law of Development (No. 3194); Regulation on Spatial Plans Making; Turkey’s National Climate Change Adaptation Strategy and Action Plan; Environment Law (No. 2872); Forest Law (No. 6831); Law on Pastures (No. 4342); Mining Law No. 3213)).

4. Incorporating SoES data in the identification of critical zones

In the designation of critical areas outlined within the legislation (areas under disaster risk, watershed protection zones, and special conservation areas), soil data is currently utilized without an explicit reference to SoES. To better highlight the significance and scope of SoES in this context, the role of SoES in defining priority critical zones for protection must be clearly outlined. Furthermore, it is recommended that the 'SoES-based watershed protection zones' mentioned in the first article, be recognized as a fundamental 'protection zone approach' for ensuring the protection and sustainable development of the watersheds. This approach would provide a framework where land use decisions are guided by SoES potentials, taking into consideration the close relationship between soil and water.

(Specifically related to Soil Conservation and Land Use Law (No. 5403); Regulation on Soil Pollution Control and Point Source Polluted Areas; Regulation on the Protection of Groundwater against Pollution and Deterioration; Regulation on

Drinking Water Basins; Regulation on Water Pollution Control; Special Provisions and Watershed Protection Plan of Buyukcekmece Dam Lake; Forest Law (No. 6831); Law on Pastures (No. 4342); Mining Law No. 3213)).

As highlighted in the preceding sections of the research, protecting and developing SoES requires not only necessary legal regulations but also spatial planning tools that directly consider SoES. In this context, the existing plan hierarchy in Turkey, as defined by the Law of Development (No. 3194) and the Regulation on Spatial Plans Making, has been thoroughly examined. Within a spectrum ranging from the national to the local scale, plans adhere to the principle of 'gradual coherence,' establishing a hierarchical yet integrated system between micro and macro scales. Accordingly, each plan must align with the decisions of the current higher-level plans and guide the plan at the lower level.

National development and regional plans are at the top of this hierarchical structure and they are prepared with a socio-economic focus and serve as guiding documents. These top-level plans are prepared to determine national/regional development trends, development potentials of settlements, and sectoral objectives. The translation of national and regional planning decisions into space is facilitated through macro and local-scale physical/spatial plans. One of the macro-scale physical plans is the Strategic Spatial Plan, which intricately links economic, social, and environmental policies and strategies with physical space to guide physical development and sectoral decisions. Another macro-/meso-scale physical plan is the Metropolitan Area Environmental Master Plan, prepared in harmony with upper-scale plans. The plan aims to ensure coherence among land-use decisions about urban and rural settlements, as well as diverse sectors such as agriculture, housing, industry, tourism, and transportation. In doing so, it seeks to maintain environmental integrity and preserve natural and cultural values. The decisions formulated at the macro level are conveyed to the local level through the execution of development plans. Herein, development plans, prepared at scales ranging from 1:5,000 to 1:25,000, aim to illustrate primary types, future population densities and development characteristics of land uses, as well as transportation systems of the respective areas. At the lowest tier of the planning hierarchy, implementation plans prepared at a scale of 1:1000 intricately depict the construction typologies of building blocks and transportation details in accordance with the decisions outlined in the higher-level plans.

Strategic Spatial Plans and Metropolitan Area Environmental Master Plans hold a significant position in reflecting top-level planning decisions onto space, particularly for developing strategies aimed at protecting watershed areas. Their significance lies in being prioritized plans due to their binding and guiding role for lower-scale plans and implementations. Metropolitan Area Environmental Master Plans present a comprehensive approach to the sustainable utilization, enhancement, preservation, and development of water resources at the watershed level, in the context of protecting vulnerable areas and environmental values (e.g., coastlines, forests, watersheds, cultural, and historical assets). The plan aligns with the principles outlined in the Regulation on the Preparation of Protection and Management Plans for Water Basins (2012) (which aims to protect surface and groundwater comprehensively and collaboratively in terms of quantity and quality). In addition, within the scope of natural structure analysis, the plan also considers soil quality and agricultural land use. However, similar to the laws examined in the previous section, Metropolitan Area Environmental Master Plans overlook urban soils, examining soil solely within an agricultural context and not making any reference to SoES (directly or indirectly).

On the other hand, when examining the Draft Evaluation Report of the Turkiye Spatial Strategy Plan (Url-8), it is observed that the plan is prepared with more comprehensive content. As mentioned in the report, the process of preparing the Turkiye Spatial Strategy Plan commenced in 2009, and in 2011, the spatial strategy plan was included in the planning legislation for the first time. Subsequently, the Regulation on Spatial Plans Making, which came into effect in 2014, clarified the definition, planning principles, basics, and research topics of spatial strategy plans. In 2018, with amendments to the Law of Development (No. 3194), Strategic Spatial Plans were positioned above Metropolitan Area Environmental Master Plans and Development Plans in the spatial planning hierarchy.

The report indicates that the preparation process for the Turkiye Spatial Strategy Plan is ongoing. However, upon examining the content of the draft report, it is noted that the vision of the plan for 2053 is defined as "An inclusive, livable, innovative, competitive, climate change- and disaster-sensitive, and sustainable national space." The plan is developed within the framework of six axes under this vision. One of these axes, considered the most important according to the participatory surveys conducted nationwide in Turkiye, is "Sustainability in Natural Structure, Natural Disasters, and

Ecosystem Services." Among the priorities of this axis are the protection and efficient management of basins (agricultural and water basins) highlighting natural disaster risks and enhancing the resilience of settlements. In this axis, it is emphasized that considering ES sensitivities in spatial development scenarios is both crucial and guiding for natural and sustainable resource planning. Accordingly, in the development of sustainable land-use decisions, it is important to identify areas of critical importance in terms of ES and aim to increase the quantity and quality of benefits derived from ES. Especially considering the increasing importance of protecting water resources due to urbanization and climate change impacts, it is recommended that the natural characteristics of the area and its ES be taken into account in planning decisions in watersheds.

The plan also includes the "Combatting Climate Change" axis. In this axis, attention is drawn to the increasing GHG emissions. To reduce this, in addition to controlling LULC changes, climate-sensitive urban planning strategies are recommended (e.g., preserving/increasing green areas, heat-reflective pavement, and green building systems). At its core, it is emphasized that climate change adaptation policies should be prioritized in land-use decisions. To achieve this, particularly in metropolitan areas, it is essential to increase the areas with critical importance in terms of ES to ensure that cities are resilient against natural hazards and climate change risks.

The assessments reveal that the key concepts discussed in the research, such as ‘protection of water resources, integrated watershed protection, adaptation and mitigation to climate change, and the development of ES-based land-use decisions,’ are highlighted in macro-scale physical plans as well. Based on this contextual coherence, before transferring macro-scale planning decisions to the local scale, it is recommended to define a new intermediate planning level specifically for watersheds within the planning hierarchy. In this newly created level, the development of a comprehensive "Watershed Protection Plan" is proposed, incorporating the methodology recommended within the In-SoES Model and the protection approach based on SoES.

The importance lies in preparing the watershed protection plan in a comprehensive, holistic, and multidisciplinary manner, considering the Nexus Framework relationships, as emphasized in the outputs of the legal evaluation section. Especially for urban watersheds under the pressure of urbanization and climate change, plans should guide land-use decisions that comprehensively protect and enhance both the quality and quantity of water resources (surface and groundwater) and their associated SoES. In Table 5.3, the integration of the proposed watershed protection plans into the existing planning hierarchy in Turkiye is exemplified through the case of Buyukcekmece Watershed. Accordingly, to serve as a binding element between macro and local-scale plans, it is recommended that the Buyukcekmece Watershed Protection Plan be positioned between macro-scale physical plans and local-scale development plans. Thus, by aligning with the principle of gradual coherence between plans, the watershed plan can ensure the integration of macro-scale planning decisions with the watershed and guide the direction of local-scale plans.

In this context, the Buyukcekmece Watershed Protection Plan will be prepared taking into account macro-scale national development and regional plan decisions, as well as the Turkiye Spatial Strategy Plan and Istanbul Metropolitan Area Environmental Master Plan decisions and finally harmonize them with the In-SoES Model strategy.

The plan adopts the methodological framework developed by the model with an aim to protect, enhance, and prevent the degradation of soil and water ecosystems. In this context, during the preparation stages of the plan, it is crucial to clearly articulate the goals and objectives of the watershed protection plan first. Additionally, the Nexus connection pool to be examined should be identified for a better understanding of mutual interactions. In the scope of watershed characterization and inventory, relevant data collection should be conducted on the physical, environmental, and socioeconomic characteristics of the area, and necessary analyses should then be completed using appropriate assessment methods/tools. At this stage, preparing a comprehensive database providing quantitative and spatial data for SoES will be instructive for future studies. As a result of the analyses, within the scope of critical zones for SoES provisions, the watershed area will be classified according to SoES provision capacities, yielding "SoES-based Watershed Protection Zones.” Within these identified protection zones, land-use decisions should be redefined according to the critical SoES potential zones. Areas with limited or absent SoES provision capacity should be designated as suitable for settlement, those with moderate capacity should be allocated for limited human activities, and areas with high provision capacity should be classified as restricted or prohibited for settlement and human activities.

Table 5.3 : Proposed integration of SoES-based watershed protection plans into the planning hierarchy in Turkiye.

Plan Type	Plan Title	Scale	Legal Basis	Competent Authority	Corresponding (Current) Plan
Socio-Economic Plans	National Development Plans	National level (report)	1982 Constitution, Article 166	Ministry of Development	Eleventh Development Plan (2019-2023)
	Regional Plans	Regional level (report)	The Law of Development (No. 3194)	Ministry of Development Regional Development Agencies	Istanbul Regional Plan (2014-2023)
Physical Plans / Spatial Plans **Meso- / Macro scale**	Strategic Spatial Plans	1:250,000 / 1:500,000	Spatial Plans Regulation (2014)	Ministry of Environment, Urbanization and Climate Change	Turkiye Spatial Strategy Plan (under development)
	Environmental Master Plans	1:50,000 / 1:100,000	The Law of Development (No. 3194) (amendment in 2018)		Istanbul Metropolitan Area Environmental Master Plan (2009)
	Watershed Protection Plans	Watershed scale	The Law of Development (No. 3194) Regulation on Spatial Plans Making (2014) Regulation on Water Pollution Control	Ministry of Environment, Urbanization and Climate Change Stakeholders: · Istanbul Metropolitan municipality · District municipalities · ISKI · Universities · NGO’s · Professional chambers · Citizens	Buyukcekmece Watershed Protection Plan
Local-scale	Development Plan (Nazım imar planı)	1:5,000 / 1:25,000	Regulation on Spatial Plans Making (2014)	Metropolitan municipalities District municipalities	e.g., Turkoba Neighborhood Development Plan (1:5,000)
	Implementation Plan (Uygulama imar planı)	1:1,000	The Law of Development (No. 3194)	Governorships	e.g., Akoren Neighborhood Implementation Plan (1:1,000)

In addition to the specifications determined by the In-SoES Model, specific guidelines should be developed to include more comprehensive information regarding the land-use decisions for each protection zone and to inform development plan decisions at the local level. In areas where multiple SoES aspects are examined, the identification of critical In-SoES zones provides multiple benefits. These zones play a crucial role in preserving the quantity and quality of water, regulating surface runoff and local climate, ensuring the continuity of water and other biogeochemical cycles, and safeguarding ecosystem functions and services dependent on them. The meticulous consideration of these critical zones, which are crucial for the overall ecosystem health of the watershed, within the scope of spatial planning, and the development of governance plans and strategies accordingly, holds critical importance in this context.

The plan, in line with the Nexus approach, should consist a multidisciplinary and multifaceted approach that encompasses relevant disciplines (e.g., urban planner, geologist, agricultural engineer, landscape architect, environmental engineer, forestry engineer, biologist, hydrogeologist). Moreover, it is critical to develop, review, and update the plan in a coordinated and collaborative manner, involving not only competent authorities and organizations but also research institutes, universities, professional chambers, NGOs, and the citizens as focus groups. Herein, care should be taken to ensure coordination and collaboration among institutions, practitioners, decision-makers, and administrations to avoid any lack of coordination.

In conclusion, for Buyukcekmece Watershed, a comprehensive and holistic protection strategy will be developed by blending the fundamental principles of the Turkiye Spatial Strategy Plan, Istanbul Metropolitan Area Environmental Master Plan, and the new Buyukcekmece Watershed Protection Plan. This strategy will consider SoES, and analyze land-use development in the watershed in a multifaceted approach within the Nexus Framework. The developed plan is expected to contribute to:

- Preserving and improving the quantity and quality of water in the watershed
- Preserving and enhancing the ecological integrity and SoES of the watershed,
- Holistically evaluating the soil, including urban soils
- Developing sustainable land-use decisions
- Enhancing resilience to natural hazards and climate change in the area
- Contributing to climate change precautions through SoES
- Facilitating the comprehensive and multifaceted examination of interconnected sources and processes in the watershed ecosystem, especially the relationship between SoES and water.

Buyukcekmece Watershed is currently protected by the protection zones determined based on proximity to the lake, and in the watershed, several environmental problems (e.g., pollution, erosion, landslides) have been documented. Therefore, given the existing urban development dynamics in Istanbul, and the pressure of ongoing and planned mega projects, it is considered essential to develop SoES-sensitive spatial planning strategies in the area to protect its ecological integrity and functions (i.e., providing drinking water and maintaining its status as a wetland ecosystem, nature reserve, and Important Bird and Biodiversity Area (IBA)).

The overall assessment of SoES in spatial planning decision-making processes sheds light on the importance of 'interconnected' thinking. However, the complex, dynamic, and cross-sectoral nature of soil could be challenging for interpretation of the nexus dynamics. Furthermore, it could be difficult to build a consensus on specific spatial strategies due to the varying interests and priorities of the provincial and ministerial actors. Further studies on quantitative analysis of the potentials, distribution, quantification, and valuation of SoES can contribute to solving these conflicts with an ultimate aim to explore and exploit the synergies.

6. CONCLUSION

The thesis, in brief, discusses the exacerbated influence of anthropogenic activities on the natural environment and focuses on the impacts of urbanization and LULC change on soil as one of the most neglected, yet vital components of the urban ecosystem.

Within the scope of the research, a detailed examination of the threats, pressures, and potentials of urban soils has been undertaken through comprehensive literature research. Discussions have centered on the global implications of soil degradation and the potential of SoES in the context of spatial planning and climate change. The findings of this hypothetical research have been consolidated and synthesized into a conceptual model, which represents a fundamental step in the development of the research methodology.

Following the establishment of the conceptual framework in the first two chapters of the study, the subsequent chapter introduces the methodological framework designed for empirical analyses. In essence, the third chapter acts as a bridge connecting the theoretical underpinnings and practical implementation of the study. In the fourth chapter, a series of quantitative analyses were systematically conducted to investigate the spatio-temporal changes in LULC and SoES in the Buyukcekmece Watershed case. The results obtained from the case study analysis are used in shaping the suggestions for the incorporation of SoES within the realm of urban spatial planning.

