HOW TO ADAPT TO CLIMATE CHANGE? AN ANALYSIS OF ECOSYSTEM VULNERABILITY IN İZMİR (TÜRKİYE)

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We don’t need anything, we only need a thing; we must be more diligent.

Mustafa Kemal ATATÜRK

ABSTRACT

HOW TO ADAPT TO CLIMATE CHANGE? AN ANALYSIS OF ECOSYSTEM VULNERABILITY IN İZMİR (TÜRKİYE)

The purpose of the thesis research is to determine how susceptible the ecosystems in the city of İzmir are to the effects of climate change and provide relevant data to policymakers so that they could develop more efficient climate change adaptation measures. İzmir city is facing challenges in addressing the vulnerabilities triggered by climate change. The biophysical components that contributed to ecosystem vulnerability in the city include the urban heat island effect, urban pluvial floods, and coastal floods. These components were evaluated using a stringent approach that utilized the most recent findings from scientific research and various technological instruments. The analysis results were provided to portray the parts of the city that were most susceptible to the effects of climate change, and the results were further evaluated to better comprehend the processes that contributed to intensifying the consequences of climate change for the vulnerable regions. A thorough investigation and in-depth inspections were carried out using representative tiles from the city, and the results showed that existence of tree and green areas, imperviousness density, Footprint Ratio, Floor Surface Index, and road ratio were the most contributing factors of climate change vulnerability. Following the process of analysis, a systematic of planning and planning parameters were developed that embraced nature-based solutions and a performance-based planning approach for enabling the adaptation of settlements to climate change. The findings contributed significantly to the expanding body of knowledge on how to adapt to the effects of climate change and provided suggestions for efficient measures to mitigate the related risks in İzmir.

Keywords: *Climate Change, Ecosystem Services, Nature-Based Solutions, Performance-Based Planning, Urban Heat Islands, Urban Pluvial Floods, Coastal Floods*

ÖZET

İKLİM DEĞİŞİKLİĞİNE NASIL UYUM SAĞLANIR? İZMİR'DEKİ EKOSİSTEM KIRILGANLIĞININ ANALİZ EDİLMESİ

Tez araştırmasının amacı, İzmir kentindeki ekosistemlerin iklim değişikliğinin etkilerine ne kadar duyarlı olduğunu belirlemek ve karar vericilere daha verimli iklim değişikliği uyum önlemleri geliştirebilmeleri için ilgili verileri sağlamaktır. İzmir şehri, iklim değişikliğinin neden olduğu/tetiklediği kırılganlıkların ele alınmasında zorluklarla karşılaşmaktadır. Şehirdeki ekosistem kırılganlığına olumsuz yönde katkıda bulunan biyofiziksel bileşenler arasında kentsel ısı adası etkisi, kentsel taşkınlar ve kıyı taşkınları yer almaktadır. Bu bileşenler, bilimsel araştırmalardan ve çeşitli teknolojik araçlardan elde edilen güncel bulguları kullanan ekosistem hizmetleri modellemesi kullanılarak değerlendirilmiştir. Analiz sonuçları, iklim değişikliğinin etkilerine en duyarlı kısımlarını belirlenmesinde, sonuçlar ise iklim değişikliğinin etkilerine karşı savunmasız olan hassas bölgelerin detaylı incelemesinde kullanılmıştır. Şehirden temsili alt bölgeler seçilerek kapsamlı bir araştırma ve derinlemesine incelemeler gerçekleştirilmiştir. Sonuçlar ağaç ve yeşil alan varlığı, geçirimsizlik oranı, Taban Alanı Katsayısı, Kat Alanı Katsayısı ve yol oranı iklim kırılganlığına en çok katkıda bulunan faktörler olduğunu göstermiştir. Analiz sürecinin ardından, yerleşimlerin iklim değişikliğine uyumunun sağlanması için doğa tabanlı çözümler ve performans temelli planlama anlayışını benimseyen bir planlama sistematiği ile standartları geliştirilmiştir. Bu çalışma, iklim değişikliğine uyum konusunda karar verme mekanizmalarına yardımcı olabilecek değerli bilgiler sunmaktadır.

Anahtar Kelimeler: *İklim Değişikliği, Ekosistem Hizmetleri, Doğa Tabanlı Çözümler, Performans Temelli Planlama, Kentsel Isı Adası, Kentsel Taşkın, Kıyı Taşkını*

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CHAPTER 1

INTRODUCTION

1.1. Problem Definition

Cities worldwide are experiencing heightened susceptibility to the consequences of climate change, which are further compounded by urbanization and degradation of urban ecosystems. The urban area of İzmir, the third largest city of Turkey, is facing challenges in addressing the potential hazards associated with urban heat island (UHI) effects, pluvial floods, and coastal floods. The ability of İzmir to adjust to evolving climatic circumstances is contingent upon the effective administration of its ecological systems and inherent assets. Insufficient ecosystem management and implementation of nature-based solutions (NBS) impede urban development and expose inhabitants to climate change (CC) related hazards.

Notwithstanding the increasing attention given to the utilization of NBS as a component of Ecosystem Services (ES) to enhance urban climate resilience, notable deficiencies exist in the execution of such solutions in both scholarly literature and practical application. The deficiency in understanding poses a difficulty in appropriately advancing urban areas, encompassing İzmir. Consequently, it is imperative to thoroughly examine İzmir's capacity to withstand both human-induced and natural hazards by implementing ES management strategies that incorporate NBS within the framework of a performance-based planning (PBP). This thesis aims to bridge the gap between theoretical understanding and practical application of measures aimed at enhancing urban climate resilience. The study seeks to identify high-risk areas in İzmir and propose equitable resource allocation solutions. Accomplishing its objective, this study intends to make a valuable contribution towards advancing urban resilience strategies in İzmir and other similar regions.

1.2. Aim of The Study

This study investigates the potential of ES management and NBS for increasing the urban climate resilience of İzmir. The study employs a PBP approach to bridge the gap between theory and practice, by identifying and providing solutions to the high-risk areas in the city with fair distribution of resources. The study specifically focuses on the capacity of İzmir to respond to natural and anthropogenic hazards, such as UHI, pluvial floods, and coastal floods, using Geographical Information Systems (GIS) based spatial analyzes and ES modeling software. The multi-risk mitigation map of the study area is created by synthesizing the spatial risk data obtained. In-depth analysis and urban policies developed cooperated with the city's green infrastructure by İzmir Municipality are used to identify priority areas and explore the barriers to urban resilience in the city. The ultimate goal of this research is to provide insight and recommendations for policymakers and stakeholders to effectively manage ES and utilize NBS to increase urban areas' resilience against CC.

1.3. Research Questions

This study aims to investigate the application of PBP to CC adaptation strategies in the İzmir region, focusing on the vulnerability of ecosystems and the development of adaptation strategies. The following research questions will guide this investigation:

1. What is the relationship between land use/urbanization standards and the occurrence of urban heat island, pluvial flood, and coastal flood events in İzmir, and how do these factors contribute to ecosystem vulnerability and CC adaptation?
2. How can ecosystem-based approaches be integrated into urban planning and design in İzmir to enhance CC adaptation, and what are the potential co-benefits and trade-offs associated with these approaches?
3. What are the key city planning parameters for İzmir to develop and establish a CC resilient city?

These research questions will be addressed through a literature review and data analysis to provide insights and recommendations for policymakers, practitioners, and other stakeholders involved in CC adaptation planning and implementation for ES in the İzmir region.

1.4. Methodology

To conduct a comprehensive analysis of the vulnerability of İzmir to CC, a rigorous methodology was devised to ensure the reliability and validity of the results. The methodology was developed by thoroughly reviewing the relevant literature and carefully considering the research objectives.

Following this review, three ES models of Integrated Valuation of ES and Tradeoffs (InVEST) Software developed by Stanford University in the scope of Natural Capital Project were selected to assess the vulnerability of İzmir's urban ecosystems:

- the Urban Cooling Model for assessing urban heat mitigation,
- the Urban Flood Risk Mitigation Model for assessing runoff mitigation,
- the Coastal Vulnerability Model for assessing coastal flood risk mitigation.

These models were chosen for their ability to simulate the impacts of CC on urban ecosystems accurately, and to provide reliable predictions of the potential vulnerabilities of these ecosystems. The models were run using the selected ecosystem modeling software, and the resulting outputs were then integrated to produce a comprehensive vulnerability map of İzmir. This map was then used to identify the city's most vulnerable and least vulnerable areas.

A detailed analysis of the vulnerability map was conducted to investigate the characteristics of the vulnerable areas further and develop strategies to enhance their capacity. This analysis included an investigation of the urban heat vulnerability, runoff retention capacity, and coastal flood risk management of the areas, as well as examining other relevant factors such as population density, land use, and infrastructure. Based on the results of this analysis, adaptation strategies were developed to increase the capability of vulnerable areas to mitigate the impacts of CC. These strategies were designed to enhance the urban heat mitigation of vulnerable areas, increase their runoff retention capacity, and increase the resilience of coastlines to storm surges and sea level rise.

By using a rigorous approach incorporating the latest ecosystem modeling techniques, this study provides valuable insights into the impacts of CC on urban ecosystems. It offers practical solutions for improving their resilience and adapting to the challenges of a changing climate.

1.5. Structure of the Thesis

The present study investigates how to adapt to CC regarding ecosystem vulnerability in İzmir. The following section outline the structure of the thesis.

The study commences with a literature review on CC research's state of the art. The first chapter introduces the research problem, the aim of the study, and research questions. This chapter then explores the science of global CC, including mitigation and adaptation measures. The chapter also examines the response of urban ecosystems to CC, specifically through the concepts of vulnerability and resilience, as well as the use of ES as a tool for achieving climate resilience. The chapter concludes with a discussion on the impact of CC on Mediterranean settlements, focusing on UHI effect, urban pluvial floods, and coastal floods.