In this chapter, an evaluation that establishes the connections between the key research components (i.e., problem statement, research questions, etc.) and the outcomes of the research is presented. Furthermore, several recommendations are provided for future studies that can deliver significant contributions to the comprehensive understanding and enhancement of SoES in the urban context.

6.1 Reflections on the Research Questions and Hypothesis

The research is based on the hypothesis that: "Spatial decision-making processes that consider SoES-based knowledge neglected at the local level (settlement scale) can be used as an effective tool to protect, strengthen and maximize the functions and services of urban soils". The central research question developed within the scope of this hypothesis examines how SoES-based urban spatial planning strategies will protect and enhance the provision of soil functions and services from the adverse effects of LULC changes. The answer to this question is found in the analysis conducted in the Buyukcekmece Watershed Case.

The research results in the case study area between 1990 and 2018 reveal the direct and indirect impacts of LULC changes on SoES provision. When examining the macro-scale plans for the area, it is observed that there is occasional non-compliance with plan decisions, and, most importantly, the prioritized conservation areas in watersheds are still recommended to be determined by distance-based protection zones defined in the Regulation on Drinking Water Basins.

Watershed areas are natural environments characterized by ecological integrity and boundaries, where ecological processes and cycles occur. The comprehensive protection of water sources, especially in watersheds that supply drinking water, is contingent upon the overall preservation of the area. In other words, the interdependent relationship between water and soil resources underscores the imperative for protection approaches to concurrently analyze and assess both these vital elements. In areas affected by soil pollution, where the soil cannot perform its vital functions, it is anticipated that discussing a healthy watershed ecosystem and achieving good water quality and quantity becomes challenging.

Therefore, the research, particularly through the Buyukcekmece Watershed case, which is under pressure from urbanization, highlights the challenges faced by urban watersheds. It underscores the need for a protection approach in these areas to be comprehensive, holistic, interdisciplinary, and consider ecological sensitivities. The quantitative analysis results obtained in the fourth chapter of the study have laid the foundation for responding to the central research question.

However, the complete answer to the research question is developed in the fifth section, where the case study results are evaluated and discussed in detail. In this section, after clarifying the positive and negative impacts of LULC changes on SoES, a methodology proposal is presented for the analysis and mapping of SoES. This is because considering SoES within the scope of spatial planning primarily necessitates a common approach and analytical method.

The developed In-SoES Model facilitates the identification of critical zones in terms of SoES provision in the watershed. The outputs obtained from the model, when integrated with the existing protection zone approach, have led to the definition of new 'SoES-based watershed protection zones' comprising four different sub-categories. Accordingly, areas with a high capacity for SoES provision are designated as priority protection zones in the watershed.

However, the proposed approach still does not fully elucidate the central research question. A further step is required for the integration of SoES-based approaches into the spatial planning decision-making process. In this context, it is recommended to prepare 'Watershed Protection Plans' based on the proposed SoES-based protection approach. It is suggested that these plans be particularly addressed in urban watersheds and positioned within the plan hierarchy between macro and local-scale physical plans. Thus, the watershed plan, which harmonizes macro-scale decisions with the SoES protection approach, will be able to transfer its offered land-use strategies to the local scale through development plans.

Considering the location of the Buyukcekmece Watershed and the anticipated LULC changes within the scope of the Turkey Spatial Strategy Plan Synthesis Report, it is evident that a protection approach considering the ecological integrity of the watershed is essential. Especially, the impacts of climate change on water resources and the significant role of SoES as a climate change measure through SOC storage underscore the importance of protecting SoES. On the other hand, when compared to the human lifespan, soil is considered as a non-renewable resource due to its prolonged formation process. However, with increasing urbanization, global population growth, changing consumption patterns, and unsustainable development patterns, the degradation of soils, in particular urban soils, is accelerating on a global scale. Therefore, the vital nature of SoES should be acknowledged not only in the long-term aftermath of soil losses but also recognized proactively, and necessary actions should be taken.

In addition to this general assessment, evaluations of the research findings within the scope of other research questions are summarized below:

- The first research question aims to understand the multidisciplinary nature of the soil ecosystem. Answering this question involved discussing the meaning of soil according to four different disciplines represented in the thesis (landscape architecture, urban planning, soil science, and geological engineering). Furthermore, the definition and scope of the term "soil" mentioned within the thesis have been clarified. Therefore, in the final chapter, it is emphasized that the proposed urban spatial planning strategies based on SoES should encompass the complex and multidisciplinary nature of soil. This, in turn, can contribute to the development of comprehensive policies where theoretical knowledge is translated into practice.
- The second research question focuses on one of the fundamental components of the study, which is SoES. It queries how the ES concept is defined and where SoES stands within the global ES classification systems. One of the significant and original outputs of the study is the comprehensive classification framework for SoES. This framework addresses this gap in the literature and provides comprehensive content for SoES based on MEA categories, which can be used in future studies. Furthermore, from a comprehensive perspective, establishing a common SoES framework can be perceived as the first step for future research. Consequently, both in understanding the relationships between SoES, climate change, and spatial planning in the Nexus Framework and in developing recommendations for the SoES-based spatial planning approach, SoES has provided a common language and framework.
- The third research question aims to understand the pressures and threats on soil and SoES. Particularly, in this era known as the Anthropocene, characterized by escalating destructive human activities, the threats to soil can be summarized in two categories: natural and anthropogenic threats. Herein, a detailed analysis has been conducted to explore the effects of urbanization and associated LULC changes, identified as one of the most important anthropogenic pressures, on SoES. In the context of these assessments, it was noted that soil in urban areas is modified by human influence, transforming into a new type of soil called ‘urban soil’. Nevertheless, it still retains the potential to provide significant SoES.

The research findings on the global impacts on soil indicate that soil and land degradation are among the top priorities of the global agenda. The problems faced by soil were highlighted in the 2015 Paris Agreement on Climate Change and the United Nations SDGs. In 2015, the United Nations designated it as the "International Year of Soil" to increase awareness about this issue. International studies have demonstrated that soil is directly linked to climate change mitigation and spatial planning, and these components interact with each other.

While addressing the third research question, another unique output of the thesis has been developed. The "Nexus approach," which examines the interconnectedness and multifaceted interactions between the pillars: SoES, climate change, and spatial planning, has been presented as the conceptual framework of the study. This framework enables a holistic and integrated evaluation of the protection and enhancement of SoES with a multi-scale understanding. It has also contributed to forming the research's methodological framework in the following sections.

- The final research question of the study relates to how SoES can be integrated into the legal and spatial planning framework in Turkiye. To address this, the case study area (Buyukcekmece Basin) was selected, and within the defined research methodology, changes in LULC and SoES were examined. The data obtained from the case study analysis were assessed in the context of the existing legislative and spatial planning framework in Turkiye.

The analyses conducted within the scope of the research, along with the proposed approaches, aim to contribute to the protection and development of urban soils and SoES, particularly in response to LULC changes. On the other hand, it is crucial to note that there can be various contributions to develop further from the limitations of this research and future studies could significantly contribute to this these gaps. Recommendations for studies that can be undertaken to enhance the accuracy of the research and address the research gaps are presented in the sub-chapter 6.2.

6.2 Recommendations for Future Research

This chapter outlines key recommendations for future research endeavors based on the assumptions, inadequacies, and limitations encountered in this study. These recommendations are listed below and they aim to address existing knowledge gaps, improve data accuracy, and broaden the scope of research in the context of SoES in the urban realm.

Suggestions on enhancing data acquisition and production:

Soil Texture**:** Future research should focus on obtaining more precise data regarding the soil texture. This can be achieved through a combination of soil sampling and laboratory analyses. Detailed soil texture information is crucial for HSG classification, calculating the unit carbon values of different soil types, and a better understanding of SoES.

Surface Water Flow Regulation (SoES-1): For future research endeavors, it is important to recognize that achieving a comprehensive understanding of hydrological modeling requires the integration of multidisciplinary knowledge and the utilization of detailed data sets. The incorporation of three-dimensional modeling tools, such as SWAT, holds significant promise in shedding light on the complex dynamics of the cyclical movement of water within watersheds. These modeling tools can play a key role in quantifying water retention and subsurface flow within the study area, paving the way for a more robust assessment of surface water flow regulation service of soil.

Carbon storage (SoES-2): Further investigations are needed to accurately calculate the amount of SOC stored in the soil. Therefore, detailed field and laboratory studies are needed to improve the understanding of this critical SoES, particularly in urban areas.

Synthesis Mapping: The current study considered all three SoES of equal importance, but assigning priority rankings to each SoES, either in a general context or specific to the study area, could enhance the precision of sensitive area mapping. Utilizing expert opinions and techniques like the Analytic Hierarchy Process (AHP) can assist in assigning importance levels to SoES, resulting in more refined sensitive area mapping.

Suggestions on Complementary Research Assessments:

Evaluation of Aquifer Vulnerability: In the context of this study, the primary focus has been directed to the ‘surface’ water flow regulation service of soil. In forthcoming studies, groundwater vulnerability maps can be generated by using appropriate methods (e,g., DRASTIC model) and hydrogeological parameters (e.g., topography, soil, hydraulic connectivity, aquifer media, net recharge). These maps not only yield outputs related to soil's ‘groundwater recharge’ service but can also inform land use decisions aimed at safeguarding the quantity and quality of groundwater resources.

Assessing other SoES: In addition to the three SoES considered in this study, future research can focus on analyzing other SoES as well. Quantifying their provision, changes, spatial distributions, and importance will contribute to a holistic understanding of SoES and their integration into existing urban spatial planning processes.

Analyzing the other components of the Nexus Framework: To enhance the understanding of the complex interactions within the Nexus framework, it is recommended to develop methodological approaches that thoroughly investigate the relationships among different elements of the SoES, climate change, and spatial planning framework. Through the use of quantitative analyses, researchers can systematically examine how these essential components interact and gain a comprehensive understanding of their dynamics. This holistic understanding will facilitate more informed decision-making processes and the formulation of strategies related to SoES.

Valuation of SoES: Further studies on estimating the economic value of SoES are critical to contribute more effectively to the development of the SoES-based spatial planning approach. Assessing the economic benefits derived from SoES has the potential to facilitate more informed and effective SoES-based policymaking and land management practices.

SoES studies in other watersheds: It is recommended to expand similar studies to other watershed areas and actively promote knowledge sharing. Extending the application of similar methodologies to various watersheds will yield practical and reliable results that can significantly contribute to the development of sustainable watershed and soil management practices. This collaborative approach will foster a comprehensive understanding of spatial differences and facilitate the implementation of effective strategies for the preservation and enhancement of SoES in urban watersheds.

Building Dataset and Monitoring**:** In the pursuit of future research objectives, it is strongly advised to establish an open-access, GIS-based dataset including geographical databases and soil maps encompassing the physical and chemical properties of the soil in urban areas. To ensure the relevance and accuracy of this digital dataset generated from satellite imagery, aerial photographs, and/or field surveys, it is imperative to establish a system for periodic updates and continuous monitoring.

Urban Soils as Living Laboratories for SoES research: In the context of this study, it is revealed that urban soils, despite their growing significance, still represent a relatively underexplored domain. Soil science itself offers a unique platform that can unite various scientific disciplines to collectively explore this vital resource. In this regard, urban areas present an opportunity to serve as vibrant, living laboratories for potential multidisciplinary investigations on SoES. Utilizing urban environments for future soil research is critical to addressing the knowledge gaps and acquiring a deeper understanding of the threats, functions, and services of urban soils.

To sum up, future research may shed light on bridging the gap between urban environments and the underlying soil ecosystem. From a futuristic perspective, while referring to urban soils, it's important to expand our understanding beyond gardens, parks, farmlands, and watersheds within urban areas. It is necessary to envision an entire city as a vast and interconnected soil system, where our living spaces are only some fragments of it. Therefore, respecting and acknowledging the integrity of the entire soil ecosystem, by recognizing the city as a part of this broader system, is essential for a deeper understanding of the intricate relationship between urban landscapes and the soils beneath them.

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APPENDICES

APPENDIX A: The population of Buyukcekmece Watershed.

Table A.1 : Population of districts and neighborhoods in Buyukcekmece Watershed (TurkStat, 2022).

District/ Neighbourhood		Population (TurkStat, 2022)	District /Neighbourhood		Population (TurkStat, 2022)
ÇATALCA (23 districts)	Oklalı	1,429	**ARNAVUTKOY** (4 districts)	Yassiören	671
	Muratbey Merkez	1,345		Hastane	10,377
	Kalfa	828		Ömerli	7,502
	Dağyenice	734		Yeşilbayır	589
	Yazlık	341		**Total population (Arnavutkoy)**	**19139**
	Çanakça	2,807			
	Subaşı	1,483	**BUYUKCEKMECE** (17 districts)	Celaliye	6,943
	Akalan	1,093		Kamiloba	8,636
	Kabakça	1,825		Kumburgaz	8,672
	İhsaniye	1,728		Bahçelievler	4,153
	İnceğiz	863		Hürriyet	22,960
	Gökçeali	1,982		Türkoba	15,056
	Kestanelik	2,418		Ulus	16,827
	Orçunlu	472		Murat Çesme	18,536
	Kızılcaali	203		Dizdariye	6,687
	Nakkaş	776		Mimar Sinan Merkez	9,448
	İzzettin	1.2		Fatih	19,323
	Kaleiçi	7,616		Cumhuriyet	8,924
	Elbasan	572		Ondokuz Mayıs	8,368
	Çakıl	2,612		Çakmaklı	5,320
	Ferhatpaşa	7,713		Alkent 2000	7,262
	Bahsayış	373		Karaağaç	4,956
	Ovayenice	1,125		Ahmediye	1,154
	Total population (Catalca)	**40,339**		**Total population (Buyukcekmece)**	**173,225**
SİLİVRİ (7districts)	Ortaköy	4,131			
	Kadıköy	1,454			
	Gazitepe	1,298			
	Akören	1,373			
	Fener	1,509			
	Kurfallı	492			
	Bekirli	207			
	Total population (Silivri)	**10,464**			

TOTAL POPULATION (WATERSHED): 243,167

APPENDIX B: Corine CLC Nomenclature

Table B.1 : Corine CLC Nomenclature (Url-2).

Level 1	**Level 2**	**Level 3**
1. Artificial surfaces	1.1. Urban fabric	1.1.1. Continuous urban fabric
		1.1.2. Discontinuous urban fabric
	1.2. Industrial, commercial and transport units	1.2.1. Industrial or commercial units
		1.2.2. Road and rail networks and associated land
		1.2.3. Port areas
		1.2.4. Airports
	1.3. Mine, dump and construction sites	1.3.1. Mineral extraction sites
		1.3.2. Dump sites
		1.3.3. Construction sites
	1.4. Artificial, non-agricultural vegetated areas	1.4.1. Green urban areas
		1.4.2. Sport and leisure facilities
2. Agricultural areas	2.1. Arable land	2.1.1. Non-irrigated arable land
		2.1.2. Permanently irrigated land
		2.1.3. Rice fields
	2.2. Permanent crops	2.2.1. Vineyards
		2.2.2. Fruit trees and berry plantations
		2.2.3. Olive groves
	2.3. Pastures	2.3.1. Pastures
	2.4. Heterogeneous agricultural areas	2.4.1. Annual crops associated with permanent crops
		2.4.2. Complex cultivation patterns
		2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation
		2.4.4. Agro-forestry areas
3. Forest and semi-natural areas	3.1. Forests	3.1.1. Broad-leaved forest
		3.1.2. Coniferous forest
		3.1.3. Mixed forest
	3.2. Scrub and/or herbaceous vegetation associations	3.2.1. Natural grasslands
		3.2.2. Moors and heathland
		3.2.3. Sclerophyllous vegetation
		3.2.4. Transitional woodland-shrub
	3.3. Open spaces with little or no vegetation	3.3.1. Beaches, dunes, sands
		3.3.2. Bare rocks
		3.3.3. Sparsely vegetated areas
		3.3.4. Burnt areas
		3.3.5. Glaciers and perpetual snow
4. Wetlands	4.1. Inland wetlands	4.1.1. Inland marshes
		4.1.2. Peat bogs
	4.2. Maritime wetlands	4.2.1. Salt marshes
		4.2.2. Salines
		4.2.3. Intertidal flats

Table B.1 (continued) : Corine CLC Nomenclature (Url-2).

Level 1	**Level 2**	**Level 3**
5. Water bodies	5.1. Inland waters	5.1.1. Water courses
		5.1.2. Water bodies
	5.2. Marine waters	5.2.1. Coastal lagoons
		5.2.2. Estuaries
		5.2.3. Sea and ocean

APPENDIX C: LULC change matrix in Buyukcekmece Watershed

Table C.1 : The change in size of each LULC class in Buyukcekmece Watershed.

Level 1	**Level 2**	**Level 3**	**Change (ha)**				
			1990-2000	**2000-2006**	**2006-2012**	**2012-2018**	**1990-2018**
1. Artificial surfaces	1.1. Urban fabric	Continuous urban fabric	0.00	0.00	122.07	0.00	122.07
		Discontinuous urban fabric	520.03	-598.71	516.90	170.88	609.11
	1.2. Industrial, commercial and transport units	Industrial or commercial units	387.98	394.81	149.27	78.73	1010.79
		Road and rail networks and associated land	233.04	-2.36	33.25	27.87	291.80
		Airports	77.94	-52.27	0.05	0.00	25.71
	1.3. Mine, dump and construction sites	Mineral extraction sites	170.94	45.08	-86.05	0.00	129.97
		Construction sites	150.15	191.07	-448.10	309.97	203.10
2. Agricultural areas	2.1. Arable land	Non-irrigated arable land	-939.48	-2509.17	-103.05	-367.05	-3918.75
		Permanently irrigated land	-	1303.02	-15.66	0.00	1287.36
	2.2. Permanent crops	Fruit trees and berry plantations	-	31.76	0.00	0.00	31.76
	2.3. Pastures	Pastures	-636.78	413.78	192.16	-159.38	-190.21
	2.4. Heterogeneous agricultural areas	Complex cultivation patterns	-101.44	1196.75	-12.23	7.68	1090.76
		Land princip. Occ. by agri., with sign.areas of natural veg.	79.69	1.94	-65.53	-7.56	8.54
3. Forest and semi natural areas	3.1. Forests	Broad-leaved forest	-3.56	1071.37	352.13	-109.08	1310.86
		Coniferous forest	25.62	450.01	92.87	-30.06	538.43
		Mixed forest	897.74	-1029.93	32.95	16.70	-82.53
	3.2. Scrub and/or herbaceous vegetation associations	Natural grasslands	0.00	21.37	-164.46	0.00	-143.09
		Transitional woodland-shrub	-987.29	-937.38	-636.82	109.08	-2452.41
5. Water bodies	5.1. Inland waters	Water bodies		92.92	42.17	0.00	135.10
		Water bodies	125.40	-84.06	-1.93	-47.78	-8.38

APPENDIX D: LULC transformations in Buyukcekmece Watershed.

Table D.1 : LULC transformations in Buyukcekmece Watershed between 1990-2000.

Corine code	**Land use/Land Cover 1990**	**Area (ha)**	**Land use/Land Cover 2000**	**Area (ha)**	**Percentage (%)**
111	Continuous urban fabric	1.84	Continuous urban fabric	1.84	100.0%
112	Discontinuous urban fabric	1908.64	Discontinuous urban fabric	1908.64	100.0%
121	Industrial or commercial units	58.35	Industrial or commercial units	58.35	100.0%
131	Mineral extraction sites	270.89	Mineral extraction sites	185.43	68.5%
			Land princp. occupied by agriculture	52.57	19.4%
			Non-irrigated arable land	32.88	12.1%
133	Construction sites	203.42	Road and rail networks and associated land	188.01	92.4%
			Industrial or commercial units	15.40	7.6%
211	Non-irrigated arable land	39314.86	Non-irrigated arable land	38020.98	96.7%
			Discontinuous urban fabric	345.18	0.9%
			Construction sites	320.72	0.8%
			Industrial or commercial units	267.72	0.7%
			Water bodies	125.40	0.3%
			Airports	77.94	0.2%
			Road and rail networks and associated land	45.03	0.1%
			Pastures	31.45	0.1%
			Broad-leaved forest	27.30	0.1%
			Complex cultivation patterns	21.61	0.1%
			Land princp. occupied by agriculture	20.27	0.1%
			Mixed forest	11.25	0.0%
231	Pastures	2001.26	Pastures	1333.04	66.6%
			Non-irrigated arable land	306.61	15.3%
			Mineral extraction sites	157.80	7.9%
			Discontinuous urban fabric	113.65	5.7%
			Complex cultivation patterns	37.18	1.9%
			Construction sites	32.85	1.6%
			Industrial or commercial units	20.14	1.0%
242	Complex cultivation patterns	1423.48	Complex cultivation patterns	1263.25	88.7%
			Industrial or commercial units	84.70	6.0%
			Discontinuous urban fabric	61.21	4.3%
			Mineral extraction sites	14.32	1.0%
243	Land princp. occupied by agriculture	2121.17	Land princp. occupied by agriculture	2121.17	100.0%
311	Broad-leaved forest	8250.94	Broad-leaved forest	7052.57	85.5%
			Transitional woodland-shrub	1137.22	13.8%
			Coniferous forest	25.62	0.3%
			Mineral extraction sites	22.46	0.3%

Table D.1 (continued) : LULC transformations in Buyukcekmece Watershed between 1990-2000.

Corine code	Land use/Land Cover 1990	Area (ha)	Land use/Land Cover 2000	Area (ha)	Percentage (%)
			Land princp. occupied by agriculture	6.85	0.1%
			Non-irrigated arable land	6.21	0.1%
312	Coniferous forest	26.17	Coniferous forest	26.17	100.0%
313	Mixed forest	858.87	Mixed forest	858.87	100.0%
321	Natural grassland	450.44	Natural grassland	450.44	100.0%
324	Transitional woodland-shrub	3824.46	Transitional woodland-shrub	1699.94	44.4%
			Broad-leaved forest	1167.51	30.5%
			Mixed forest	886.49	23.2%
			Mineral extraction sites	61.82	1.6%
			Non-irrigated arable land	8.69	0.2%
512	Water bodies	2447.72	Water bodies	2447.72	100.0%

Table D.2 : LULC transformations in Buyukcekmece Watershed between 2000-2006.

Corine code	**Land use/Land Cover 2000**	**Area (ha)**	**Land use/Land Cover 2006**	**Area (ha)**	**Percentage (%)**
111	Continuous urban fabric	1.84	Continuous urban fabric	1.84	100%
112	Discontinuous urban fabric	2428.67	Discontinuous urban fabric	1261.49	51.9%
			Non-irrigated arable land	408.19	16.8%
			Complex cultivation patterns	339.29	14.0%
			Construction sites	290.55	12.0%
			Land princp. occupied by agriculture	66.13	2.7%
			Pastures	33.01	1.4%
			Mixed forest	9.10	0.4%
			Broad-leaved forest	8.76	0.4%
			Mineral extraction sites	3.39	0.1%
			Coniferous forest	3.30	0.1%
			Transitional woodland-shrub	2.94	0.1%
			Industrial or commercial units	2.46	0.1%
121	Industrial or commercial units	446.33	Industrial or commercial units	381.02	85.4%
			Non-irrigated arable land	41.53	9.3%
			Natural grassland	9.12	2.0%
			Discontinuous urban fabric	8.75	2.0%
			Land princp. occupied by agriculture	2.53	0.6%
			Transitional woodland-shrub	1.66	0.4%
			Pastures	1.65	0.4%
122	Road and rail networks and associated land	233.04	Road and rail networks and associated land	230.01	98.7%
			Industrial or commercial units	2.24	1.0%
			Non-irrigated arable land	0.58	0.2%
124	Airports	77.94	Non-irrigated arable land	52.20	67.0%
			Airports	25.66	32.9%
			Water bodies	0.05	0.1%
131	Mineral extraction sites	441.84	Mineral extraction sites	408.25	92.4%
			Non-irrigated arable land	24.55	5.6%
			Broad-leaved forest	8.87	2.0%
133	Construction sites	353.57	Discontinuous urban fabric	101.33	28.7%
			Construction sites	82.45	23.3%
			Non-irrigated arable land	81.00	22.9%
			Industrial or commercial units	47.81	13.5%
			Pastures	40.97	11.6%
211	Non-irrigated arable land	38375.3	Non-irrigated arable land	33575.55	87.5%
			Complex cultivation patterns	1294.39	3.4%
			Permenantly irrigated land	1253.84	3.3%
			Land princp. occupied by agriculture	1230.21	3.2%
			Industrial or commercial units	266.26	0.7%

Table D.2 (continued) : LULC transformations in Buyukcekmece Watershed between 2000-2006.

Corine code	Land use/Land Cover 2000	Area (ha)	Land use/Land Cover 2006	Area (ha)	Percentage (%)
			Discontinuous urban fabric	248.62	0.6%
			Broad-leaved forest	134.92	0.4%
			Pastures	132.58	0.3%
			Construction sites	130.94	0.3%
			Natural grassland	70.15	0.2%
231	Pastures	1364.49	Pastures	1056.74	77.4%
			Non-irrigated arable land	159.72	11.7%
			Complex cultivation patterns	50.56	3.7%
			Permenantly irrigated land	48.89	3.6%
			Construction sites	35.01	2.6%
			Discontinuous urban fabric	7.32	0.5%
			Industrial or commercial units	3.55	0.3%
			Mixed forest	2.59	0.2%
242	Complex cultivation patterns	1322.04	Complex cultivation patterns	623.32	47.1%
			Non-irrigated arable land	476.82	36.1%
			Discontinuous urban fabric	151.10	11.4%
			Industrial or commercial units	38.12	2.9%
			Mixed forest	12.44	0.9%
			Water bodies	8.81	0.7%
			Fruit trees and berry plantations	8.05	0.6%
			Mineral extraction sites	3.01	0.2%
243	Land princp. occupied by agriculture	2200.86	Land princp. occupied by agriculture	842.74	38.3%
			Non-irrigated arable land	779.84	35.4%
			Complex cultivation patterns	187.57	8.5%
			Transitional woodland-shrub	134.60	6.1%
			Broad-leaved forest	109.81	5.0%
			Natural grassland	60.61	2.8%
			Pastures	31.79	1.4%
			Discontinuous urban fabric	30.81	1.4%
			Industrial or commercial units	16.10	0.7%
			Coniferous forest	4.95	0.2%
			Mixed forest	1.45	0.1%
311	Broad-leaved forest	8247.39	Broad-leaved forest	7469.24	90.6%
			Transitional woodland-shrub	478.77	5.8%
			Mixed forest	106.29	1.3%
			Non-irrigated arable land	80.88	1.0%
			Mineral extraction sites	40.94	0.5%
			Land princp. occupied by agriculture	25.00	0.3%
			Natural grassland	16.05	0.2%

Table D.2 (continued) : LULC transformations in Buyukcekmece Watershed between 2000-2006.

Corine code	**Land use/Land Cover 2000**	**Area (ha)**	**Land use/Land Cover 2006**	**Area (ha)**	**Percentage (%)**
			Coniferous forest	15.65	0.2%
			Industrial or commercial units	12.07	0.1%
312	Coniferous forest	51.79	Coniferous forest	47.51	91.7%
			Transitional woodland-shrub	4.14	8.0%
			Complex cultivation patterns	0.14	0.3%
313	Mixed forest	1756.62	Mixed forest	568.84	32.4%
			Broad-leaved forest	514.41	29.3%
			Coniferous forest	387.93	22.1%
			Transitional woodland-shrub	142.39	8.1%
			Non-irrigated arable land	52.79	3.0%
			Industrial or commercial units	48.76	2.8%
			Land princp. occupied by agriculture	19.27	1.1%
			Pastures	9.32	0.5%
			Discontinuous urban fabric	5.06	0.3%
			Natural grassland	3.97	0.2%
			Complex cultivation patterns	3.87	0.2%
321	Natural grassland	450.44	Pastures	243.74	54.1%
			Transitional woodland-shrub	135.29	30.0%
			Natural grassland	41.83	9.3%
			Non-irrigated arable land	21.20	4.7%
			Construction sites	5.68	1.3%
			Complex cultivation patterns	2.54	0.6%
324	Transitional woodland-shrub	2837.17	Broad-leaved forest	1072.38	37.8%
			Transitional woodland-shrub	991.00	34.9%
			Natural grassland	270.08	9.5%
			Pastures	227.31	8.0%
			Non-irrigated arable land	110.55	3.9%
			Coniferous forest	37.26	1.3%
			Fruit trees and berry plantations	22.88	0.8%
			Industrial or commercial units	22.71	0.8%
			Mineral extraction sites	20.32	0.7%
			Land princp. occupied by agriculture	16.81	0.6%
			Complex cultivation patterns	16.23	0.6%
			Mixed forest	15.00	0.5%
			Discontinuous urban fabric	14.62	0.5%
512	Water bodies	2573.12	Water bodies	2479.25	96.4%
			Water courses	92.53	3.6%

Table D.3 : LULC transformations in Buyukcekmece Watershed between 2006-2012.