Chapter three provides a comprehensive understanding of the biophysical aspects of the area of interest. The chapter focuses on three key ecosystem model assessments: urban cooling, flood mitigation, and coastal flood vulnerability. The main objective of this chapter is to offer a thorough methodology for evaluating the biophysical factors that contribute to ecosystem vulnerability and inform policy makers for climate adaptation strategies. To achieve this objective, the chapter employs a rigorous methodology that draws on the latest scientific research and technical tools to assess the biophysical conditions in the study area.

Chapter four of this thesis presents the results of the research conducted to assess the vulnerability of ecosystems in the city of İzmir to CC. In this chapter, the findings are presented and discussed. The research aimed to identify the areas within the city that are most vulnerable to CC impacts, including the UHI effect, urban pluvial floods, and coastal floods.

Chapter five of this thesis engages in a comprehensive discussion and detailed site analysis to identify the factors contributing to the vulnerability hotspot of CC. This chapter aims to foster a deeper understanding of the mechanisms that exacerbate the effects of CC in these areas and to pinpoint the most pressing issues that require immediate attention.

CHAPTER 2

THE STATE OF THE ART

2.1. Performance-Based Planning Approach

PBP is a municipal planning approach that prioritizes desired results over rules and procedures. Compared to conventional planning, which prioritizes short-term concerns such as zoning and land use, PBP prioritizes achieving broad objectives and looking to the future[1]. The future objectives of the community are central to the planning and expansion process under this approach[2].

According to the central tenet of PBP, plans should be regarded as strategic instruments instead of administrative directives. A PBP system does not specify how results are to be achieved; rather, it specifies the performance standards against which those means must be evaluated[3]. Prioritization is placed on effective and efficient means of attaining predetermined objectives. This method enables stakeholders to be more adaptable to new circumstances and patterns and more aggressive when confronting difficult issues such as social justice, environmental preservation, and economic growth[1,4].

The term "PBP" refers to a municipal planning strategy that emphasizes outcomes more than procedures and standards. A long-term perspective enables planners to respond more proactively to complex issues such as social justice, environmental protection, and economic growth, and to adapt more quickly to new information and trends. PBP has the potential to produce more adaptable plans that consider the needs and goals of the community as a result of the involvement of stakeholders in the planning process.

2.1.1. The Advantages of PBP in Urban Development

The asset of PBP lies in its flexibility. Without stringent regulations, governmental and commercial entities can engage in unrestricted dialogues concerning the optimal means of attaining their project objectives[5]. The adaptability of project plans and requirements allows for necessary modifications, leading to increased efficiency and effectiveness in the development of municipalities. Furthermore, the PBP approach prioritizes attaining pre-established goals over strict adherence to predetermined protocols[6]. This approach enables a more holistic comprehension of the impacts of development and can stimulate innovative solutions that are advantageous to society and the natural world[6,7].

Moreover, implementing PBP enhances the level of assurance in the approval process. Conventional planning techniques lead to protracted clearance procedures for developers due to their strict adherence to intricate zoning and building regulations. PBP is a methodology that places significant importance on attaining pre-established results[3,6]. This approach offers producers enhanced lucidity regarding project standards and diminishes uncertainty throughout the authorization procedure[1]. Enhancing transparency can facilitate the prompt issuance of project permits, leading to a decrease in project expenses and promoting metropolitan growth that is more sustainable.

PBP offers the benefit of ensuring uniformity in applying treatment approaches. PBP centers on achieving pre-established results, fostering uniformity across interventions and guaranteeing that all endeavors meet identical performance standards[4]. The disparities in zoning regulations and building codes across different jurisdictions often lead to incongruities in the standard and durability of urban development projects when using traditional planning techniques[1]. The standardization of urban development can facilitate the promotion of well-being in urban areas and amplify the advantages for nearby populations[5].

Conclusively, the adoption of PBP holds great potential for municipal development due to its emphasis on attaining desired outcomes rather than rigidly adhering to preconceived protocols. This approach fosters flexibility and creativity in strategizing, mitigates authorization concerns, and advances intervention consistency.

PBP carries inherent risks; however, it holds the potential to augment the comprehensive effectiveness and enduring nature of municipal planning.

2.1.2. Limitations of PBP

Despite its widespread use, PBP has exceptions. This section focuses on the managerial burden of establishing and administering the system and the unpredictability of plan execution results as two crucial aspects of PBP.

PBP presents certain benefits but also entails potential hazards that must be considered. Among the potential drawbacks of transactions are unpredictability and additional expenses. The exchange and collaboration between management and planners can potentially waste time and financial resources, particularly for businesses that are not yet well-established[1]. The absence of established standards can increase trade costs due to uncertainty and miscommunication among the parties involved. Notwithstanding, the aforementioned hazards can be alleviated via transparent communication and collaboration among all parties involved, culminating in a more streamlined and proficient urban expansion[8].

One of its greatest obstacles is the administrative work necessary to establish and maintain a PBP system[9]. This requires identifying relevant performance indicators, accumulating relevant data, and monitoring the progress toward the goals. Setting up a performance-based system can be a time-consuming, challenging, and expensive endeavor requiring substantial manpower, resources, and education[10]. It is challenging enough to collect data without also having to design performance metrics that accurately reflect the organization's stated objectives and priorities[11].

A further obstacle for PBP is the uncertainty surrounding the results of plan execution. This is due to the challenges associated with predicting the outcomes of initiatives, evaluating the combined effects of multiple changes, and monitoring the execution process. The prioritization of short-term over long-term results and the neglect of immeasurable aspects of corporate performance pose risks and potential trade-offs[9].

In conclusion, performance - based planning is a prevalent method of strategy planning, but it is not immaculate. In addition to the administrative burden of setting up and administering the system, there is also the difficulty of not knowing what will occur when the plan is implemented. When deciding whether to implement a performance-based strategy, businesses must consider these limitations and ensure they have the personnel, technology, and training to do so.

2.1.3. The State of PBP

Several countries, including the United States, the United Kingdom, and the Commonwealth nations of Australia and New Zealand, employ the PBP approac [9].

The international implementation of PBP has been limited despite its many advantages. In Europe, for example, the approach has been discussed predominantly regarding large-scale strategic plans and their evaluation, with limited municipal applicatio [12]. In the United States, Oregon has been at the forefront of implementing PBP, which employs a variety of metrics to assess the value of transit expenditures. Water and fisheries are two natural resources that have benefited from New Zealand's implementation of PBP. Infrastructure initiatives in Queensland, Australia are governed by PBP, prioritizing specific economic, social, and environmental outcomes[1]. Planners and programmers have generally supported PBP, its implementation in some regions has been inadequate. Due to the difficulty of establishing and maintaining the system and the unpredictability of plan execution, local governments have reinstated some prescribed elements in the planning system, resulting in hybrid methods[1].

Although PBP has become more prevalent in some areas, it is still not widely used internationally. Success requires adequate technological knowledge, resources, and an in-depth comprehension of the benefits of the approach, but it can enhance decision-making, accountability, and resource allocation. Additional research is required to discover solutions to the obstacles that prevent its widespread adoption.

2.2. Global Climate Change

One of the most pressing environmental issues of the Earth is anthropogenic CC [13–15]. The Anthropocene is a geologic era that began when human activity superseded natural processes as the major driver of Earth's systems[15]. Anthropogenic CC is referred to as a "wicked problem" in social contexts because it lacks a definitive formulation and involves many players with various opinions and emotions[16]. The intricacy of the problem needs an objective approach to creating integrated solutions, with an abundance of objective scientific data essential for policymakers and planners to make advanced choices.

To minimize ambiguities, scientists have sought consensus on the origins and consequences of CC, concluding that it results from natural and human patterns and processes affecting the Earth's energy budget and energy flows[17]. The United Nations CC Conferences are forums for reviewing progress in adapting to CC and minimizing its effects, CC risks, related disasters, and participating in limiting global temperature increases. Parties have committed to limiting the global temperature increase to below 2^{o}C over pre-industrial levels by 2100[18], with further efforts to limit it to 2 or 1.5^{o}C in more recent negotiations[19,20]. The Paris Agreement, which became legally binding in 2016, requires signatory governments to strive to limit global temperature rises below 2^{o}C and, if possible, below 1.5^{o}C. The agreement outlines international objectives that are desirable and feasible for member parties, with reliable and objective data and statistics from the science of CC and the future scope of human activities contributing to decision-making[14].

The Intergovernmental Panel on Climate Change (IPCC) report offers natural and social scientists, planners, and decision-makers comprehensive and objective information and data based on CC observations. The last IPPCC Assessment report released in 2022, IPCC Sixth Assessment Report, categorizes observed changes in climate systems, including temperature, energy budget and heat content, water cycle and ice sheets in the Greenland and Antarctic regions, sea levels, extremes, and carbon and other biogeochemical cycles. Variations in the global surface temperature, a well-known indicator of CC[17], allow climate scientists to anticipate the scale of future climatic changes (Figure 1). According to IPCC (2022), from the late 1800s, average land and ocean surface temperatures have increased by 0.85°C (0.69 to 0.95) between 1850-1900 and 1995-2014. The average temperature rose 0.99°C (0.84 to 1.10) over the first two decades of the 21st century (2001-2020). The most recent decade, 2011-2020, had an even larger temperature rise of 1.09°C (0.95 to 1.20). In fact, each of the four most recent decades has been warmer than every decade since 1850. Intriguingly, the pace of warming over land has been quicker than over the seas, with a rise of 1.59°C (1.34 to 1.83) between 1850-1900 and 2011-2020, compared to 0.88°C (0.88 to 1.01) for the oceans. These results show that our world is undergoing huge and fast temperature shifts, especially on land, which may have far-reaching consequences for the ecosystems and way of life.

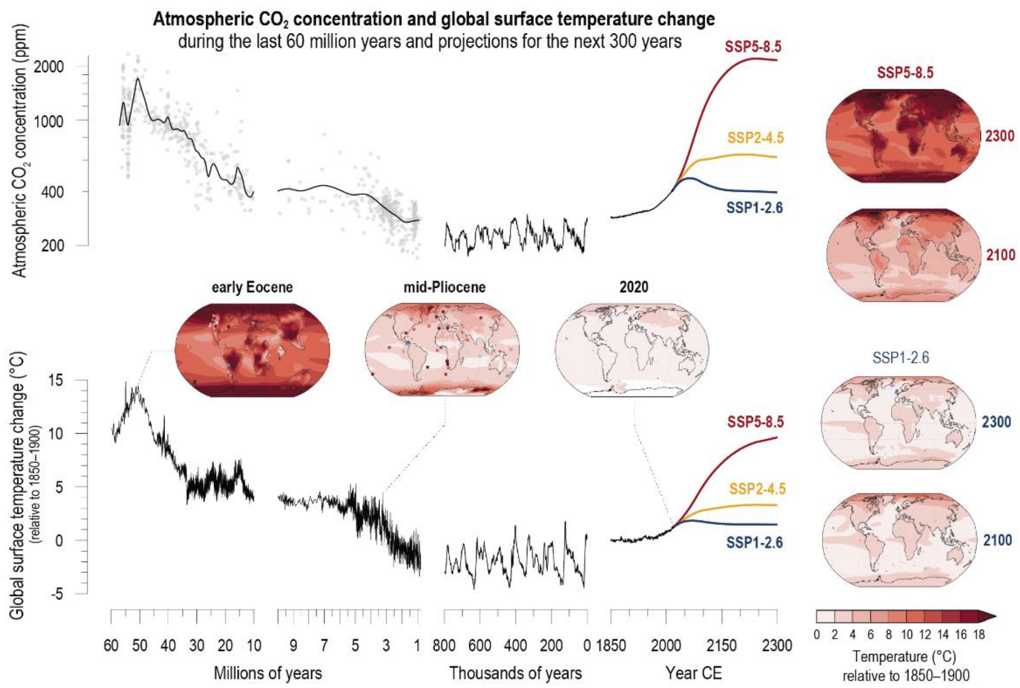

Figure 1. Changes in atmospheric CO_2 and global surface temperature
(From IPCC[17])

The report's multilevel indicators show historical patterns in the effects of CC. Since 1900, the northern hemisphere's spring snow cover and summer sea ice cover have decreased, while the upper ocean heat content and world sea level have increased. Across the globe, glaciers have melted at an alarming pace during the last two decades. According to the report, the pace of global glacier mass loss between 2000 and 2019 is expected to reach an astounding 266 16 Gt yr^{-1}. This is a huge rise over the previous decade when the predicted pace was 240 9 Gt yr^{-1}. The present mass loss rate is comparable to around 4 (3 to 6) percent of the glacial mass in 2000 [17]. These results underscore the rising danger of sea level rise over time and the urgent need for us to address this vital problem.

The rising sea level poses a significant threat to coastal areas, with the potential to cause flooding, erosion, and the relocation of people and infrastructure. The IPCC report also underlines the growing frequency and intensity of severe weather events, such as heatwaves, droughts, and heavy rainfall, which may have disastrous implications on ecosystems, agriculture, and human health[17]. Flood events are occurring both in cities and coastal areas due to changing precipitation patterns (Figure 2) and melting glaciers.

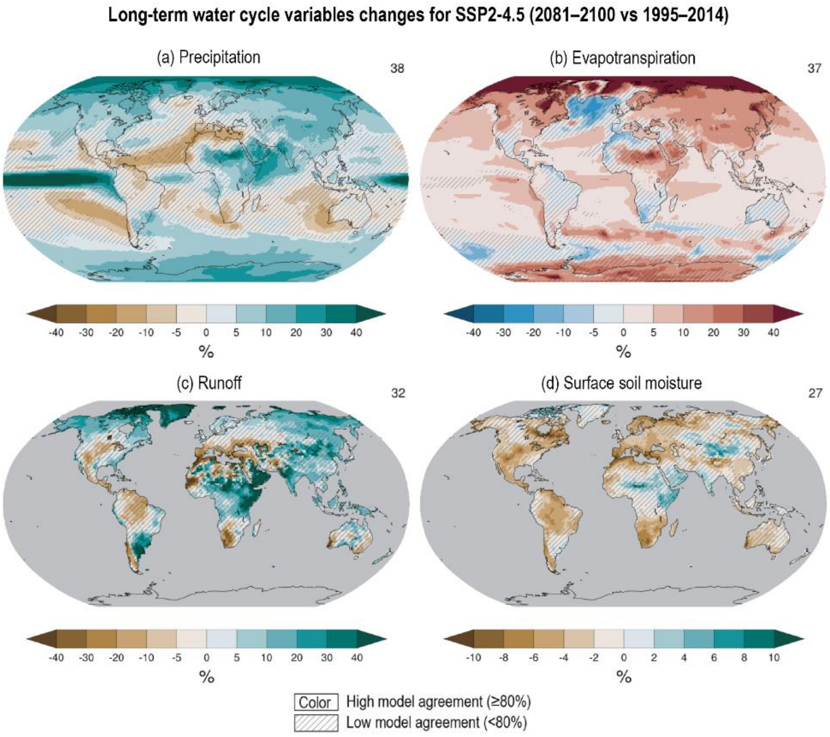

Figure 2. Projected water cycle changes
(From IPCC[17])

Policymakers and stakeholders have implemented several mitigation and adaptation initiatives to address these issues. Adaptation strategies prepare communities and ecosystems for the consequences of a changing climate, while mitigation measures aim to reduce GHG emissions and cope with CC. For instance, the Paris Agreement incorporates countries' pledges to reduce emissions and strengthen resilience to CC[20].

The scientific community is crucial in providing decision-makers with objective, evidence-based information in this setting. The IPCC report and other scientific studies may provide policymakers and stakeholders with the data and insights to build effective CC mitigation strategies. Planners and decision-makers may conduct more systematic, transparent, and accountable examinations of the issue using scientific evidence and methodologies[22].

In conclusion, CC is a complex and multifaceted issue with significant environmental, social, and economic consequences. Considering the diversity of stakeholder viewpoints and interests, scientific evidence is essential for informing policy and decision-making. As we continue to face the challenges presented by anthropogenic CC, we must depend on objective, evidence-based methods to develop effective solutions and strategies for addressing this challenging issue.

2.3. Climate Change Impacts

The impacts of CC can be experienced in different ways (Table 1). CC has profound impacts on the planet, and some of the most noticeable effects can be seen in the Mediterranean region. The urban heat island effect phenomenon, characterized by elevated temperatures in urban areas relative to their rural counterparts, has been exacerbated by the escalation of ambient temperatures. This exacerbates heatwaves and poses a threat to human well-being.

The incidence and magnitude of pluvial floods, characterized by inundation of urban drainage systems and consequent localized flooding in urban areas, have increased in response to CC. The escalation of coastal flooding can be attributed to the endangerment of coastal populations and ecosystems, as well as the elevation of sea levels and the intensification of storms. The Mediterranean region urgently needs mitigation and adaptation strategies to protect its inhabitants, infrastructure, and ecosystems from the impacts of CC.

Table 1. Climatic impacts on urban ecosystems
(From Bartlett[23])

Climate Impacts	Impact on Natural Ecosystems	Impact on Urban Areas	Impact on Health and Household Coping
Warm Spells and Heat Waves	Reduced crop yields in warmer regions; wildfire risk; wider range for disease vectors	Urban heat islands effect; concentration of vulnerable people; increased air pollution	Increased risk of heat related mortality and morbidity; more vectors borne disease; increased respiratory disease; food shortages
Heavy Precipitation Events	Damage to crops; soil erosion; waterlogging; water quality problems	Increase in floods and landslides; disruption to livelihoods and urban economies; damage to homes, possessions, businesses and to transport and infrastructure; often risks to social networks from large displacements of population	Deaths, injuries, increased food and both water-borne and water washed diseases; more malaria; decreased mobility; dislocations; food shortages; mental health risks from displacement
Intense Tropical Cyclone	Damage to crops, trees and coral reefs; disruption to water supplies		
Drought	Land degradation; lower crop yields; livestock deaths; wildfire risks and water stress up	Water shortages; distress migration into urban centers; hydroelectric constraints; lower rural demand for goods/services; higher food prices	Increased food and water shortages; increase in malnutrition and waterborne diseases; mental health risks; respiratory problems from wildfires
High Sea Level	Salinization of water sources	Loss of property and businesses; damage to tourism; damage to buildings from rising water table	Coastal flooding; risk of death and injuries up; loss of livelihoods; health problems from salinized water

2.3.1. Impacts of Climate Change on Mediterranean Region

Each year, many individuals globally journey to the Mediterranean basin to relish its advantageous weather conditions, cultural heritage, delectable culinary delights, and inspiring natural landscapes. Nonetheless, the looming threat of CC poses a potential risk of converting this region into a hostile and unsupportive environment, thereby causing significant adverse effects on vital economic sectors, including tourism and agriculture. Since the end of the nineteenth century, the average temperature in the Mediterranean basin has risen by 1.4ºC, much greater than the global average of 1.1ºC[24]. In that case, temperatures are anticipated to climb by an additional 1.5ºC by 2050, worsening hydrological unpredictability and raising the risks of droughts, water shortages, wildfires, and floods.

According to Rogelj[25], the number of days with a high temperature of 37ºC or more is projected to triple in North Africa, southern Spain, and Turkey by 2050, and climb everywhere else in the region. The risk of heat exhaustion, drought, and disease outbreaks would rise if water supplies decreased by 10–25% between 2030 and 2050 across many areas. The annual area consumed by wildfires on the Iberian Peninsula is anticipated to have quadrupled by 2050[26].

In conclusion, rising temperatures have already impacted the region, and without coordinated efforts to reduce carbon emissions, the situation is expected to worsen, leading to ecological, social, and economic risks. Urgent action is necessary to protect the region's vulnerable ecosystems and diverse communities.