Corine code	Land use/Land Cover 2006	Area (ha)	Land use/Land Cover 2012	Area (ha)	Percentage (%)
111	Continuous urban fabric	1.8	Continuous urban fabric	1.84	100.0%
112	Discontinuous urban fabric	1830.0	Discontinuous urban fabric	1617.40	88.4%
			Continuous urban fabric	114.77	6.3%
			Non-irrigated arable land	70.04	3.8%
			Pastures	10.84	0.6%
			Complex cultivation patterns	9.40	0.5%
			Industrial or commercial units	2.55	0.1%
			Mixed forest	1.91	0.1%
			Land princp. occupied by agriculture	1.15	0.1%
121	Industrial or commercial units	841.1	Industrial or commercial units	772.90	91.9%
			Non-irrigated arable land	26.47	3.1%
			Road and rail networks and associated land	16.19	1.9%
			Pastures	12.59	1.5%
			Discontinuous urban fabric	5.61	0.7%
			Land princp. occupied by agriculture	5.13	0.6%
			Broad-leaved forest	1.25	0.1%
122	Road and rail networks and associated land	230.7	Road and rail networks and associated land	220.90	95.8%
			Non-irrigated arable land	8.22	3.6%
			Discontinuous urban fabric	1.14	0.5%
124	Airports	25.7	Airports	23.87	93.0%
			Non-irrigated arable land	1.71	6.7%
			Water bodies	0.08	0.3%
131	Mineral extraction sites	486.9	Mineral extraction sites	375.52	77.1%
			Pastures	41.72	8.6%
			Non-irrigated arable land	36.72	7.5%
			Transitional woodland-shrub	24.67	5.1%
			Broad-leaved forest	8.01	1.6%
133	Construction sites	544.6	Discontinuous urban fabric	499.37	91.7%
			Non-irrigated arable land	26.98	5.0%
			Pastures	16.87	3.1%
			Transitional woodland-shrub	0.91	0.2%
211	Non-irrigated arable land	35866.2	Non-irrigated arable land	35157.44	98.0%
			Discontinuous urban fabric	174.49	0.5%
			Pastures	173.55	0.5%
			Construction sites	96.02	0.3%
			Industrial or commercial units	76.97	0.2%
			Complex cultivation patterns	64.08	0.2%
			Road and rail networks and associated land	25.26	0.1%
			Land princp. occupied by agriculture	23.09	0.1%

Table D.3 (continued) : LULC transformations in Buyukcekmece Watershed between 2006-2012.

Corine code	Land use/Land Cover 2006	Area (ha)	Land use/Land Cover 2012	Area (ha)	Percentage (%)
			Broad-leaved forest	21.19	0.1%
212	Permanently irrigated arable land	1303.0	Permanently irrigated arable land	1250.05	95.9%
			Water courses	46.30	3.6%
			Non-irrigated arable land	6.54	0.5%
222	Fruit trees and berry plantations	31.8	Fruit trees and berry plantations	30.92	97.4%
			Mineral extraction sites	0.65	2.1%
231	Pastures	1778.3	Pastures	1559.47	87.7%
			Non-irrigated arable land	84.04	4.7%
			Transitional woodland-shrub	43.99	2.5%
			Discontinuous urban fabric	41.85	2.4%
			Permanently irrigated arable land	26.70	1.5%
			Mineral extraction sites	12.48	0.7%
			Mixed forest	4.20	0.2%
242	Complex cultivation patterns	2518.8	Complex cultivation patterns	2426.12	96.3%
			Non-irrigated arable land	62.32	2.5%
			Industrial or commercial units	11.25	0.4%
			Discontinuous urban fabric	6.05	0.2%
			Pastures	2.13	0.1%
			Mixed forest	2.49	0.1%
			Broad-leaved forest	2.06	0.1%
			Transitional woodland-shrub	1.85	0.1%
243	Land princp. occupied by agriculture	2202.8	Land princp. occupied by agriculture	2021.29	91.8%
			Non-irrigated arable land	127.61	5.8%
			Industrial or commercial units	18.71	0.8%
			Broad-leaved forest	16.78	0.8%
			Transitional woodland-shrub	13.63	0.6%
			Pastures	2.43	0.1%
311	Broad-leaved forest	9318.8	Broad-leaved forest	9139.83	98.1%
			Land princp. occupied by agriculture	79.69	0.9%
			Non-irrigated arable land	78.17	0.8%
			Transitional woodland-shrub	6.54	0.1%
312	Coniferous forest	501.8	Coniferous forest	446.00	88.9%
			Industrial or commercial units	46.29	9.2%
			Broad-leaved forest	3.75	0.7%
			Transitional woodland-shrub	2.69	0.5%
313	Mixed forest	726.7	Mixed forest	666.34	91.7%
			Non-irrigated arable land	22.84	3.1%
			Industrial or commercial units	17.50	2.4%
			Transitional woodland-shrub	9.85	1.4%
			Coniferous forest	4.81	0.7%
			Broad-leaved forest	3.96	0.5%

Table D.3 (continued) : LULC transformations in Buyukcekmece Watershed between 2006-2012.

Corine code	Land use/Land Cover 2006	Area (ha)	Land use/Land Cover 2012	Area (ha)	Percentage (%)
			Non-irrigated arable land	10.25	2.2%
			Mixed forest	1.29	0.3%
324	Transitional woodland-shrub	1899.8	Transitional woodland-shrub	1149.92	60.5%
			Broad-leaved forest	472.47	24.9%
			Coniferous forest	135.52	7.1%
			Mixed forest	75.52	4.0%
			Non-irrigated arable land	28.97	1.5%
			Industrial or commercial units	28.72	1.5%
511	Water courses	92.9	Water courses	87.02	93.6%
			Permenantly irrigated land	4.69	5.0%
			Non-irrigated arable land	1.21	1.3%
512	Water bodies	2489.1	Water bodies	2472.51	99.3%
			Non-irrigated arable land	12.42	0.5%
			Complex cultivation patterns	1.77	0.1%

Table D.4 : LULC transformations in Buyukcekmece Watershed between 2012 - 2018.

Corine code	Land use/Land Cover 2012	Area (ha)	Land use/Land Cover 2012	Area (ha)	Percentage (%)
111	Continuous urban fabric	123.91	Continuous urban fabric	123.91	100.0%
112	Discontinuous urban fabric	2346.9	Discontinuous urban fabric	2346.87	100.0%
121	Industrial or commercial units	990.4	Industrial or commercial units	990.41	100.0%
122	Road and rail networks and associated land	263.9	Road and rail networks and associated land	263.93	100.0%
124	Airports	25.7	Airports	25.71	100.0%
131	Mineral extraction sites	400.9	Mineral extraction sites	400.87	100.0%
133	Construction sites	96.5	Construction sites	53.57	55.5%
			Discontinuous urban fabric	38.08	39.4%
			Industrial or commercial units	4.89	5.1%
211	Non-irrigated arable land	35763.	Non-irrigated arable land	35340.33	98.8%
			Construction sites	217.58	0.6%
			Discontinuous urban fabric	118.43	0.3%
			Industrial or commercial units	51.30	0.1%
			Road and rail networks and associated land	27.87	0.1%
			Complex cultivation patterns	7.68	0.0%
212	Permanently irrigated arable land	1287.4	Permanently irrigated arable land	1287.36	100.0%
222	Fruit trees and berry plantations	31.8	Fruit trees and berry plantations	31.76	100.0%
231	Pastures	1970.4	Pastures	1763.27	89.5%
			Construction sites	124.34	6.3%
			Non-irrigated arable land	55.81	2.8%
			Discontinuous urban fabric	14.37	0.7%
			Mixed forest	12.65	0.6%
242	Complex cultivation patterns	2506.6	Complex cultivation patterns	2506.56	100.0%
243	Land princp. occupied by agriculture	2129.7	Land princp. occupied by agriculture	2129.71	100.0%
			Construction sites	7.56	
311	Broad-leaved forest	9670.9	Broad-leaved forest	9561.80	98.9%
			Transitional woodland-shrub	109.08	1.1%
312	Coniferous forest	594.7	Coniferous forest	564.60	94.9%
			Industrial or commercial units	22.53	3.8%
			Mixed forest	7.53	1.3%
313	Mixed forest	759.6	Mixed forest	756.17	99.5%
			Construction sites	3.48	0.5%
321	Natural grassland	307.4	Natural grassland	307.36	100.0%
324	Transitional woodland-shrub	1263	Transitional woodland-shrub	1262.97	100.0%
511	Water courses	135.1	Water courses	135.10	100.0%
512	Water bodies	2487.1	Water bodies	2439.35	98.1%
			Pastures	47.78	1.9%

APPENDIX E: Reference table for HSG designation.

Table E.1 : Hydrologic soil groups based on the combination of major soil groups and soil properties (Ozer, 1990).

Hidrolojik Toprak Grubu	**Büyük Toprak Grubu**	**Toprak Özelliklerinin Kombinasyonu (TOK) ve Arazi Kullanım Kabiliyeti Alt Sınıf (ATS) birleşimi**
A Minimum İnfitrasyon Derecesi: 7,5-10 mm/sa	L	1-11, 13-15, 17-19, 21,22
	A	3, 6, 9, 10
	E, T	1-16
	O	m, p, r ya da bunlarla birlikte h, s, a, k v sembollerinden biri ya da daha fazlası ile
B Minimum İnfitrasyon Derecesi: 3-7,5 mm/sa	P, G	1, 2, 5, 6, 9, 10
	C, D, M, N	1-10
	E, T	17-24
	B, F, R, Y	1-8
	U	1, 2, 3
	L	12, 16, 20, 24
	X	1-4
	K	4-6, 13-15, 22-24
	A	3, 6, 9, 10 ile h, s, a, k, v sembollerinden biri ya da daha fazlası ile
C Minimum İnfitrasyon Derecesi: 0.8-3 mm/sa	P, G	3, 4, 7, 8, 11-22
	C, D, M, N	11-18
	B, F	9-23
	U	4-21
	R	9-21
	L, E, T	25
	Y	9-25
	X	5-20
	K	1-3, 10-12, 19-32
	Ç	3, 6, 9
	A	2, 5, 8 ile h, s, a, k, v sembollerinden biri veya daha fazları ile

APPENDIX F: Biophysical carbon values by LULC classes.

Table F.1 : Biophysical carbon values by LULC classes (prepared by compiling the carbon data from selected studies).

Soil Carbon Density Values in the Literature (t ha^{-1})													
*nd: no data	Pamukcu, 2015 - Istanbul					Ma et al., 2019 - Germany (Schleswig-Holstein)					Cruickshank et al., 2000, Ireland	Molin, 2010, Portugal	Muñoz-Rojas et al., 2011., Spain
LULC class	C_above	C_below	C_soil	C_dead	C_density total	C_above	C_below	C_soil	C_dead	C_density total	C_density	C_density	C_density
Urban fabric [continuous]	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00	0.00	0.00
Industrial or commercial units	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00	0.00	0.00
Road and rail networks, ass. land	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00	0.00	0.00
Mineral extraction sites	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00	0.00	0.00
Construction sites	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00	0.00	0.00
Surface water	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00	0.00	0.00
Permanently irrigated land	0.75	0	50.49	0.27	51.51	nd	nd	nd	nd	nd	2.20	5.00	5.00
Pastures (mera)	0.49	1.37	100.56	0.06	102.48	6	0.7	97.75	0	104.45	0.90	6.00	nd
Broad-leaved forest (yaprakli)	157.75	37.86	97.29	2.86	295.76	112	33.6	79.48	7.5	232.58	38.00	28.24	28.24
Coniferous forest (ibreli)	130.6	26.12	127.38	4.43	288.53	87	21.75	85.05	5.11	198.91	29.90	59.48	59.48
Mixed forest (karisik)	135.16	28.23	122.7	4.02	290.11	99.5	27.68	76.12	6.3	209.6	32.80	40.80	40.80
Fruit trees and berry plantations	nd	nd	nd	nd	nd	5.53	15.47	89.91	0.08	110.99	nd	21.00	21.00
Complex cultivation patterns	nd	nd	nd	nd	nd	1.25	0.35	93.22	2.05	96.87	1.60	11.52	11.52
Land princ. Occ. by agriculture, with sign.t areas of natural veg.	nd	nd	nd	nd	nd	1.56	0.44	86.89	1.2	90.09	2.00	11.37	11.37
Natural grasslands	nd	nd	nd	nd	nd	1.34	0.16	97.97	0	99.47	1.50	6.00	3.04
Transitional woodland-shrub	nd	nd	nd	nd	nd	3.82	10.68	81	0.36	95.86	14.50	17.74	17.74
Non-irrigated arable land	nd	nd	nd	nd	nd	1.71	0.49	92.62	0	94.82	2.20	5.00	5.00
Discontinuous urban fabric	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	3.1	4.71	3.23
Airports	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.50	0.50	0.50

APPENDIX G: Carbon storage in Buyukcekmece Watershed.

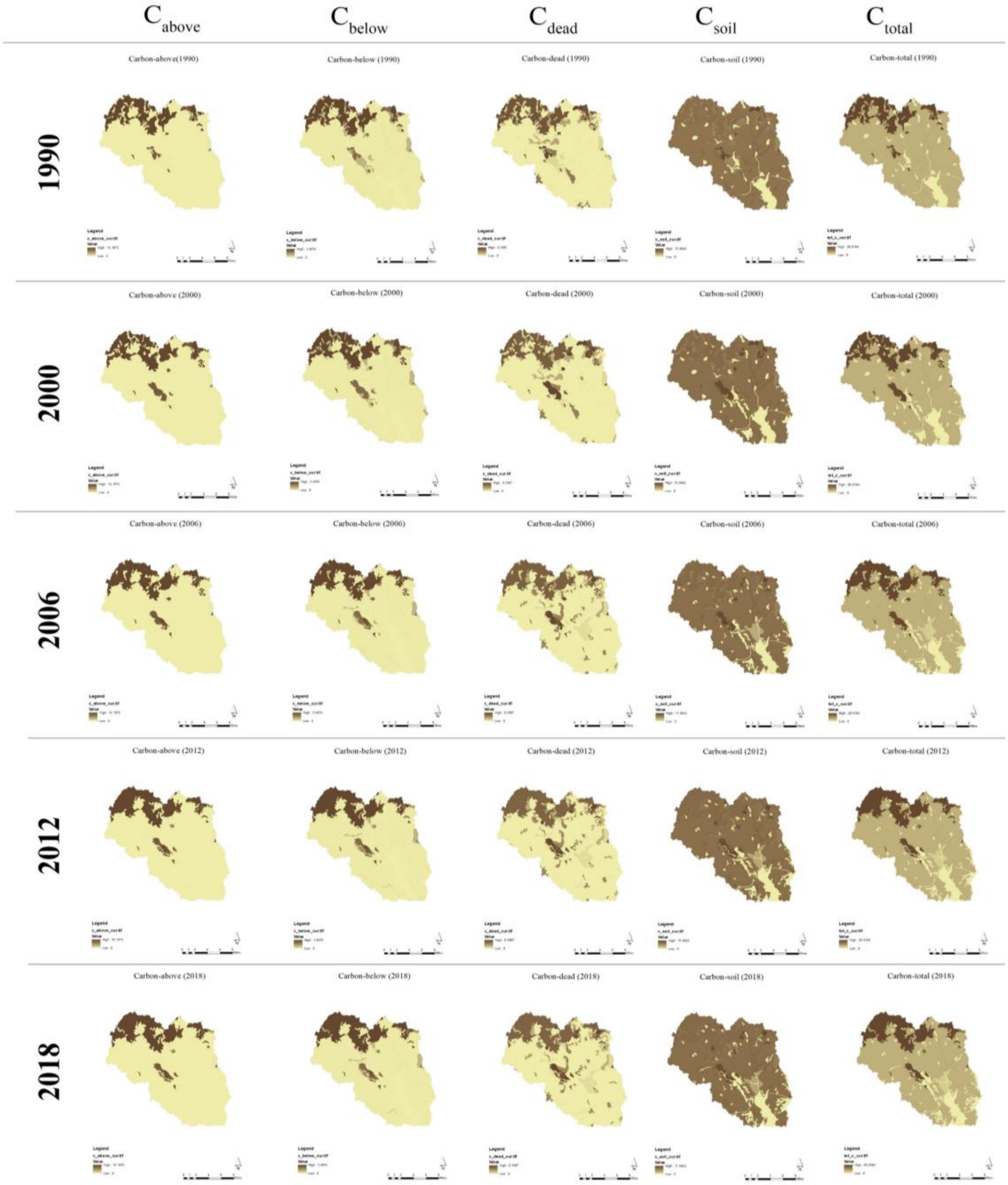

Figure G.1 : Buyukcekmece Watershed carbon storage maps (1990-2018).