2.3.2. Urban Heat Island and Mitigation

UHI has become a significant issue in modern urban development due to its detrimental effects on the environment, human well-being, and the overall quality of urban life. The UHI phenomenon has been found to have adverse impacts on human health, specifically through increased temperatures. These effects include elevated risks of respiratory and cardiovascular illnesses, dehydration, fatigue, and mortality, particularly among susceptible groups such as children and the elderly[27,28].The UHI phenomenon is characterized by higher temperatures in urban areas relative to their adjacent rural regions[29].

Accelerating urbanization is anticipated to heighten the UHI phenomenon, resulting in augmented dependence on air conditioning and energy usage. This, in turn, will impact human comfort, health, and overall well-being [30]. Studies have dedicated significant research endeavors toward comprehending UHI's prevalence, dispersion, and mitigation[31].

The intricate interplay between natural environmental factors, such as air temperature, humidity, wind speed, and solar radiation, and morphological parameters, such as urban density, building form, road and street geometry, canopy configuration, and building orientation, is crucial in shaping the urban microclimate. This highlights the significant role of urban design in this process[32]. Increased surface irregularity and building diversity in urban blocks can lead to heightened heat retention, ultimately reducing thermal comfort in urban environments[31,33,34].

Natural Capital offers essential functions like air control, water purification, and food production, therefore its efficient management may be part of mitigating UHI effects in urban areas[35]. Taking cues from the natural world, NBS are a flexible and cost-effective way to address environmental problems while also providing social and economic gains[36,37].

Green Infrastructures (GI) are a kind of NBS that consist of a system of interconnected natural and semi-natural areas that work together to support ecosystems[38,39]. The capacity of cities to fight the detrimental impacts of excessive heat has been greatly improved by GI[40,41]. Successfully mitigating the UHI impact and boosting the efficiency of cooling systems may be achieved via the strategic integration of GI development with the provision of ES through spatial planning and greening design measures[42–44].

An accurate evaluation of ES is essential to lessen urban systems' exposure to dangers, pinpoint prime spots for greening design measures, and lead sustainable urban transformation[44]. The most effective urban design criteria for mitigating the UHI impact may be determined by evaluating representative samples of metropolitan areas. Implementing NBS to increase cooling capacity of urban areas in urban transformation, improving the delivery of ES, and incorporating them into planning procedures are all made possible by this approach[45].

Moreover, cooling capacity which refers to the cooling potential of an urban area resulting from shading, evapotranspiration, and wind, is closely linked to various urban design parameters, including building height and density the imperviousness of materials, green space coverage, and other morphological criteria[46,47]. However, relying solely on site-specific assessments to examine this relationship may not yield a systematic investigation. Consequently, the significance and ability of urban planning and efforts to influence the cooling performance of public space architecture in cities, and thus their role in mitigating the UHI effect, have been undervalued[45].

Finally, incorporating NBS and Natural Capital into urban planning is essential for long-term control of the UHI impact. A green and resilient urban environment that improves citizens' quality of life and the sustainability of urban systems is possible with the method of integrating ES and urban catchments[44,48,49].

2.3.3. Floods

Flooding can be attributed to various factors, such as pluvial, coastal, and fluvial flooding. In instances where the quantity of precipitation surpasses the drainage system's capacity within a community, an accumulation of water may occur on urban surfaces such as roadways, resulting in pluvial flooding[50]. Pluvial floods or urban floods refer to flooding events caused by cloudburst events, resulting in the overflow of water which is called runoff[51]. Coastal flooding occurs due to rising sea levels, storm surges, or tidal events, leading to the submergence of low-lying coastal areas[52]. The phenomenon of fluvial flooding is observed when watercourses such as rivers and streams exceed their banks due to factors such as intense precipitation, rapid snowmelt, or malfunctioning dams[53].

This study primarily focuses on the issues of pluvial and coastal flooding in urban areas. The correlation between urbanization and inadequate drainage systems has heightened apprehension regarding pluvial floods[54]. The negative impacts of urban expansion are manifold, including but not limited to the impairment of infrastructure, property loss, and disruptions to daily routines[55]. It is known that urban settlements located in coastal regions are especially susceptible to the adverse impacts of coastal flooding, which can result in significant harm to residential and commercial infrastructure situated along the coastline[56].

2.3.3.1. Pluvial Floods and Management

The increase in the frequency and severity of urban floods has been linked to CC[17,57]. The impacts of global CC on urban areas are widely recognized. Urban areas experiencing rapid growth encounter significant challenges stemming from urban pluvial floods caused by intense cloudbursts and inadequate outflow management[51,58,59]. The process of urbanization exacerbates the situation by decreasing infiltration and amplifying runoff[60–62]. The conventional approach to urban planning, which favors grey infrastructure, is often inadequate in protecting cities from flooding[48,63–65].

Alterations in land use and ecology are supplementary outcomes of urbanization that intensify the impacts of pluvial floods[66]. Urban areas should prioritize their natural environmental resources and employ inventive approaches to urban planning in order to bolster climate resilience and mitigate the negative impacts of flooding[67,68].

The efficient management of urban pluvial floods requires a comprehensive understanding of current and future weather patterns, the vulnerability of urban systems, and suitable management strategies[69]. Monitoring and classifying cloudbursts, which are the primary cause of urban pluvial flooding, presents a challenge[70,71]. The presence of elevated levels of impermeable cover and alterations in water flow routes can increase the susceptibility of urban regions to pluvial flooding[72].

Implementing NBS such as green roofs, urban woodlands, and rain gardens, has enhanced the permeability of urban soils[51]. This, in turn, facilitates improved retention and infiltration of precipitation. According to Cohen-Shacham[73], implementing these strategies can also result in various benefits such as enhanced air and water quality, conservation of wildlife, and improved physical and mental health. It is imperative to engage in long-term planning due to the increasing frequency and severity of climate-related natural disasters[74]. Incorporating resilience into local and urban planning can enhance communities' ability to adapt to disasters[75].

NBS offer a more environmentally sustainable option for mitigating and minimizing the impact of pluvial flooding compared to traditional gray infrastructure[73,76,77]. Various measures can be implemented to enhance water supply security, mitigate the effects of runoff, and enhance water quality. Wetlands, green walls, and porous walkways are among the measures suggested for this purpose[78]. Using green infrastructure in conjunction with gray infrastructure is an energy-efficient and cost-effective approach to effectively manage cloudbursts comprehensively[79,80].

To conclude, effectively managing pluvial floods in urban areas necessitates the incorporation of NBS into existing methodologies. The integration of NBS within the framework of urban planning and design can enhance cities' resilience to the impacts of CC, mitigate the risk of pluvial flooding, and offer various ecological, economic, and social benefits.

2.3.3.2. Coastal Floods and Management

The heightened frequency and severity of coastal flooding, caused by high tide and storm surges, is being linked to CC and other extreme weather events, as evidenced by several studies[81–85]. The risk of floods is exacerbated by the gradual increase in sea level[17].

Coastal populations, especially those residing in the Mediterranean Basin, are highly susceptible to the impacts of CC due to the regional terrain and latitude[86,87]. The mean sea level in the Mediterranean is anticipated to rise by 40-100 centimeters by the conclusion of the 21st century. Nevertheless, the scientific community has expressed divergent views regarding the projected Extreme Sea Levels in forthcoming predictions[86].

According to Houghton[14], all projections based on the Representative Concentration Pathway (RCP) indicate an increase in the frequency of the present 100-year event by the end of the century. Approximately one-third of the European Union's population resides within a 50-kilometer radius of the coastline. Furthermore, it is projected that by the conclusion of this century, approximately 5 million EU citizens may be subjected to annual coastal flooding[89].

Evaluating vulnerability in coastal communities is crucial to adapting to CC. Vousdoukas[90] suggest that biophysical and social factors influence flood risk. It is anticipated that there will be a significant increase in coastal flood risk over the next twenty years. This is attributed to changes in climate-induced extreme sea levels as well as socioeconomic factors[91].

An analysis of flood hazards, vulnerability, and susceptibility may inform management techniques in different nations. The utilization of computing approaches for estimating flood protection system costs has been observed in China[92]. Australia is considering innovative strategies, such as incentivizing individuals and entities, to mitigate risks and enhance the resilience of urban areas[93].

Comprehending the characteristics and interrelatedness of infrastructure is imperative in the formulation of efficacious techniques for mitigating coastal flooding[94]. The process of developing and implementing alternative methods is facilitated by quantifying resilience and establishing standards for both quality and quantity[95].

2.4. Climate Change Mitigation and Adaptation

Fighting against CC is very complex and sensitive. It can be achieved in two ways: by limiting human activity that contributes to the phenomenon (mitigation), and by adapting the strategies for coping with the consequences of CC as they unfold now and, in the future (adaptation)[96]. Additionally, Ayers[97] emphasize the necessity of concurrently considering preventive and remedial CC policies.

2.4.1. Mitigation

CC is a complex and multifaceted global, political, social, and economic dilemma. As a consequence, the mitigation of CC has arisen as a crucial topic, evoking diverse viewpoints from academics in a number of fields.

IPCC[17] comprehensively explains CC mitigation as the group's efforts to reduce human activities that cause climate system alterations. This involves using several strategies to minimize greenhouse gas (GHG) emissions and sources while enhancing GHG sinks. Simply expressed, CC mitigation aims to reduce the amount of GHGs that humans emit into the atmosphere.

According to Ayers[97], CC mitigation is the approach of lowering GHG emissions such as carbon dioxide (CO_2) and methane (CH_4) to reduce or halt the evolution of CC caused by human activities. The authors emphasize the relevance of this technique since it is necessary to mitigate the negative consequences of CC on the global community.

The Paris Agreement, the Kyoto Protocol and other international agreements are examples of institutional arrangements created as part of mitigation efforts; these agreements seek to reduce GHG emissions by promoting technological innovation and development[98]. These guidelines have spawned a range of methods, strategies, and procedures to achieve top-down GHG emission reduction. Among these are market-based techniques such as carbon trading, carbon taxes, and cap-and-trade systems[99].

For nations that have historically made substantial contributions to GHG emissions, the mitigation problem has grown increasingly serious. Aakre et al[96] classify as GHG emitters the United States, Canada, Russia, Germany, the United Kingdom, France, and Scandinavian states in Europe, as well as China, Japan, India, Iran, Malaysia, South Korea, and North Korea in Asia. Due to their considerable contribution to global GHG emissions, these countries play a critical role in mitigating CC.

In conclusion, CC mitigation is an urgent issue that requires a comprehensive plan. Researchers from various disciplines have emphasized the need to mitigate the consequences of CC caused by humans. While efforts have been made globally, more must be done to reduce GHG emissions and mitigate the consequences of CC.

2.4.2. Adaptation

Several scientific domains and disciplines, including biology, ecology, and geography, have extensively used the idea of adaptation. The increasing threat of environmental degradation and CC makes developing and implementing sustainable solutions all the more imperative[100,101]. These paths are centered on preserving Earth's life-support systems and supplying high levels of well-being for all people[102].

Nevertheless, in the context of CC, the word "adaptation" has several connotations and may include a variety of components, including adaptive capacity, vulnerability, sensitivity, exposure, and preparedness[103–108]. In addition, complementary and overlapping sectors must be considered when examining CC adaptation, such as disaster risk reduction (DRR) and resilience[109–112].

Adaptation to CC can be defined as the actions taken to respond to actual or anticipated climate stimuli, such as tornadoes, drought periods, storm surges, heatwaves, insect migration, and epidemic diseases, to mitigate the negative effects of CC[113]. Individuals, communities, and public or private organizations must adapt autonomously or via planning to not just present and future threats, shifting resources, and new knowledge regimes, but also to changes in resource access and control[114]. It is essential to consider, however, that adaptation is "neither inevitable nor automatic"[108].

In other words, having a high adaptive ability or tolerance to climate-related risks and dangers does not ensure effective adaptation[115]. Planning and execution of CC adaptation are often related to or embedded inside other complementing aims, such as the "100 Resilient Cities" Program, which frames the CC adaptation problem within the Urban Resilience concept. Similarly, the United Nations Office for Disaster Risk Reduction (UNDRR) has included CC adaptation into its guiding schemes, such as the Sendai Framework, and programs in conjunction with its primary goal, the DRR idea[112].

DRR and CC adaptation are "linked via a shared approach: decreasing the consequences of severe events and enhancing disaster risk management capability, especially among vulnerable urban populations"[116]. Integration remains restricted despite decades of study and experience in disciplines[117].

Based on the preceding procession, it is evident that adaptation to CC is a complicated and diverse process, including, among others, adaptive capacity, vulnerability, sensitivity, exposure, and preparedness. In addition, the integration of complementary and overlapping sectors, such as DRR and resilience, is essential for successfully addressing the issues presented by CC. Therefore, adaptation to CC is a dynamic and iterative process that demands adaptability, teamwork, and creativity to accomplish its objectives.

2.5. Responses to Climate Change in Urban Ecosystems

Urban ecosystems, in particular, are highly vulnerable to the effects of CC, including extreme weather events, sea-level rise, and changing precipitation patterns. Building resilience and mainstreaming climate adaptation in urban ecosystems is crucial for ensuring their long-term sustainability and the well-being of the people who live and work within them. This requires a comprehensive understanding of the social, ecological, and economic systems that underpin urban ecosystems and innovative strategies for managing them in the face of ongoing and future CC.

2.5.1. Vulnerability

As the world continues to grapple with the effects of CC, the concept of vulnerability has become more important. Ribot, Najam and Watson[118] define vulnerability as "a scale of the relative likelihood of different socio-economic groups and geographic regions experiencing negative consequences," while Adger[119] defines it as "the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt." IPCC describes Vulnerability as " the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt."

Although vulnerability may be interpreted in several ways, Gallopín[120] (p. 294) emphasizes the significance of doing so to "identify the relationship between vulnerability, resilience, and adaptive capacity." From a social and economic perspective, vulnerability is linked to sensitivity, and adaptability. Assessing the vulnerability of urban ecosystems is the first step in establishing an efficient strategy for responding to CC. Vulnerability assessment in complex systems should include underlying social patterns and the effects on individuals and communities[119].

It is well recognized that a complex connection between urban climate effects and urban vulnerabilities exists. Natural and urban ecosystems and human health are affected by CC, either immediately or in the long run. Heat waves, air pollution, floods, water shortages, and increasing food costs are only some of how cities are negatively impacted by CC[121–124].

Important factors in determining urban vulnerability include location and the interplay between urban processes, ordinary activities, and climatic threats[104]. To understand the interplay of urbanization, environmental sustainability, and global warming, one can examine the case of New Orleans[17]. Because of its low height and lack of protective barriers, the city was hit extremely hard by Hurricane Katrina's environmental destruction[125]. The scarcity of resources necessitated a lengthy period of recovery for the city. Suppose more is not done to create a flood warning system and allocate stable financial resources to climate-related projects (such as New York's municipal green bonds or the $350 million and 100-year certificated green bond issuance by the District of Columbia Water and Sewer Authority). In that case, these areas will remain vulnerable to flooding. When establishing and executing location-specific urban adaptation strategies, it is equally vital to adhere to dependable data on climate risks and vulnerabilities[17].

The interaction between urbanization and CC's consequences may be considered a source of social vulnerability. UHIs, for example, disproportionately negatively affect the city's poor. The distribution of income, the availability of economic resources, and the dependency on those resources all have a role in determining the poverty level in a given population, which in turn has a ripple effect on the vulnerability of its individual members [126]. However, inequality due to deteriorating institutional and market systems might be seen as a collective vulnerability that could impede prosperous urbanization and economic development by making city dwellers less secure. As well as increasing their susceptibility, the degradation of aquatic and terrestrial environments might weaken their ability to adapt.

2.5.2. Resilience

The concept of "resilience," which describes a system's ability to withstand and recover from stress without fundamental change, has gained prominence recently[119,127–

[129]. Folke[130] describes resilience as a dynamic process involving continual adaptation and self-organization of complex adaptive systems across temporal and geographical scales.

The notion of urban resilience is very new and has not yet been agreed upon by researchers, despite its frequent use in urban context research[131]. Urban resilience inculcates the notion that urban environments must be responsive to various stressors and able to recover from climatic and/or non-climate shocks, or even rebound[132,133]. Urban resilience is often connected with flexible processes, network management, and collaborative governance[134]. It is considered the capacity to resist various shocks and stressors[117,135].

Complexity and adaptability are hallmarks of the urban ecosystem. The urban environment is especially vulnerable to CC and other disturbances because of the intricate web of social and ecological interactions. Even though many cities have some degree of adaptive ability due to their social and cultural infrastructure, such capacity may be substantially augmented or much lowered depending on the availability of adaptation techniques[136]. No complete urban adaptation plans or approaches are available, despite the fact that building effective CC adaptation strategies requires a wide variety of resilience resources. A well-rounded approach to coping with the unanticipated impacts of CC includes ecosystem management, adaptive capacity development, and self-organizing ability[137–139].

Not only do natural ecosystems have the capacity to expand their adaptive capabilities, but so do all other urban ecosystems[140–142]. However, the effectiveness of this capacity is strongly contingent on the kind and extent of the available possibilities for services like education and infrastructure. Built adaptive capacities and infrastructure display inadequate ability to cope with the detrimental impacts of CC on people's lives. In the United Kingdom, for example, prolonged and heavy rains during the winter of 2013 caused significant flooding and damage to homes and communities, highlighting the need for improved flood risk management and adaptation techniques, including early warning systems and swift rescue operations [136].

To effectively address the challenges posed by CC in urban contexts, it is necessary to adopt a comprehensive and integrated plan considering the geographical and sectoral adaptation components. By categorizing adaptation solutions according to these characteristics, policymakers and urban planners may assess which sectors and scales need more resources and adopt targeted initiatives to increase resilience in vulnerable systems. This may necessitate a mix of resilience measures, such as ecosystem management, adaptive capacity building, and self-organization. Strengthening cities' resilience to CC and other pressures via increased adaptive capacity and reduced vulnerability may protect the health and well-being of their residents. The concept of ES provides a feasible means to boost urban resilience, therefore, it may be useful to include it in planning and management practices.

2.5.3. ES as A Tool to Achieve Climate Resilience

To achieve climate resilience, better design and knowledge of ES are required. This knowledge enables us to better manage ecosystems, therefore boosting their resilience and capacity to offer essential services[143]. By prioritizing ecosystem-based resilience, it is possible to assign greater significance to natural systems and leverage them to improve human welfare amidst the challenges posed by CC. The effective implementation of climate adaptation strategies that promote the sustainability of communities and safeguard the planet can be achieved through prioritizing the management and maintenance of ES[144].

As a way of achieving this balance, ES has arisen as a feasible instrument for studying the connection of human civilizations and the environment and as a beneficial tool for achieving sustainability [145]. According to the ES Definition Framework, ES are "the activities and products of ecosystems that benefit humans or promote social welfare"[146].

In the 1970s, the biodiversity conservation debate gave rise to the concept of ES, originally known as environmental services. During the 1990s, research on measuring, analyzing, and valuing the benefits ecosystems give to humans has expanded rapidly[147]. Due to their recognized relevance in decision-making processes, policies for economic evaluation and remuneration for ES have been devised[148]. In such economic systems, however, the inherent problems of ecosystem service supply and the diverse values given by these services have been questioned[149].