APPENDIX H: Proposed amendments for relevant legislation.

Table H.1 : Proposed amendments for the integration of SoES approach into relevant legislation.

Competent Authority	Law No. & Title	Section Article	CONTENT	PROPOSED CONTENT	RATIONALE
Ministry of Agriculture and Forestry	5403 - Soil Conservation and Land Use Law	Definitions Article 3	“(l) Land capability classification: Describes the classification of land based on fundamental soil surveys and climatic conditions, integrating land use and conservation data to determine the most suitable land use patterns that do not lead to soil degradation.”	“(l) …based on fundamental soil surveys, SoES and climate conditions, … that do not lead to soil degradation and negative impacts on urban soils and SoES.”	Recommendation for broadening the definitions of land capability classes and land use planning by incorporating urban soils and SoES.
			“(m) Land use planning: Describes the rational land use planning that determines and systematically evaluates the potential of soil and water, considering ecological, social, and economic conditions to create different land use forms in accordance with the principle of sustainability, in order to prevent the degradation of soil and other environmental resources, and to establish land use plans at all scales that form the basis for planning, taking into account their relationships with each other.”	“(m)…that determines and systematically evaluates the potential of soil, water and associated SoES considering ecological, social, and economic conditions to create different land use forms in accordance with the principle of sustainability, in order to prevent the degradation of soil…”	
		Duties of the Board Article 6	“a) Conducting examinations, evaluations, and monitoring for the conservation, improvement, and efficient use of land in all land-use activities, identifying any emerging adverse conditions, and formulating opinions to enhance soil conservation, address related issues, develop measures, and ensure their implementation.”	“a) …, and formulating opinions to enhance conservation and improvement of urban soils and SoES, address related issues … and lands assets including SoES, along with…”	Recommendation to consider urban soils and SoES within the scope of the tasks of the Soil Conservation Board (in Turkish: Toprak Koruma Kurulu).
		Article 7	“The Ministry will formulate regulations specifying the principles and methodologies for the identification, classification, analysis, and categorization of soil and land assets, along with the establishment of standards, the creation of maps and databases, and their accessibility to users.”	“… for the identification, classification, analysis, and categorization of soil and land assets and SoES along with …”	Recommendation for SoES analyses and mapping as well as building an accessible SoES database.
		Article 12	“The fundamental principle is the preservation of the soil in its original location to ensure the sustainability of its natural functions.”	“The fundamental principle is the preservation of the soil in its original location to ensure the sustainability of its natural functions and services.”	Recommendation to include SoES for soil conservation projects.
		Article 15 Article 16	“Identification and Conservation of Areas Susceptible to Erosion” “Monitoring and Prevention of Soil Pollution”	Suggestion for a new article: “Article 18: “Identification and Protection of the Critical Zones for SoES Provision”	Proposal for the inclusion of a distinct article dedicated to the critical zones for SoES. This article is suggested to offer inclusive insights into the capacities and challenges associated with SoES.
Ministry of Agriculture and Forestry	Regulation on Soil Pollution Control and Point Source Polluted Areas	Definitions Article 4	“(m) Contaminated soil is defined as soil containing hazardous pollutants resulting from human activities, confirmed to present substantial risks to human health and the environment, taking into account current or potential future soil usage…”	Suggestion for an additional clause: “Soil ecosystem services (SoES): The ecological, social and economic benefits, conditions and processes provided by soil ecosystem.” “(m) … confirmed to present substantial risks to human health, provision of SoES, and the environment.”	Proposal for the incorporation of the definition of SoES and considering SoES as one of the indicators for soil pollution risk.
Ministry of Agriculture and Forestry	Regulation on the Protection of Groundwater against Pollution and Deterioration	Measures Program Article 12	“(a) Activities that pose a risk to water quality, human health, and the quality of terrestrial and aquatic ecosystems, with the aim of reducing contamination of groundwater and preventing chemical degradation of groundwater, are not permitted."	“… to water quality, human health, soil quality, SoES provision and the quality of …”	Recommendation to emphasize the importance of soil quality and SoES due to its close relation with groundwater quality measures.
			“j) (Amended: Official Gazette-12/5/2023-32188) In the selection of sanitary landfill sites, the status of surface and groundwater resources, the condition of protection watersheds, groundwater levels, and groundwater flow directions are taken into consideration”	“…the status of surface and groundwater resources, soil characteristics, functions and services, the condition of protection watersheds…”	Suggestion to emphasize the importance of soil characteristics (permeability, texture, etc.) in the selection of sanitary landfill site locations.
		Groundwater Protection Areas Article 13		Suggestion for an additional clause: “(9) Areas of significant importance for groundwater recharge and quality, based on soil characteristics, are designated as critical SoES zones. Within these designated zones, any form of construction, as well as the disposal of solid or liquid waste, is strictly prohibited and necessary measures are taken to prevent them.”	Recommendation to consider critical SoES zones as protection areas for safeguarding groundwater resources.

Table H.1 (continued) : Proposed amendments for the integration of SoES approach into relevant legislation.

Competent Authority	Law No. & Title	Section Article	CONTENT	PROPOSED CONTENT	RATIONALE
Istanbul Water and Sewerage Administration (ISKI)	Regulation on Drinking Water Basins	Definitions Article-4	The watershed protection zones are defined as: "Absolute protection zone (0–300 m)" "Short-distance protection zone (300–1000 m)" "Middle-distance protection zone (1000–2000 m)" "Long-distance protection zone (beyond 2000 m from the water to the Watershed boundary)"	Proposed watershed protection zones are defined as: "Absolute protection zone: (0-300 m) and areas with high SoES capacity" "Primary protection zone: (300-1000 m) and areas with medium SoES capacity" "Secondary protection zone: (1000-2000 m) and areas with low SoES capacity) "Tertiary Protection zones: beyond 2000 m, to the ultimate Watershed boundary"	Re-defining the watershed protection zones based on SoES provision capacity and integrating "SoES-based Watershed Protection Zones" into the relevant regulation.
		Special Provisions Article-6	"(3) Existing Environmental Master Plans within the boundaries of Istanbul, along with zoning plans endorsed by ISKI (Istanbul Water and Sewerage Administration) and approved urban plans by the Metropolitan Municipality Presidency, serve as the basis for administrative practices"	"(3) … along with the watershed protection plans and zoning plans endorsed by ISKI (Istanbul Water and Sewerage Administration) and …"	Proposal for the inclusion of watershed protection plans prepared by the Ministry in the plans to be considered in administrative practices
			"(8) Dumping Activities of Soil, Construction, and Demolition Wastes"	A new limitation statement is recommended: "e) Based on specific soil properties and hydrogeological conditions, dumps are prohibited in the areas characterized by high and medium SoES capacity, specifically the zones with the potential to recharge groundwater."	Suggestion on considering soil characteristics and SoES for construction and waste dumping activities.
Ministry of Environment, Urbanization and Climate Change	Regulation on Water Pollution Control	Definitions Article-3		Suggestion for an additional clause: "Soil ecosystem services (SoES): The ecological, social and economic benefits, conditions and processes provided by soil ecosystem."	Proposal for the inclusion of the definition of SoES in the relevant article.
		Principles Article 4	The principles considered in the protection and maintenance of water quality.	Suggestion for an additional clause: "m) Ensuring the conservation of mid and high-capacity SoES provision zones, compliance with the restrictions outlined in the "SoES-based Watershed Protection Zones".	Proposal for considering the critical role of soil and SoES (specific to water purification) in protecting water quality.
		Watershed Protection Plan Article 5	"In order to ensure the preservation of continental water resources for all types of use, prevent pollution, and improve the water quality of polluted water sources, it is essential to develop a watershed protection plan that takes into account the characteristics of the watershed"	"… preservation of continental water and soil resources ... to prevent pollution, and improve the soil quality and … it is essential to develop a watershed protection plan that takes into account SoES provision capacities and protection zones in the watershed".	Recommendation for the inclusion of soil quality and SoES protection and considering critical zones for SoES provision in the scope of watershed plans.
Ministry of Environment, Urbanization and Climate Change	3194 - The Law of Development	Definitions Article-5		Suggestion for an additional clause: "Ecosystem Services (ES): The ecological products, conditions, and processes consumed, utilized, and benefited from directly or indirectly from ecosystems for human life and well-being." "Soil ecosystem services (SoES): The ecological, social and economic benefits, conditions and processes provided by soil ecosystem."	Recommendation on the inclusion of the ES approach and, in particular, SoES in the overall content of the Law.
		The preparation of plans Article 8	d) (Additional: 12/7/2013-6495/73 Article) In land use and construction, only the decisions of spatial strategy plans, environmental plans, and zoning plans are complied with."	"d) … only the decisions of spatial strategy plans, environmental plans, watershed protection plans, and zoning plans are complied with."	Recommendation for the inclusion of watershed protection plans among the plans to be adhered to in land use decisions.
			"h) (Amendment: 12/7/2013-6495/73). The Ministry is authorized to develop or commission the creation of plans and projects that prioritize energy efficiency, climate sensitivity, and ecological vulnerabilities for settlements falling under the purview of this Law."	"h) (Amendment: 12/7/2013-6495/73) … The Ministry is authorized to develop or commission the creation of plans and projects that prioritize energy efficiency, climate sensitivity, the provision of ES and ecological vulnerabilities for settlements falling under…"	Proposal to include ecological sensitivities and critical areas supporting ES in plans conducted or implemented by the Ministry, aiming to enhance environmental sustainability and ES provision.

Table H.1 (continued) : Proposed amendments for the integration of SoES approach into relevant legislation.

Competent Authority	**Law No. & Title**	**Section Article**	**CONTENT**	**PROPOSED CONTENT**	**RATIONALE**
Ministry of Environment, Urbanization and Climate Change	3194 - The Law of Development	The preparation of plans Article 8		Suggestion for an additional clause: “Protecting and enhancing natural LULC patterns in urban areas should be encouraged for urban ecosystems’ integrity and precautions for climate change. Changes in LULC should be planned and monitored considering environmental degradation risks, SoES, and ecosystem sensitivities”	Suggestions for pursuing the protection and enhancement of natural LULC patterns as areas of significance in urban areas in terms of SoES provision, climate change, and overall ecosystem health. It is imperative to acknowledge their interconnected nature.
Ministry of Environment, Urbanization and Climate Change	Regulation on Spatial Plans Making	Definitions Article-4		Suggestion for an additional clause “Ecosystem Services (ES): The ecological products, conditions, and processes consumed, utilized, and benefited from directly or indirectly from ecosystems for human life and well-being.” “Soil ecosystem services (SoES): The ecological, social and economic benefits, conditions and processes provided by soil ecosystem.”	Recommendation on the inclusion of the ES approach and SoES, in particular, in the overall content of the Regulation.
		Principles for Spatial Land Use Article 5	“(i) This category encompasses both public and private sector establishments, including educational, healthcare, religious, cultural, and administrative institutions, along with open and verdant spaces. These spaces encompass parks, playgrounds, sports facilities (both indoor and outdoor), squares, children's gardens, play areas, and recreational zones. They are developed by public or private entities with the purpose of fulfilling the cultural, social, and recreational requirements of individuals and society while promoting an enhanced quality of life within a healthful environment.”	“(i) … recreational zones, ecological corridors, and ES provision zones. They are developed by public or private entities with the purpose of fulfilling the cultural, social, and recreational requirements of individuals”	Proposal to incorporate the ES approach into efforts aimed at improving quality of life and fulfilling the needs of individuals and society for a healthier environment.
		Planning Principles Article 7	“ğ) Planning shall be grounded in disaster, geological, and natural data.”	“ğ) Planning shall be grounded in disaster, geological, and natural data including ES provision zones.”	Suggestion to incorporate critical areas providing ES into the planning process along with areas of geological and disaster risk significance.
		Research and Analysis Article 8	"(9) Scientific, technical, economic, social, cultural, political, historical, sectoral, and technological research, as well as problem and potential analysis, are conducted to ascertain the position of the planning area within the broader regional or urban context. These research efforts are carried out alongside physical studies, including threshold analysis and on-site inspections."	"(9) Scientific, technical, economic, social, cultural, environmental, political, …”	Suggestion to incorporate the environmental and ecological attributes of the planning area into research and analysis endeavors of spatial plans.
		Data Structure and Analysis Article 17	"(b) Areas that require development restrictions or possess unique conditions, including those exposed to specific hazards such as earthquakes, landslides, floods, and climate change. This encompasses regions of considerable biological diversity, agricultural ecosystems, and forests, along with freshwater ecosystems and water sources. It also includes coastal ecosystems housing endemic species or ecologically significant areas."	b) … This encompasses regions of considerable biological diversity, critical areas for SoES provision, agricultural ecosystems, and... It also includes areas with high ES capacity and other ecologically significant areas”	Proposal to include the zones with high ES and SoES potential as areas that require development restrictions or possess unique conditions.
		Urban Planning Principles Article 21	"(7) Adherence to the settlement suitability status maps within the approved geological-geotechnical surveys or microzoning reports, is obligatory."	"6) Adherence to the settlement suitability status maps within the approved “Watershed Protection Plans” and geological-geotechnical surveys or micro zoning reports is obligatory.”	Suggestion for adhering to suitability criteria associated with the Watershed Protection Plans that include the proposed SoES-based watershed protection zones approach.
		Threshold Analysis Article 22	“In the threshold analysis, a comprehensive evaluation is conducted, taking into account topographical features, geological-geotechnical characteristics, hydrogeological structures, land use patterns, agricultural and forested regions, drinking water catchment areas, conservation zones, including archaeological sites and sensitive locales, coastal regions, infrastructure, natural and physical data, as well as disaster risks.”	“… hydrogeological structures, soil characteristics and … including archaeological sites and sensitive locales, coastal regions, infrastructure, natural and physical data, as well as critical zones for SoES provision and disaster risks.”	Suggestion to incorporate critical zones for SoES provision in the scope of the threshold analysis.

Table H.1 (continued) : Proposed amendments for the integration of SoES approach into relevant legislation.

Competent Authority	**Law No. & Title**	**Section Article**	**CONTENT**	**PROPOSED CONTENT**	**RATIONALE**
Ministry of Agriculture and Forestry	Special Provisions and Watershed Protection Plan of Buyukcekmece Dam Lake	1.3 Definitions	“Ecosystem Services (ES): The ecological products, conditions, and processes consumed, utilized, and benefited from directly or indirectly from ecosystems for human life and well-being.”	Suggestion to include SoES under the "definitions" section. “Soil ecosystem services (SoES): The ecological, social and economic benefits, conditions and processes provided by soil ecosystem.”	Incorporation of the SoES into the plan to highlight its significance and roles in protecting the water quality and quantity and the overall ecosystem health of the Buyukcekmece Watershed.
		1.5 General Provisions	“19. The adoption of good agricultural practices in the watershed should be implemented in 5 years.” “20. It is mandatory to implement erosion-reducing methods and take necessary measures in the watershed.”	“19. The adoption of good agricultural practices considering soil quality, SoES, and water quality in the watershed should be implemented within 5 years.” “20. …and take necessary measures to ensure the provision of SoES in the watershed”	Recommendation to emphasize the positive effects of supported good agricultural practices and erosion reduction efforts on SoES.
		1.12. Critical Areas for Water-Related ES Capacity	“Areas that provide ecosystem services related to water cycle regulation, water flow regulation, and the. provision of freshwater, based on land cover/land use”	“Critical areas for SoES provision to regulate, infiltrate and store water:” “Areas that provide SoES related to water flow and storage as well as water cycle regulation.”	The existing "water-related ES" statement can directly be linked to respective SoES.
		1.7 and 1.8 Green Buffer Zone	Green buffer zone 1: The zone with a 150-meter width in the horizontal plane around the lake commences at an elevation of 6.68 meters, corresponding to the maximum water level” “Green buffer zone 2: The zone encompasses a horizontal area that spans 150 meters starting from the green buffer zone 1.” is defined in the “Map of Protection Areas in Buyukcekmece Watershed”	“The green buffer zone can be expanded to consider the soil's biomass production service. Also, brown and green infrastructures can be encouraged to be designed considering SOC and water-related SoES including water-sensitive and climate-sensitive urban planning and design strategies at the local level.	Suggestions for integrating SoES into the Map of Protected Areas in Buyukcekmece Watershed.
Ministry of Environment, Urbanization and Climate Change	Turkey’s National Climate Change Adaptation Strategy and Action Plan (NCCAP) (2011-2023)	Part 1: Water Resources Management	“Besides, it is highly needed to identify the land use and changes in flora more comprehensively to predict the future condition of water resources in a better way.”	“…and changes in flora and the increase of impervious surfaces (soil sealing) in relation to soil’s “surface water regulation and water purification services” more comprehensively to predict...”	Suggestions on highlighting the role of SoES in runoff and flood control as well as in water quality.
			“Increasing temperatures in Turkey as a result of climate change would lead to loss of surface waters, degradation of soil, erosion in coastal regions and …”	“.. degradation of soil and its negative consequences on SoES, triggered by the LULC changes and mismanagement and planning practices…”	Shedding light on the links between climate change, soil degradation, and SoES.
		Part 2: Agriculture Sector and Food Security	“Climate change in Turkey is expected to lead to increasingly negative impacts on water and soil resources…” “Climate change will lead to a higher risk of reduction in agricultural yield.”	“Climate change in Turkey is expected to lead to increasingly negative impacts on water and soil resources in urban and rural areas”	Emphasizing “urban soil” in the context of climate change impacts.
		Part 4: Natural Disaster Risk Management	“In rural and in urban areas there will be flood risks or the existing level of risk will be higher. … therefore, disaster hazard maps should be developed”	“… In particular, soil provides critical SoES that are pivotal in decreasing GHG emissions by sequestering and storing carbon” **“…** therefore, disaster hazard maps should be developed considering the soil conditions, vulnerabilities and SoES and their contribution to regulating flood, drought or climate-related disaster risks”	Prioritizing the central role of SoES in climate change mitigation. Indicating the role of SoES in natural disaster risk management.
Ministry of Environment, Urbanization and Climate Change	2872 - Environment Law	Definitions Article 2		Suggestion for an additional clause: “Ecosystem Services (ES): The ecological products, conditions, and processes consumed, utilized, and benefited from directly or indirectly from ecosystems for human life and well-being.” “Soil ecosystem services (SoES): The ecological, social and economic benefits, conditions and processes provided by soil ecosystem.”	The law solely encompasses the definition of "ecosystem”. Therefore, it is proposed to include the ES approach and, in particular, SoES in the overall content of the Law.
				“Soil quality refers to the overall condition or health of the soil, taking into account various physical, chemical, and biological properties that affect its ability to function effectively and provide SoES.”	The law includes the definition of air quality, but it does not address soil quality. Considering the interconnected nature of environmental health, the integration of soil quality into the relevant legislation is recommended.

Table H.1 (continued) : Proposed amendments for the integration of SoES approach into relevant legislation.

Competent Authority	**Law No. & Title**	**Section Article**	**CONTENT**	**PROPOSED CONTENT**	**RATIONALE**
Ministry of Environment, Urbanization and Climate Change	2872 - Environment Law	Principles Article 3	"(Amended: 26/4/2006-5491/3 Art.) a) Everyone, including authorities, professional organizations, associations, and non-governmental organizations, is responsible for the protection of the environment and the prevention of pollution. They are obligated to comply with the measures and principles established in this regard."	"…responsible for the prevention of pollution and protection of the environment considering ecological integrity, which is critical for ensuring ecosystem functions and ES."	Recommendation for the evaluation of environmental protection, defined as one of the fundamental principles of the law, through the lens of ecological integrity and ES.
		Protection of the Environment Article 9	a) The preservation of the biological diversity constituting the natural environment and the ecosystem that harbors this diversity is considered fundamental."	"The preservation of the biological diversity constituting the natural environment and the aquatic and terrestrial ecosystems that harbor this diversity is considered fundamental"	Suggestion for a more specific description that addresses aquatic and terrestrial ecosystems, rather than a singular definition that refers to the biodiversity provision by a single ecosystem.
			"d) To secure the protection of soil and water areas of ecological importance at both national and global levels, areas that are susceptible to environmental pollution and disruptions, and that play a pivotal role in conserving biodiversity, natural resources, and related cultural heritage for future generations, regulatory measures can be implemented to designate and declare them as 'Special Environmental Protection Zones."	"d) … and that play a pivotal role in the provision of ES, conservation of biodiversity…. can be implemented to designate and declare them as 'Special Environmental Protection Zones including ES Protection Zones", which significantly contribute to environmental conservation and the enhancement of the quality of life."	In accordance with the law, specific regions are designated as 'Special Environmental Protection' areas due to their ecological importance and vulnerability to environmental influences and disruptions, and the necessity to secure them for the benefit of future generations. Within this framework, it is advisable to formulate the 'Special Areas for the Protection of ES' as a subset of ''Special Environmental Protection' areas and establish their protective designations.
			"h) Ensuring the conservation and sustainable use of the country's marine, underground, and surface water resources, as well as the areas of aquatic product production, and protecting them from pollution, are considered fundamental."	"h) Ensuring the conservation and sustainable use of the country's marine, underground, and surface water resources, soil resources, as well as…"	Due to the importance of soil in preserving the quantity and quality of water resources, the inclusion of soil resources in this article is recommended.
		Definitions Article 3		Suggestion for an additional clause: "Ecosystem Services (ES): The ecological products, conditions, and processes consumed, utilized, and benefited from directly or indirectly from ecosystems for human life and well-being." "Soil ecosystem services (SoES): The ecological, social and economic benefits, conditions and processes provided by soil ecosystem."	Recommendation the inclusion of the ES approach and, in particular, SoES in the overall content of the Law.
Ministry of Agriculture and Forestry	6831 - Forest Law	The preservation of forests Article 16	"(Revised Paragraph 1: 23/3/2023-7442/10 Art.) However, during the license period, including renewals, mining exploration, and operations within the boundaries of state forests, in seed stands, genetic conservation areas, conservation forests, productive forest areas, forest parks, and areas containing endemic and rare ecosystems that require protection, shall be subject to the approval of the Ministry of Agriculture and Forestry, provided that acquired rights are preserved."	"…areas containing endemic and rare ecosystems that require protection, zones with high SoES capacity, shall be subject to the approval of the Ministry of Agriculture and Forestry…"	Proposal to include areas with high SoES capacity in sensitive areas restricted for mining activities in forest areas.
		Manufacturing and sales Article 26	"(Amended: 23/9/1983 - Article 2896/16) In forest-human relations, with the aim of preserving the forest and prioritizing its utility values, as well as introducing principles of multi-purpose utilization in forestry and management plans, production from state forests shall be carried out by the State in accordance with the principles to be determined by the Ministry of Agriculture and Forestry and the forest management plans."	"(Amendment: 23/9/1983 - 2896/16 md) …with the aim of preserving the forest and the ES provided by the forest and soil ecosystems, prioritizing its utility values…"	Proposal concerning the preservation of ES provided by forest ecosystem, in the context of forest management plans.
		Private Forests: Restriction, Mapping, Management, and Development Article 52	"Article 52 – (Amended: 22/5/1987 - Article 3373/11) ... However, in areas where urban, town, and village structures are collectively located within private forest areas, construction in accordance with urban planning may be permitted under Article 17 of this Law, provided that it does not exceed six percent (6%) of the horizontal area. Special attention is devoted to the preservation of the natural qualities of forest areas during construction."	"…Special attention is devoted to the preservation of the natural qualities of forest areas, maintaining the integrity of the forest ecosystem, and preventing any harm to ES and, in particular, SoES during construction."	Suggestion for maintaining the integrity of forest ecosystems and safeguarding SoES during construction endeavors in privately-owned forest areas.

Table H.1 (continued) : Proposed amendments for the integration of SoES approach into relevant legislation.

Competent Authority	**Law No. & Title**	**Section / Article**	**CONTENT**	**PROPOSED CONTENT**	**RATIONALE**
Ministry of Agriculture and Forestry	6831 - Forest Law	Reforestation and Urban Planning Activities/Article 58	"In areas designated for inclusion in the forest regime or for reforestation, integrated projects are developed, coordinated by the Ministry of Environment and Forestry in collaboration with relevant organizations. These projects encompass afforestation, erosion and flood control, prevention of avalanches and landslides, conservation and enhancement of ecosystems, as well as improving the living conditions of the inhabitants within the watershed."	"These projects encompass afforestation, … conservation and enhancement of ecosystems and ES, initiatives aimed at mitigating the adverse effects of climate change such as increasing SOC, as well as improving the living conditions…"	Proposal to consider the preservation and enhancement of ES and SoES-based initiatives addressing climate change in watershed-based afforestation and environmental protection activities.
		Definitions Article 3		Suggestion for an additional clause: "Ecosystem Services (ES): The ecological products, conditions, and processes consumed, utilized, and benefited from directly or indirectly from ecosystems for human life and well-being." "Soil ecosystem services (SoES): The ecological, social and economic benefits, conditions and processes provided by soil ecosystem."	Recommendation the inclusion of the ES approach and, in particular, SoES in the overall content of the Law.
			"(h) Grazing Capacity: The number of large livestock units that can be grazed in a given area over a prolonged period without causing harm to vegetation, soil, water, and other natural resources, at regular intervals and equal time intervals."	"(h) Grazing Capacity: The number of large livestock units that can be grazed in a given area over a prolonged period without causing harm to vegetation, soil and water ecosystems, the ES they provide, and other natural resources."	Suggestion for considering the soil and water ecosystems and their capacity to provide ES in determining the grazing capacity defined by the law.
Ministry of Agriculture and Forestry	4342 - Law on Pastures	Determination of Needs for Allocation Article 11	"The commission takes into account the region's economic conditions, climate characteristics, soil cultivation principles, land use patterns, and land-use capability classes to identify and delineate current pastures, highland pastures, and winter grazing areas, as well as other areas that can be utilized for this purpose, irrigation, and transit points on maps"	"…climate characteristics, soil cultivation principles, soil attributes and SoES potentials, land use patterns …"	Recommendation for considering the soil characteristics and SoES potentials in the determination of pastures.
		Change of Allocation Purpose Article 14	"d) (Amended: 3/7/2005 - Article 5403/27) For the preparation of additional zoning plans for village settlements, implementation of zoning plans, soil preservation, conservation of genetic resources, the establishment of national parks and conservation forests, conservation of natural, historical, and cultural assets, flood control, and the production of aquatic products and agricultural activities based on thermal resources that are required in these resources"	"… For the preparation of additional zoning plans for village settlements implementation zoning plans, soil, and SoES preservation, conservation of genetic resources…"	Suggestion for the inclusion of SoES in the decisions for altering the allocation purpose of pastures, due to its critical role in providing essential SoES and natural hazard mitigation
		Conservation Maintenance, and Improvement of Pastures, Summer Pastures, and Winter Quarters		Suggestion for an additional article: "Consideration of SoES Capacity in the Conservation of Pastures Article 21: In the conservation and rehabilitation of existing pastures, soil quality and SoES, in particular soil carbon storage, must be taken into account. Proposed LULC decisions for the area should be planned in a manner that does not diminish the SoES potentials and does not harm soil quality and functions as well"	New article proposal for conserving soil quality and SoES provision against conservation, rehabilitation, and development of new LULC decisions for Pastures.
Ministry of Energy and Natural Resources	3213- Mining Law	Mining Activity Permissions Article 7	**"(Additional paragraph: 10/6/2010-5995/3 Art.)** Permission is granted for mineral exploration and mining activities within state forests, as well as temporary facilities established for these activities, in accordance with the provisions of the Forest Law numbered 6831, subject to mandatory requirements and the duration of the license, as of August 31, 1956."	Suggestion for an additional clause: "**(Additional paragraph**: Exploration and mining activities within the watersheds as well as temporary facilities established for these activities, are permitted in accordance with the provisions of the Watershed Protection Plan"	Recommendation for the consideration of Watershed Protection Plan provisions in permitting mining activities in the watersheds.
		Article 32	"The license holder is obligated to implement the measures specified above within six months at the latest and to bring the operating area in compliance with the environmental requirements in accordance with the operation project."	Suggestion for an additional statement: "… operation project. Restoration and rehabilitation projects related to the soil characteristics, morphology, and vegetation cover of the area take into account the integrity of the soil ecosystem and the continuity of SoES"	Recommendation for considering soil ecosystem and the continuity of SoES in restoration and rehabilitation efforts following the mining activities.