Viewing nature holistically, putting a monetary value on ES, and including humans as both consumers and actors of ecosystem management have all led to the birth of the ecosystem approach as a framework for elucidating measures of natural resource production[150]. To understand all how the natural world enhances lives, it is useful to have a comprehensive framework, and the ecosystem approach provides just that (Defra, 2013). Recently, it has gained popularity as a human-centered instrument for assessing the natural environment[151].

As seen in Table 2, the ecosystem service approach is based on twelve principles that fall under four broad categories[152]. Nonetheless, definition and classification conflicts have marred the ES literature[153]. Due to the integrative and interdisciplinary nature of ecosystem service research, a variety of definitions and frameworks have been developed to account for factors such as efficient economic accounting[22,154], geographical coverage [155], and service exclusivity[156]. Due to the diversity of terminology, it may be challenging to discuss results and convey conclusions across scientific disciplines[151,157].

Table 2. The twelve principles of the Ecosystem Approach
(Adapted from UKNEAFO)

People	Objectives are a societal choice	**Scale and Dynamics**	Identify space and time scales
	Use all relevant available knowledge		Recognize that ecosystems are dynamic
	Emphasize inclusion		Accept that change will happen
Management	Decentralize to lowest appropriate level	**Function, Goods and Services**	Maintain ecosystem services
	Consider "downstream" effects		Recognize functional limits
	Understand economic context		Balance demands for use and conservation

Notwithstanding these challenges, the underlying concept of ES remains applicable to research, policy, and management decisions. Many studies have shown the benefits of ES on human well-being; hence, the notion that ecosystems provide important goods and services to humans is generally recognized[146,158]. For example, forests offer several ecological services, including timber, carbon sequestration, and recreational opportunities[52]; wetlands are crucial because they prevent floods, filter water, and provide habitat for a vast array of plant and animal species[159]; fishing, coastal protection, and tourism are just a few of the many advantages that coral reefs bring to civilization [160]

Due to their recognized significance, several policy and management frameworks have been developed to safeguard and enhance ES. The Millennium Ecosystem Assessment (MEA), which examined the health of the planet's ecosystems and their benefits to humanity, is the most prominent[161]. As a direct consequence of the study's focus on ES, several international accords and initiatives, such as the United Nations Convention on Biological Diversity (CBD) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), were developed[162].

The CBD is an international agreement that aims to safeguard and promote the use of the various ecosystems and the products and services they produce. The CBD, one of the most widely recognized international agreements, has been ratified by 196 countries [163]. Because of their benefits on human well-being, the CBD encourages the conservation and sustainable use of biodiversity and its components, including ecosystems and the services they offer.

The IPBES was established in 2012 as an international body to provide scientific evaluations of the worldwide status of biodiversity and ES and the benefits to human well-being. The IPBES aims to provide policymakers with information for the effective conservation of biodiversity and the sustainable use of ES. IPBES has released several assessment reports, each of which sheds light on the status of global ecosystems and the benefits they provide to people[162].

To sum up, it is evident that the ES concept is generally considered a useful framework for understanding the benefits that ecosystems provide to humans. Notwithstanding the challenges posed by the vast diversity of definitions and methodologies for measuring and assessing ES, the concept is beneficial for driving research, policy, and management.

2.5.4. Bridging Theory and Practice

Urban planning plays a crucial role in addressing the challenges of CC and promoting urban climate resilience. However, translating academic knowledge into practical applications in city planning encounters several barriers.

The existing gap between academic knowledge and practical applications in urban planning can be categorized into theoretical and practical critiques. Theoretical critiques emphasize the risk of reducing modeling to a purely technological practice, disregarding its socio-political dimensions and the involvement of various stakeholders. On the other hand, practical critiques highlight the limitations of modeling itself, acknowledging that all models are imperfect but can still be useful. These critiques, although distinct, impact the effective utilization of modeling in addressing practical and complex problems in urban areas[164].

The gap between academic knowledge and practical applications arises from multiple reasons. Firstly, academic knowledge tends to focus on theoretical concepts and research conducted in controlled environments, which may not fully capture the complexities of real-world urban contexts academic knowledge tends to focus on theoretical concepts and research conducted in controlled environments, which may not fully capture the complexities of real-world urban contexts[165]. Adapting and contextualizing theoretical frameworks to specific urban challenges and constraints is essential for practical implementation[166,167]. Secondly, there is often a lack of effective communication and collaboration between academia and practitioners. Academic research is often published in specialized journals and conferences, making it inaccessible for practitioners. Similarly, practitioners may face difficulties in conveying their real-world challenges to academia[168,169]. Bridging this communication gap is crucial for translating theoretical knowledge into practical solutions. Additionally, the involvement of diverse stakeholders, each with their own priorities and levels of understanding, necessitates inclusive engagement and the navigation of differing perspectives[170].

Integrating theoretical knowledge into city planning applications is vital for enhancing urban climate resilience. Theoretical foundations provide a conceptual framework for understanding the complex dynamics of urban systems and their interactions with the environment. Planners can gain valuable insights into CC risks and vulnerabilities using ES modeling and GIS. ES modeling refers to the process of quantifying and assessing the benefits that ecosystems provide to humans, such as clean water, air purification, soil fertility, pollination, and climate regulation, using various mathematical and computational models[171]. There are several software programs available for ES modeling, including InVEST (Integrated Valuation of Environmental Services and Tradeoffs), ARIES (Artificial Intelligence for Ecosystem Services), RIOS (Resource Investment Optimization System), GLOBIO (Global Biodiversity Model), and LUCI (Land Utilization and Capability Indicator), each offering unique features and applications. These tools facilitate spatial multilayer analysis, enabling planners to assess vulnerability to multiple hazards and inform adaptive design. Using theoretical knowledge serves as a basis for informed decision-making in urban planning[172–174].

Moreover, ES modeling is a valuable tool used in city planning to bridge the gap between academic knowledge and practical applications, particularly in urban climate resilience. This modeling approach enables planners to quantify and assess ecosystems' benefits to urban areas, such as flood mitigation, air purification, and temperature regulation. By incorporating ES into decision-making processes, planners can better understand the trade-offs associated with different development scenarios and make informed choices to enhance urban resilience. Modeling tools like InVEST play a crucial role in this process by providing spatial analysis capabilities, data visualization, and scenario testing. GIS allows planners to integrate diverse datasets and evaluate the spatial distribution of ES, vulnerability to CC impacts, and potential adaptation strategies. By leveraging these modeling tools, city planners can bridge the gap between theoretical knowledge and practical applications by incorporating ES into urban planning decisions, thereby fostering more resilient and sustainable cities[175].

2.5.5. Mainstreaming Climate Resilience

Mainstreaming climate resilience is a crucial step in building adaptive capacity and resilience to CC's impacts and promoting sustainable development. The term "mainstreaming," which has become widespread in conversations about health, gender, and sustainable development, has lately entered the discourse on global warming. The word "mainstreaming" has been subject to several interpretations and definitions due to its extensive use. Nevertheless, Mackay and Bilton[176] define mainstreaming as a "social justice-led approach to policymaking in which equal opportunities principles, strategies and practices are integrated into the everyday work of government and other public bodies. It should aim to transform the organizational culture of governments and public bodies and improve the quality of public policy and governance itself."

Ayers et al[177] define mainstreaming as the "integration of an issue into existing, mostly development-oriented organizations and decision-making processes." When used to adapt to CC, mainstreaming acquires a different element in focusing primarily on environmental concerns. According to Dalal-Clayton and Bass[178], it means integrating relevant environmental concerns into selecting institutions that determine national, local, and sectoral development policy, norms, plans, investment, and action. In other words, CC mainstreaming is the process of incorporating CC challenges, information, concerns, activities, actions, and policies into all aspects of development-related decision-making, planning, and practices.

Moreover, integration or incorporation are the core concepts of mainstreaming. In the context of CC adaptation, it refers to the inclusion of CC concerns in various development policies, plans, practices, and processes[97,179,180]. This may be accomplished by integrating CC information and concerns into the existing institutional frameworks and decision-making processes of varied sectors, including agriculture, forestry, energy, water management, and urban planning. By doing so, CC mainstreaming aims to integrate CC resilience concerns into institutions' decision-making processes and promote adaptation to CC.

In addition, mainstreaming needs the ongoing integration of CC information, policies, and actions into development planning and decision-making. Such integration minimizes duplication and leads to a more effective allocation of resources, which is essential for the successful adaptation to CC[181]. By streamlining procedures and eliminating redundancies, resources may be allocated and directed to the most crucial areas[177].

In conclusion, mainstreaming is a crucial concept for addressing adaptation to CC. It seeks to integrate CC concerns into various development policies, strategies, practices, and processes, to make cities more climate-resilient and adaptable to changing climatic conditions.

2.6. The Spatial Modeling of Ecosystem Services

The concept of "Natural Capital" pertains to abundant natural resources and ecosystems that offer humanity a wide range of essential services. ES encompass various elements such as air, water, food, and entertainment. The considerable worth of natural capital is calculated biophysically and economically by its annual valuation, which is estimated to be in the billions of dollars. The rapid decline of natural capital can be attributed to several factors, including CC, pollution, and deforestation. In addition to its impact on CC and other environmental issues, the degradation in question has adverse effects on human welfare, including heightened poverty levels, malnutrition, and illness.

To address the pressing need for sustainable natural capital management, novel tools have emerged to assist in mapping and valuing the goods and services provided by ecosystems. Mapping has become crucial to bridge the gap between the theoretical assessment of the ES and their evaluation in plans and projects. In fact, it is only when dealing with the spatial distribution of ES that planners, architects, and decision-makers can effectively understand where these ecosystems, and their threats, are concentrated spatially thus providing tailor made policies, plans and design solutions.

When considering the selection of software for ES modeling in urban areas, InVEST stands out as a particularly valuable tool. InVEST offers a comprehensive and versatile approach to assessing urban ES. While other software programs such as ARIES, RIOS, GLOBIO, and LUCI also contribute to ES modeling, InVEST provides distinct advantages in urban contexts. InVEST incorporates a wide range of ES, including carbon storage, water purification, and flood regulation, allowing for a holistic evaluation of urban environmental quality. It also features a user-friendly interface and accessible data inputs, making it suitable for urban planners and decision-makers with varying levels of technical expertise. Moreover, InVEST generates spatially explicit outputs, enabling the identification of specific areas within urban environments that require targeted conservation or restoration efforts to enhance ES provision. By considering these factors, it becomes evident that InVEST is a preferred choice for ES modeling in urban areas, facilitating informed decision-making processes and promoting the integration of environmental considerations into urban planning and management strategies.

The Natural Capital Project has reported that the InVEST Natural Capital framework has been extensively employed to assess the economic value of ES in diverse settings, including but not limited to forests, wetlands, and coastal areas. The utility of this assessment extends beyond a mere financial evaluation, as it has been instrumental in shaping policies and procedures aimed at ensuring the sustained conservation of crucial natural resources such as water and agricultural land. The InVEST of Natural Capital Project of Stanford University tool facilitates the spatially explicit analysis of ES, providing decision-makers with the necessary information to make informed decisions regarding the preservation and sustainable utilization of natural capital.

CHAPTER 3

METHOD

3.1. Area of Interest

The area of interest (AOI) of the study was determined as the İzmir city extents. İzmir is the third largest city of Turkey and the largest city in the Aegean Sea coast. The AOI is the urban agglomeration of İzmir that encompasses 10 of all 30 districts of the province namely Narlıdere, Balçova, Karabağlar, Gaziemir, Konak, Buca, Bornova, Bayraklı, Karşıyaka, and Çiğli (Figure 3). The study area covers administrative borders of the districts and approximately 900 km^2 and has population around 3 million[182]. İzmir city is located in the surrounds of Gulf of İzmir on the scenic Aegean Sea coast and it has a magnificent coastline. İzmir city, formerly known as Smyrna (ancient Greek), through its 5,000-year-long history, has endured several hardships, including earthquakes, fires, diseases, and more. However, the province now confronts a new and urgent threat: CC's effects.

As reported by many studies, Turkey is situated in one of the most sensitive areas to CC, and İzmir is no exception[183–185]. With rising temperatures, decreased and irregular precipitation, and more frequent and extreme droughts and heat waves, the Mediterranean region's environment is becoming more volatile and difficult to manage.

İzmir's natural environment has a key role in amplifying the effects of CC. The combination of the city's slope and poor soil geology is mainly responsible for its environment with higher natural hazard risks[184]. In addition, the proliferation of unauthorized urban settlements and weak construction types exacerbates the disaster risk[183].

The future of İzmir's sea level in relation to coastal flooding is a critical concern necessitating proactive measures [186]. With global sea levels projected to rise between 0.26 to 0.82 meters by 2100, and the Mediterranean Sea experiencing higher rates of rise, İzmir faces a potential sea level increase of up to 82 centimeters within the century[17]. This escalation in sea level height could have profound ramifications, including displacement of residents, infrastructural damage, disruption of economic activities, and potential contamination of freshwater sources through saltwater intrusion.

Despite these obstacles, İzmir has remained a major and prosperous city. Yet, fast population expansion and development demands on rural regions have faced the city with a number of challenges. For example, urban housing supply has not met demand, housing regulations have struggled to integrate with urban land use, and housing subsidies have failed to serve low-income groups sufficiently[184].

İzmir city, where CC and urban growth pressures pose considerable difficulties to both the natural environment and the inhabitants, is the focus of this research. The repercussions of these difficulties will be examined in detail in the next chapters, along with various mitigation techniques.

Figure 3. Area of interest

3.2. Risk Mitigation Assessment

The calculation of the risk mitigation index in of AOI utilized three models provided by InVEST, namely the Urban Cooling Model, Urban Flood Risk Mitigation Model, and Coastal Vulnerability Model. The data processing procedure was conducted using the ESRI ArcMap 10.8 program, licensed by the Izmir Institute of Technology.

The workflow of the study is represented in Figure 4.

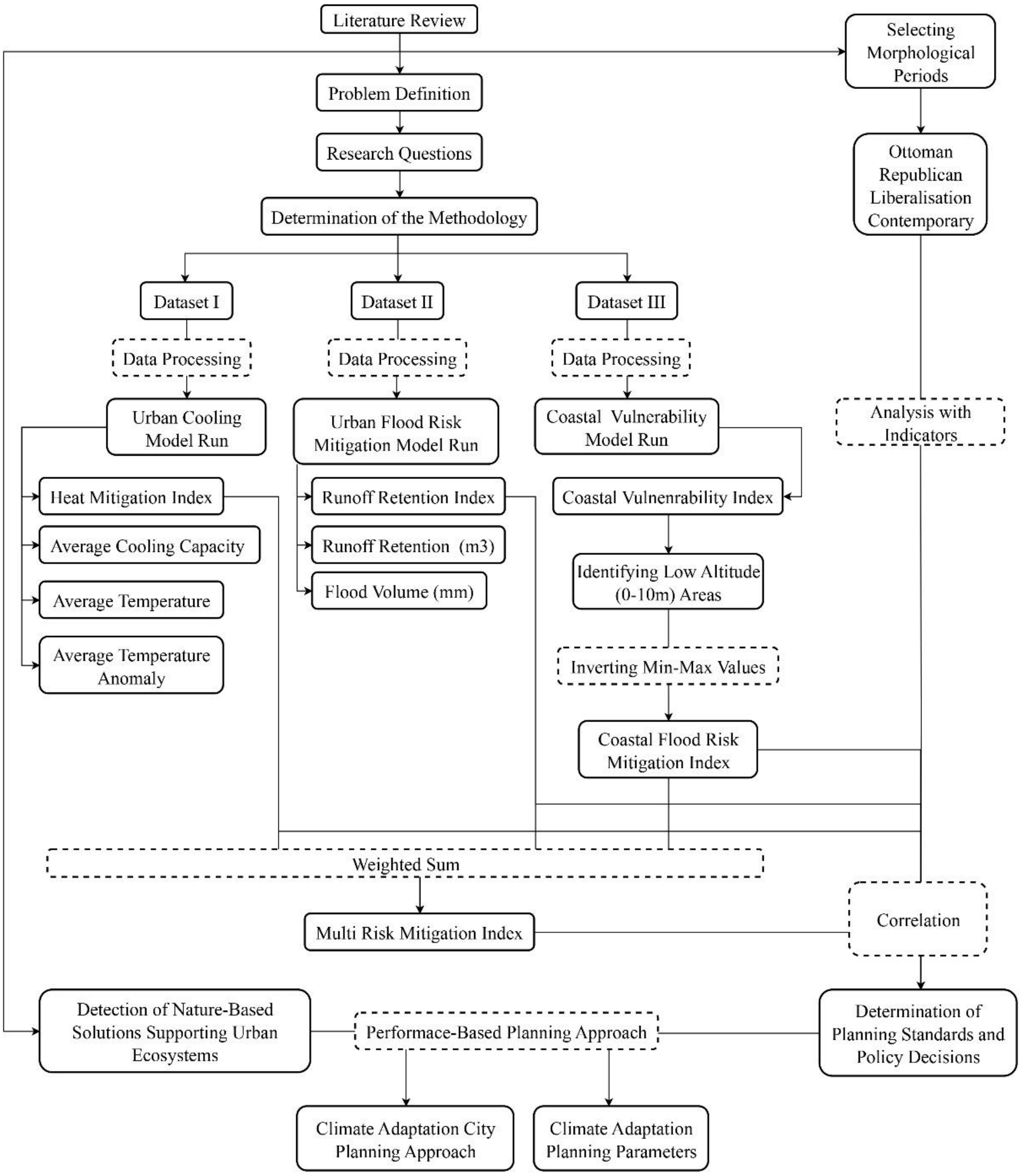

Figure 4. Workflow of the study

3.2.1. Urban Heat Mitigation Assessment

The impacts of UHIs on human health, energy consumption, and greenhouse gas emissions cannot be understated. There is, therefore, a pressing need for effective urban heat mitigation strategies that can reduce surface and ambient temperatures while providing ecological and socio-economic benefits.

The InVEST "Urban Cooling Model" provides a comprehensive approach to evaluate the heat mitigation service provided by urban green spaces. This model incorporates various factors that contribute to cooling, including shade, evapotranspiration, albedo, and distance from cooling islands such as parks. By employing diverse valuation methodologies such as energy consumption and labor productivity, the model determines the temperature reduction achieved by vegetation.

At the core of the model lies the calculation of the cooling capacity index for each pixel, which considers the effects of shade, evapotranspiration, and albedo. In assigning a value between 0 and 1 to represent the shade factor, the model considers the percentage of tree canopy cover if the trees are taller than 2 meters[187].

The evapotranspiration index (ETI) is a normalized measure of potential evapotranspiration that incorporates plant and soil evaporation. The model calculates the ETI for each pixel by multiplying the user-supplied reference evapotranspiration (ET_0) by the K_c and dividing by the ET_{max} value from the ET_0 raster.

$$ETI = \frac{K_c \cdot ET_o}{ET_{max}} \quad (1)$$

Where K_c is defined as crop coefficient and it is determined based on Land Use and Land Cover (LULC) classes (Table 3), ET0 is defined as reference evapotranspiration the rate of evapotranspiration from a hypothetical reference crop that is well-watered uniform height grass, ET_{max} is defined as maximum value of ET_0.

It is important to note that the model assumes adequate irrigation for vegetated areas, although K_c values can be adjusted to account for water-limited evapotranspiration. These factors combine in the cooling capacity index to determine the cooling capacity of each grid cell in the study area, expressed as:

$$CC_i = 0.6 \cdot shade + 0.2 \cdot albedo + 0.2 \cdot ETI \quad (2)$$

Where CC_i is defined as cooling capacity of each pixel. Here, cooling capacity ranges from 0 to 1, with 0 indicating no cooling capacity and 1 representing maximum cooling capacity. Shade is described as the percentage of land area within the LULC class under consideration that is occupied by tree canopy with a minimum height of 2 meters. Albedo is an important component of the Urban Cooling model, as it allows us to calculate the amount of solar radiation reflected by different surfaces. This information is crucial in determining the surface temperature of various LULC classes, which in turn affects the cooling potential of these areas.