APPENDIX I: A Glossary and Fundamentals of Soil Research

This section provides a comprehensive overview of the fundamental background information on the soil ecosystem, encompassing soil formation and composition, as well as the physical and biological properties of soil and their definitions. The decision to extensively explore these themes is driven by their direct relevance to the essence and content of the research. Conversely, certain other crucial soil information, such as chemical properties, classification, and soil mapping, have been excluded from this section due to their weak linkages with the analysis and findings presented in the research.

The purpose of preparing this section is twofold: to gather the terminology that serves as a source for this multidisciplinary SoES research and to facilitate a better understanding of the research scope and outcomes.

Soil Formation: Soil, technically, is formed by "pedogenesis processes", which indicates the gradual transformation of rock and mineral materials into a fertile substrate for plant growth (0guz, 2006). As Brady and Weil, (2017) state, the process of soil formation includes overlapping stages influenced by several factors, and it begins typically with the weathering of rock and mineral materials followed by the microbial activity that decomposes dead plant and animal matter and provides nutrient through physical, chemical, and biological processes. There are, in general, five primary factors -active and passive- work together to form diverse soil types (Brady and Weil, 2017; Erpul, 2014):

- Climate (active factor): It has a significant role in soil formation. Especially temperature and precipitation affect the physical breakdown of parent material and the following chemical reactions driven by soil microorganisms. These biochemical processes are directly affected by the changes in temperature and moisture levels, as the speed of chemical reactions increases two-fold for every 10 degrees Celsius rise in temperature (Brady and Weil, 2017). Therefore, soils tend to form more quickly in warm and moist climates.
- Organisms (active factor): Plants, bacteria, and other organisms accelerate the breaking down process of large soil particles into small pieces and they function in decomposing and integrating organic material into the soil. According to Oguz (2008), soil formation processes occur faster in regions where vegetative communities are dense and microorganism activities are high.
- Relief-Landscape (passive factor): The topography and orientation (slope exposure) of the land have an indirect influence on soil formation by affecting the amount of sunlight that soil receives and the water quantity it holds. Soils on flat land and constantly exposed to the sun form more quickly and are deeper, while soils on sloping land with less sun tend to form slower and are less deep (Oguz, 2008).
- Parent material (passive factor): It is the material that decomposes and forms the soil. Therefore, the physicochemical characteristics of soil are greatly influenced by the nature of the parent material. Climatic conditions and vegetation play a role in determining the influence of parent material on soil properties.
- Time (passive factor): All these factors interact over time. Soil formation is a slow process in nature because the physical and chemical processes involved

occur at a sluggish pace. According to Pany (2014), as soil ages, it differs from the parent material it originated from. This is because soil is not static, but rather a dynamic system that is constantly evolving.

Soil composition and thus, soil fertility and ability to sustain different plant species varies across the world depending on its location and formation (Oguz, 2008).

Soil Composition: Soil is composed of three groups of substances: solid, liquid, and gas. Soil solids are divided into two main groups, namely inorganic and organic matter. The main source of inorganic substances in the soil is the parent material and includes mineral particles that originate from the degradation of rocks and sediments (e.g., stone, gravel, sand, dust, and clay) and determine the soil types. On the other hand, the source of organic matter in the soil is plant residues mainly (dead cover and underground parts), which have central roles in most of the physical (structure, water holding capacity, temperature) and chemical (nutrient source and cation exchange complex) properties and processes of soil. Air and water share the spaces (pores) between solid soil particles. The pores are mostly filled with air, and if the soil is irrigated or after rainfall, the pores are mainly filled with water. The composition of air in soil is different from that in the atmosphere, with typically higher levels of moisture and carbon dioxide, and lower levels of oxygen. On the other hand, soil water (i.e., soil solution) is an extremely important soil element for plant life, as it contains nutrient salts, many ions, organic substances, and oxygen (Brady and Weil, 2017; Erpul, 2014; FAO, 1985). According to McCauley et al, (2005), the ideal soil for optimal plant growth is composed of 45% mineral, 5% organic matter, 25% air, and 25% water (Figure I.1).

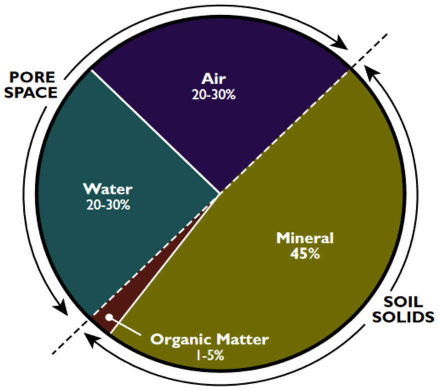

Figure I.1 : Soil composition (McCauley et al, 2005).

Soil Profile (horizons): The soil profile refers to a vertical section of soil. Erpul (2014), Oguz (2008), and FAO (1985) declare that as the formation of soil completes its developmental stages, layers of soil called "horizons" are formed. These horizons have distinct physical, chemical, and biological properties (e.g., color, thickness, grain size, arrangement of soil particles, etc.) produced by soil formation processes, and the majority of soils consist of three principal layers (A, B, C), and some have an organic layer (O) (Figure I.2).

- A - (topsoil) refers to the zone where organic matter mixes with mineral soil materials and provides high biological activity. Palm et al, (2007) indicate that it is the most productive (fertile) horizon that is rich in organic matter and suitable for plants and other organisms to live in.

- B - (subsoil) contains a high concentration of minerals that have been washed down from the A or E horizons (zone of eluviation) and accumulated in this layer. A scarce amount of organic matter or live roots can be found in this layer (FAO, 1985).
- C - (parent material) is the layer of the deposit that exists at the earth's surface and from which the soil has been formed over time. It is also called the zone of regolith (a mix of decaying bedrock and rock fragments) (Oguz, 2008). This layer has been relatively unaffected by soil formation processes and has not been compacted.

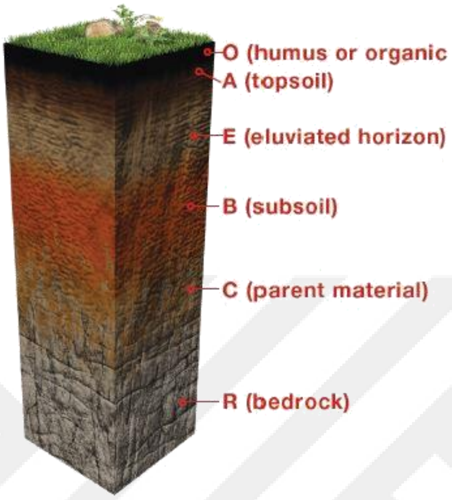

Figure I.2 : Soil profile (Url-1).

Not every soil may contain every horizon, and having certain horizons varies depending on the stage of soil development. Similarly, the horizons are not always distinct and the depth of each horizon can vary from soil to soil. Soil profile is a typical research tool to understand the soil formation processes, the history of soil formation, the maturity degree of soil, etc. Therefore, the investigation and study of soil should begin with the assessment of the soil profile in the field (Brady and Weil, 2017; FAO, 1985).

<u>Physical Properties of Soil:</u> Soil physical characteristics consist of both inherent and dynamic properties. Inherent characteristics encompass soil texture, soil depth, and soil parent materials, whereas dynamic properties can be altered through management practices and include soil structure, bulk density, available soil water holding capacity, soil porosity, SOM, compaction layers, infiltration, crusting, and aggregate stability. These properties determine how air and water/dissolved chemicals move through soil, as well as the conditions that influence root growth, nutrient cycling, biological activity, infiltration, and erosion (Pany, 2014; Oguz, 2008; FAO, 2006; Gobat et al, 2004). Due to this strong relationship, it is necessary to consider the physical characteristics of soils for their intended use. Some of these properties are summarized below.

<u>Soil texture:</u> Soil is composed of mineral particles that are categorized into three groups by size: sand (2mm – 0.05mm), silt (0.05mm – 0.002mm), and clay (< 0.002mm) (McCauley et al, 2005; FAO, 1985). As stated by Brady and Weil (2017) Erpul (2014) and Oguz (2008), soil texture refers to the relative proportions of these particles in the soil. Different percentages of sand, silt, and clay particles are grouped as soil texture classes, which are schematized by the “soil texture triangle” (Figure

I.3). According to this classification, coarse-textured soils (sandy soil) have a high proportion of larger particles (such as Sand, Loamy sand, and Sandy loam), which has low water-holding capacity with good water drainage and aeration due to the large size of pore spaces. In contrast, fine-textured soils (primarily made up of clay) have a high proportion of smaller particles (such as Clay, Silty clay, and Sandy clay) and facilitate slow water and air movement with a high water-holding capacity (Brady and Weil, 2017; Palm et al, 2007; Gobat et al, 2004). Lastly, medium-textured soils (loamy soil) contain approximately equal amounts of sand, clay, and silt, which provide optimum water retention and aeration conditions for plant growth.

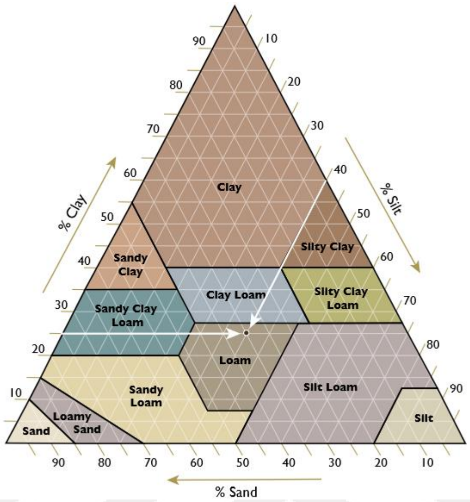

Figure I.3 : Soil texture triangle (McCauley et al, 2005).

Soil texture is closely related to many other soil characteristics and profoundly affects the ability of soil to retain water, facilitate the movement of air and nutrients, and resist erosion (Erpul, 2014; FAO, 1985).

Soil structure: The structure of soil refers to the arrangement of solid particles and the pore spaces in soil (Oguz, 2008). FAO (1985), defines soil structure as the organization of sand, silt, and clay particles, which form small clusters known as peds or aggregates. They can be granular, blocky, columnar, platy, prismatic, massive, or single-grained (Figure I.4).

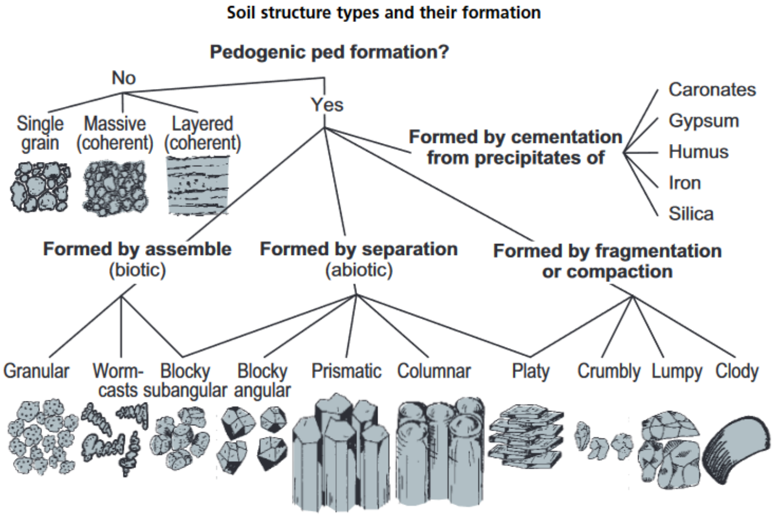

Figure I.4 : Types of soil structure (FAO, 2006).

Since soil structure is directly related to the pore spaces in soil, it is critical for root growth, aeration, and water movement. Compacted soils, such as urban soil, have a significantly decreased amount of pore space as stated by Brady and Weil (2017). Soil structure is closely related to permeability (drainage), water-holding capacity, erosion resilience, biological activity, and the porosity-air-water balance of soil.

Soil porosity: The term refers to the portion of pore space in soil, which is not filled by organic or mineral matter, but is instead occupied by water or air (FAO, 2006). Soil porosity is often expressed as a ratio or percentage, representing the volume of pore space relative to the total volume of soil (Oguz, 2008). Since soil porosity plays an important role in soil fertility and plant growth, the total pore space should make up around 50% of the soil volume to provide an adequate supply of oxygen to plant roots and soil organisms that are involved in the decomposition processes of organic matter and humus, while enabling the movement and storage of water and dissolved nutrients (Brady and Weil, 2017). As clarified by Erpul (2014) and Gobat et al. (2004), coarse-textured soils (sandy) have larger pores, but their total pore volume is less, whereas fine-textured soils (clayey) have smaller pores, but their total pore volume is greater. Unlike texture, soil porosity, and structure are subject to alteration by water, management practices, and chemical processes. Crusting and compaction are among the factors that can reduce porosity, obstruct water infiltration, and potentially decrease water storage in soil, raise surface runoff, and soil erosion (McCauley et al, 2005).

Soil permeability: Permeability is a measure of how quickly air and water can move through the soil (FAO, 1985). As Brady and Weil (2017) and Oguz (2008) mentioned, permeability is affected by various factors, such as soil texture, structure, porosity, and compaction. The soils that have a high level of permeability allow water and air to flow through them quickly, while soils with low permeability restrict the movement of air and water, which may cause inadequate drainage and aeration (Erpul, 2014).

Soil water: Soil water and moisture are crucial for plant growth, chemical reactions, and microbial activity (FAO, 1985) as well as an essential component of the hydrological cycle and groundwater replenishment (Li et al, 2012). Water in soil is often not in a static equilibrium state due to various factors including temperature-induced evaporation, transpiration by plants, precipitation, and gravitational forces (FAO, 2006) as it was illustrated in Figure I.5. In the first place, when water is applied to the soil surface as rain or irrigation, it soaks into the soil and becomes absorbed (capture and infiltration). If watering continues or the rate of water supply surpasses the soil's infiltration capacity (when all the pores in the soil are occupied by water), the soil gets gradually saturated with water and eventually, it cannot retain any additional water. This excess water accumulates on the soil surface and causes runoff (surface runoff).

The water absorbed by soil flows downward through the subsoil (percolation), reaches the water table, and recharges groundwater. The movement of infiltrated water through the soil profile occurs through gravity, osmosis, and capillarity (McCauley et al, 2005). Both surface water flow and the water steadily draining through soil layers end up in water sources and riverine systems, but a significant portion of it is retained by soil (storage). After all the gravitational water has drained out, the remaining amount of water in the soil is known as "field capacity", while the amount of water held in micropores is the soil's "water holding capacity" or "plant available water" that is available to plants (Erpul, 2014; Oguz, 2008). Some of the water stored by soil is progressively drawn up by plant roots (upward movement/transfer) and, depending on the climatic conditions, the water transpires again from the plant and soil surface through evapotranspiration (release) (Brady and Weil, 2017; EC, 2014).

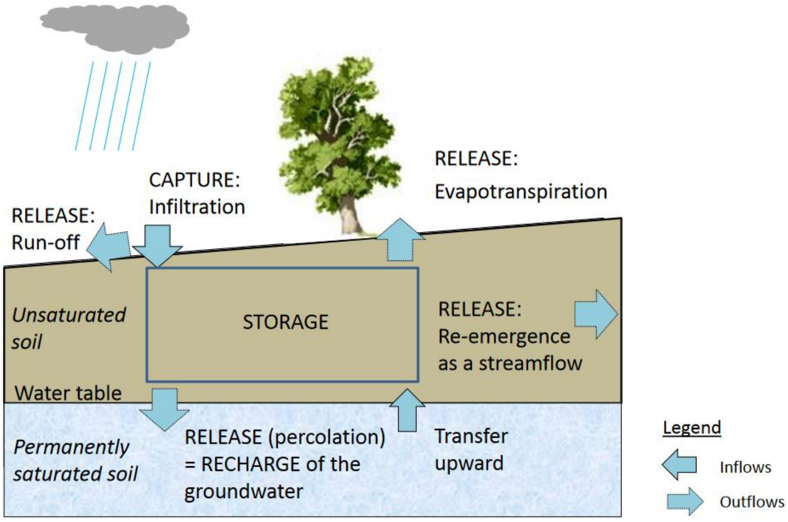

Figure I.5 : Dynamics of soil water movement (EC, 2014).

Soil temperature: According to EC (2010) and Oguz (2008), it is one of the most important properties of soil, that directly influences the physical, biological, and chemical processes (e.g., germination, soil microbial activity, plant growth, nutrient cycling, soil carbon storage). The main source of soil temperature is solar radiation that reaches the earth's surface and moves towards the deeper layers of the soil. The amount of radiation absorbed in soil depends on various factors such as air temperature, moisture level, soil type, topography, vegetation cover, and human activities (Oguz, 2008; FAO, 2006). Vegetation affects soil temperature by reducing soil warming and heat loss (during low air temperatures), while soil compaction increases the thermal conductivity of soil, and therefore the soil temperature (Brady and Weil, 2017; EC, 2010).

The physical, chemical, and biological properties of soil are interconnected and have a mutual influence on each other. However, the remaining physical properties of soil (such as bulk density, soil color, soil depth, and consistency), chemical properties (such as soil pH, cation exchange capacity, soil salinity), and soil classification have not been included in the scope of this chapter due to their lack of direct relevance to the research context. Accordingly, detailed explanations regarding these topics have not been provided.

Biological Properties of Soil: The number, distribution, and activities of macro and microorganisms in the soil collectively determine soil’s biological characteristics (Oguz, 2008). As FAO and ITPS (2015) mentioned, soil is considered to be the most complex and diverse ecosystem of nature as it hosts a myriad of organisms such as microbes, fungi, bacteria, and invertebrates, which correspond to more than a quarter of all living species on earth. According to Lavelle et al. (2006), a single square meter of soil can support 1000 or more species of invertebrates within the volume of soil below the surface, while the number of bacteria present in one gram of soil can range from 100,000 to several billion, depending on the environmental conditions. Therefore, to date, only about 1% of the total soil biodiversity has been identified and described (EC, 2010).

According to Joos and De Tender (2022), soil microbiome is primarily accountable for the physiochemistry dynamics of the soil and mediates approximately 80-90% of soil processes. Under favorable environmental conditions characterized by low oxygen levels, high organic matter availability, and optimal temperature, soil microorganisms can convert nitrate in rainwater, surface runoff, and groundwater, thereby helping to prevent nitrogen pollution in water bodies, which can lead to environmental problems such as eutrophication (Brady and Weil, 2017; EC, 2010). Furthermore, they play crucial roles in pest control, carbon storage, and release as well as nutrient recycling and decomposition processes (FAO and ITPS, 2015; EC, 2010); support the formation of soil structure (Oguz, 2008); supply plants with essential nutrients, (McCauley et al, 2005); and create pores by burrowing through the soil, thus improve water absorption and provide more space for roots to grow (Erpul, 2014). Most importantly, soil microbial diversity is central to supporting and driving Earth's biogeochemical cycles that ensure the sustenance of all life forms on the planet (Ponge, 2015; EC, 2010).

Hydrological cycle: The hydrological cycle, also known as the water cycle, is a continuous process of water movement that takes place on, above, and below the surface of the earth (i.e., within the hydrosphere) (Brady and Weil, 2017). As Marchildon et al. (2017) indicate, the water cycle begins with the evaporation of water from various water bodies, such as oceans and rivers, and then its subsequent transportation into the atmosphere as water vapor. The water vapor then condenses to form clouds (condensation), which eventually precipitate in the form of rain, snow, sleet, or hail (precipitation). The water that falls on land is distributed in four main ways: some returns to the atmosphere through evaporation, some may be intercepted by vegetation and then evaporated from the surface of leaves (transpiration), some infiltrates into the soil by gravity and capillary forces, and the remainder directly flows over the land as surface runoff and reaches to the water bodies. Some of the infiltrated precipitation may be stored in the soil or percolate into the subsurface and groundwater (Figure I.6).

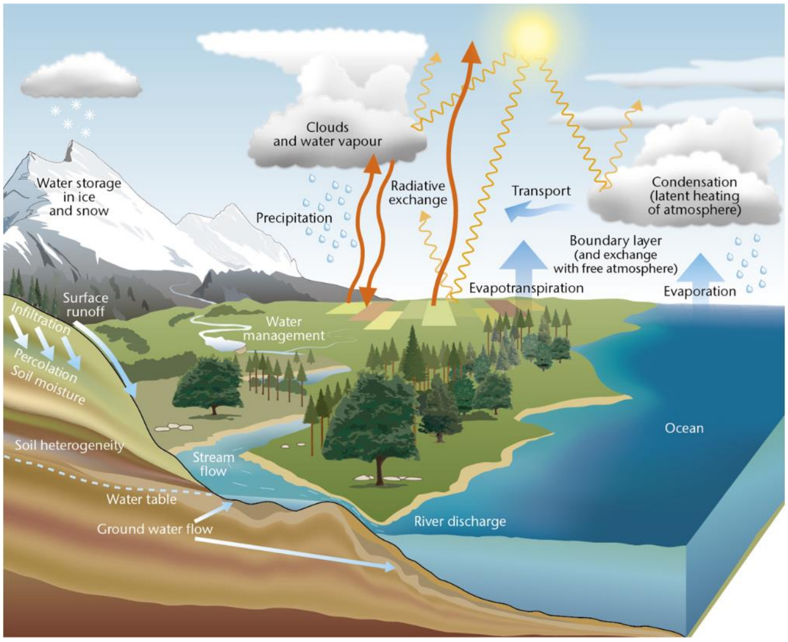

Figure I.6 : Global hydrological cycle (Marchildon et al, 2017).

This process is crucial for preserving the equilibrium of water (distribution and availability) on Earth and ensuring a sufficient reserve of freshwater resources for both human and environmental requirements as well as sustaining aquatic ecosystems and the biodiversity they support. Moreover, it plays a critical role in regulating Earth's temperature and climate through the transfer of heat from tropical to higher latitudes (Brady and Weil, 2017; Quinton, 2015; Li et al, 2012). Soil as a porous material where water is stored and able to move plays a crucial role in the hydrological cycle by capturing, infiltrating, storing, and releasing the water (FAO and ITPS, 2015).

Carbon cycle: The carbon cycle is a natural phenomenon that characterizes the continuous transfer and storage of carbon among various carbon sinks including the atmosphere, oceans, land (soil), and living organisms (FAO, 2017). It involves a diverse range of biological, chemical, and physical processes that can be classified into three main phases: absorption of carbon (via photosynthesis); release of carbon (respiration, decomposition, and combustion); and storage of carbon (Figure I.7) (Scharlemann et al, 2015; EC, 2011; Dumanski, 2004).

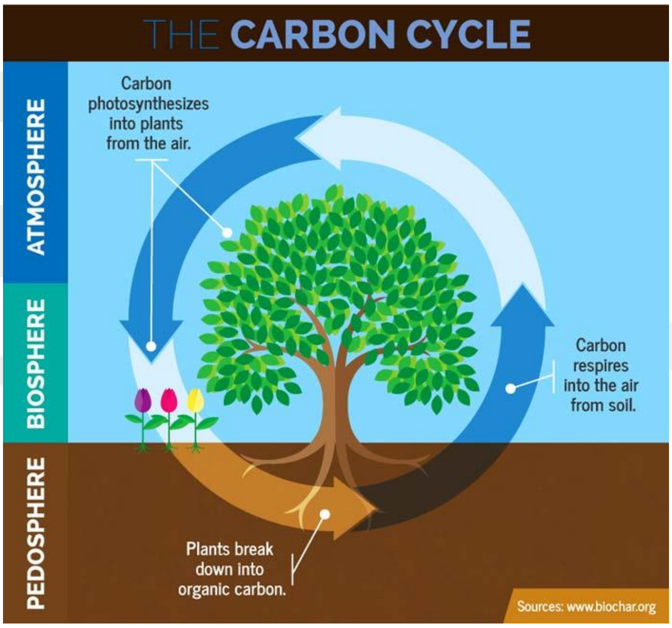

Figure I.7 : Global carbon cycle (Url-9).

Soil is recognized as the second largest carbon sink after the oceans (EC, 2011), and is, therefore, a critical component of the global carbon cycle, contributing to both the sequestration and storage of atmospheric carbon dioxide, as well as its release back to the atmosphere via respiration (Lal, 2008). Herein, soil microorganisms play a vital role as they decompose organic matter and release carbon dioxide, while also storing carbon in the soil and contributing to mitigate the impact of climate change. Carbon, on the other hand, is the primary component of all biological compounds, as well as the backbone of SOM, which contributes to the overall stability, fertility, and productivity of soil (Oguz, 2008). EC (2011) defines the carbon cycle as an integral part of a sequence of interconnected processes, including the nitrogen and water cycles, that are crucial for Earth to sustain life.

Nitrogen cycle: The nitrogen cycle constitutes a natural phenomenon that entails the circulation and conversion of nitrogen in multiple forms in the environment. It includes a series of complex biological, chemical, and physical processes, in which the nitrogen compounds continuously circulate between soil and living organisms, and then back to the soil again (FAO and ITPS, 2015). As Vitousek (1997) described, this cycle encompasses various stages, including nitrogen fixation, nitrification, assimilation, ammonification, and denitrification (Figure I.8), all of which play a crucial role in preserving the equilibrium of nitrogen in the ecosystem. The nitrogen cycle mainly involves the process of transforming atmospheric nitrogen into nitrogen-containing compounds since nitrogen cannot be utilized by plants and animals in its gaseous form. Therefore, most of the important stages in the nitrogen cycle occur in soil, and herein soil microorganisms, (e.g., bacteria and fungi), play a vital role in nitrogen fixation and conversion of nitrogen gas into nitrogen compounds.

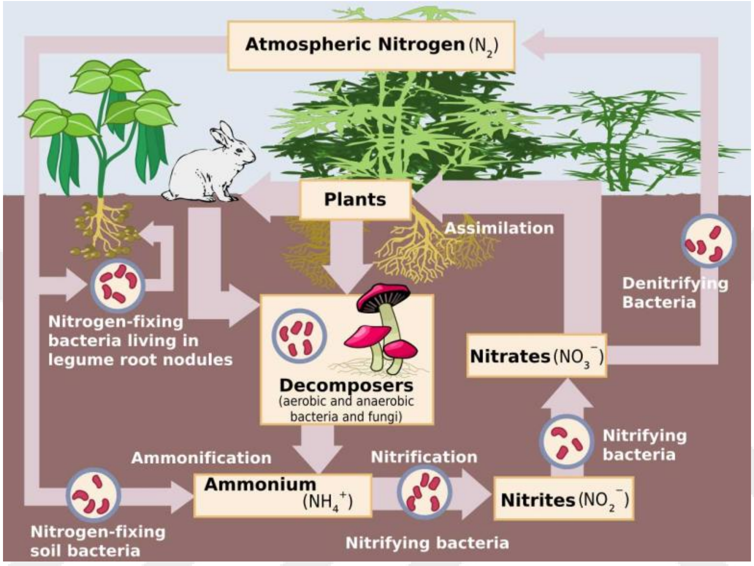

Figure I.8 : Global nitrogen cycle (Url-10).

As nitrogen is an essential element for living organisms, being a component of proteins and DNA, the nitrogen cycle is, therefore, a natural process that ensures the continued existence of life on Earth (Brady and Weil, 2017).

Despite the traditional emphasis on chemical and physical soil properties as soil quality indicators, the role of soil biodiversity in regulating soil functions and determining soil quality is gaining recognition (Creamer et al, 2021) as was highlighted also in the Soil Thematic Strategy (EC, 2012). According to EC (2012), soil quality, ecosystem multifunctionality, and soil functions are at risk due to the potential impacts of changes in soil communities and/or loss of particular groups of soil biota. Likewise, Brady and Weil (2017) and Baveye et al. (2016) describe soil organisms as the crucial drivers of soil functions.

<u>Soil Functions:</u> According to de Groot et al. (2002) and Blum (1993), the functions of an ecosystem refer to the intricate and dynamic processes and interactions that take place within an ecological system, to maintain its structure, perform vital ecological processes on the planet, and provide services for human needs. Hereof, soil ecosystem performs a variety of functions that are essential to support life on Earth. Some key soil functions are summarized below (FAO, 2022; Greiner et al, 2017; Baveye et al, 2016; FAO and ITPS, 2015; Stolte et al, 2015; Blum, 1993).

Soil as a source provides:

- Food and biomass production thus supports primary production

- Raw materials (water, minerals, biofuel, etc.) and pharmaceuticals
- Habitat for soil biota and gene reservoir
- Cultural environment, and - geological and archeological- heritage

Soil as a buffer:

- Purifies and stores water for use by plants and animals
- Serves as a filter and sink for pollutants like heavy metals and organic chemicals that could contaminate air and water sources (pollution control)

Soil regulates:

- Surface runoff and thus, flood risk
- Earth's climate by sequestrating, storing, and releasing carbon as a carbon pool
- The cycling of water and crucial nutrients such as carbon, nitrogen, and phosphorus between living and non-living components of the ecosystem

Soil as a foundation provides,

- Medium for plant growth and crop production
- Support and basis for man-made structures (e.g., buildings, infrastructure)

According to the FAO (2022), it is not feasible to establish a hierarchy among the importance of various soil functions since they all have crucial significance for sustaining life on earth and, consequently, human welfare. Soil functions perform interconnectedly and contribute to the overall well-being of the ecosystem (FAO, 2013). Besides its vital importance for nature, ecosystem functions are critical also for human survival. The subset of ecosystem functions that are useful to humans is defined as ‘ES’ (Kremen, 2005) by referring to the contribution of ecosystems to human wellbeing (MEA, 2005a). The concept of soil functions can be accepted as an early configuration of today’s concept of ‘SoES.’

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