Landsat 8 Level-2 imagery data with a spatial resolution of 30 meters is a suitable data source for estimating albedo. Landsat Level-2 imagery is obtainable as processed satellite data from the Landsat program for research purposes. The integration of top-of-atmosphere (TOA) data and surface reflectance facilitates a comprehensive depiction of the land's topography.

The albedo estimation process involves scaling the bands of the Landsat data to calculate the surface reflectance (Equation 3), and subsequently albedo values were calculated using the Equation 4 developed by Liang (2000) and presented in Figure 5. Since the model requires the albedo values of each LULC class, the average albedo values were calculated using ArcGIS (Table 3). The albedo factor ranges from 0 to 1 and represents the proportion of solar radiation reflected by the LULC type[188].

$$Surface\ Reflectance = p \cdot 0.0000275 - 0.2 \quad (3)$$

$$Albedo = \frac{(0.356 \cdot p_1 + 0.130 \cdot p_3 + 0.373 \cdot p_4 + 0.085 \cdot p_5 + 0.072 \cdot p_7) - 0.0018}{0.356 + 0.130 + 0.373 + 0.085 + 0.072} \quad (4)$$

where p_n denotes the bands of Landsat 8.

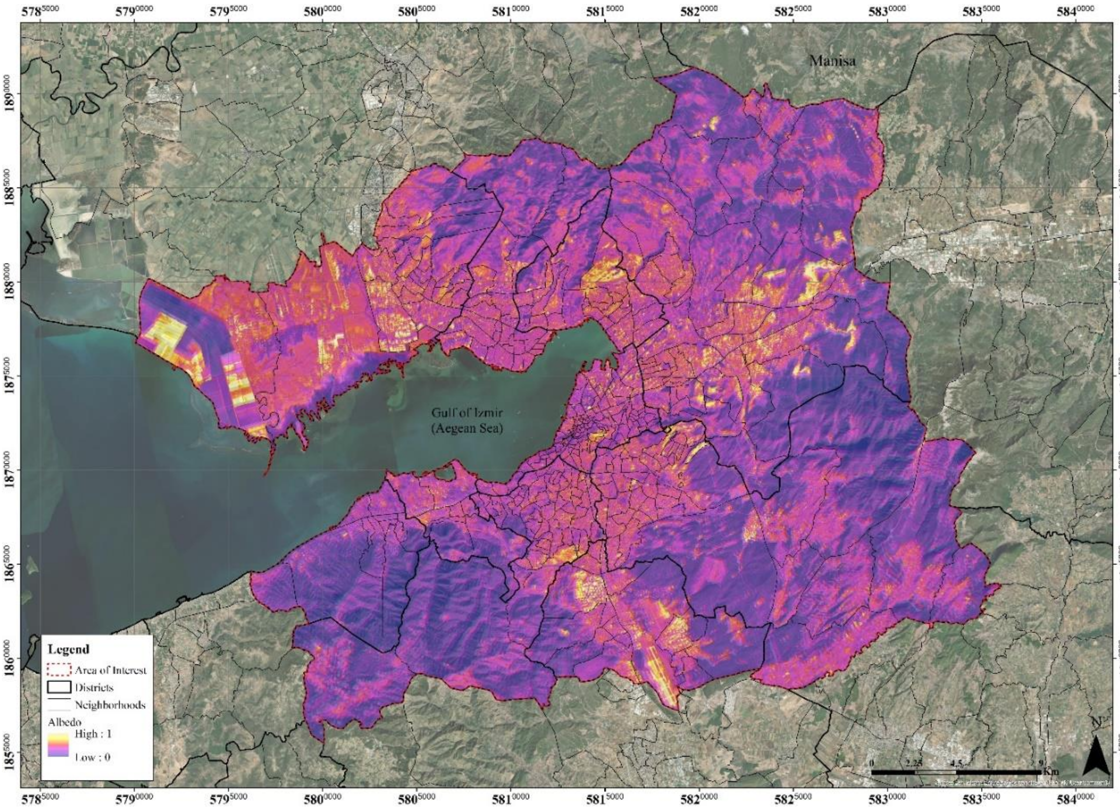

Figure 5. Albedo map of AOI

The heat mitigation index (HMI) is a measure that determines the cooling capacity of a particular grid cell, taking into account the cooling capacity of the parks and green areas within the cooling distance radius. The HMI is calculated for each grid cell in the land cover map based on its location concerning large green spaces, cooling distance, and other conditions. At each grid cell i, the HMI value is determined based on the cooling capacity of the grid cell i (CC_i) and the cooling capacity of the green spaces (CC_{Parki}) within the cooling distance radius. The HMI is expressed as:

$$HM_i = \begin{Bmatrix} CC_i & if \;\; CC_i \geq \; CC_{park_i} \; or \; GA_i < 2ha \\ CC_{park_i} & otherwise \end{Bmatrix} \quad (5)$$

The CC_{Parki} represents the cooling capacity of the green spaces and parks within the cooling distance radius and is calculated as the weighted average of the individual cooling capacity values. The area of green space within the cooling distance radius of a particular grid cell i is represented by GA_i, which is calculated using the equation:

$$GA_i = cell_{area} \cdot \sum_{i \in d\ radius\ from\ i} g_j \tag{6}$$

where $cell_{area}$ represents the complete area of grid cell j, and gj is set to 1 if grid cell j is within the cooling distance radius; otherwise, it will be set to 0.

The cooling capacity of the green spaces (CC_{Parki}) is within the cooling distance radius. The equation to calculate CC_{Parki} is:

$$CC_{Park_i} = \sum_{i \in d\ radius\ from\ i} g_j \cdot CC_i \cdot e^{\left(\frac{-d(i,j)}{d_{cool}}\right)} \tag{7}$$

The gj indicates the existence of green areas, and the cooling capacity of grid cell i, CC_i, is multiplied by the weighted average distance between cells i and j, d(i,j). The cooling capacity of places located at a cooling distance radius d_{cool} from major green spaces (>2ha in size) is denoted by CC_{Parki}.

Apart from the cooling capacity of the green spaces and parks, the model can also integrate information about a building's energy consumption to determine the overall cooling capacity of a particular area. However, due to the unavailability of the relevant data, the model was executed in isolation in this study. To calculate HMI, the model requires accurate data on various inputs, including the cooling capacity of the grid cell and the cooling capacity of green spaces and parks within the cooling distance radius. However, to make the model more comprehensive, it can also consider additional variables, such as building energy consumption.

The Urban Cooling model requires diverse types of data and materials to effectively estimate the potential cooling effect of urban green spaces (Figure 6). The data required includes LULC and tree data, shade value, albedo estimation data, evapotranspiration data, maximum cooling distance, reference air temperature, UHI effect, and air blending distance.

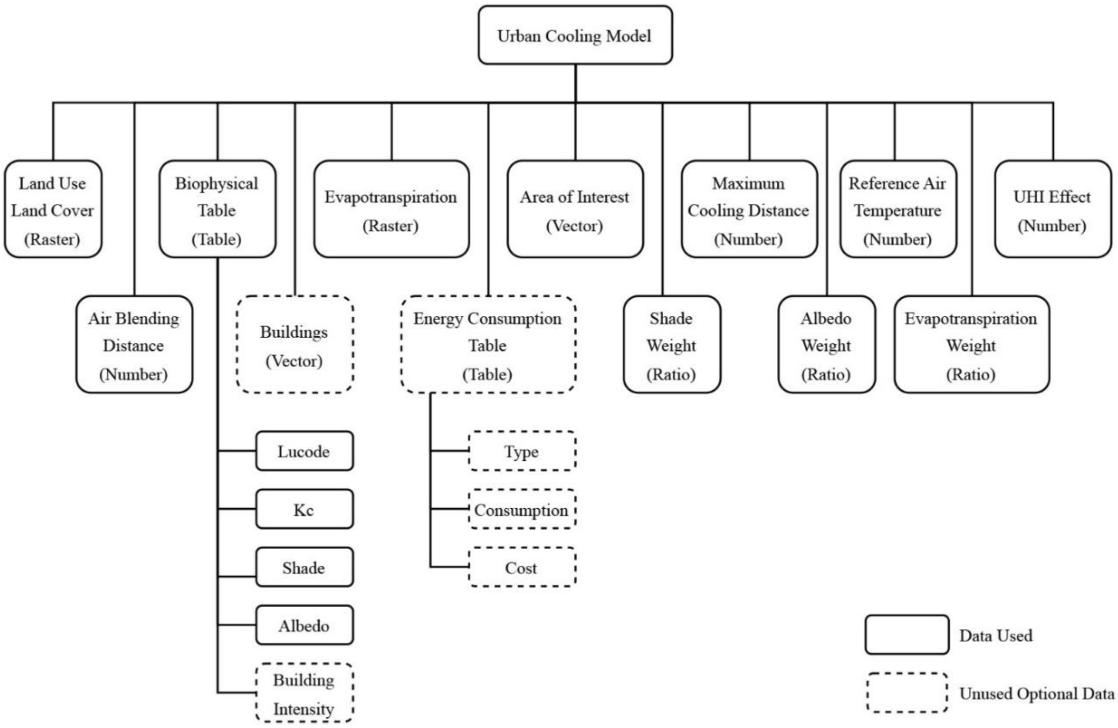

Figure 6. Input data of Urban Cooling Model
(Adapted from Sharp[187])

The Urban Cooling model needs accurate information on LULC connected to biophysical values of the classes (Table 3). The Urban Atlas dataset from the European Commission as part of the Copernicus Project is a suitable source for this information. This dataset provides comprehensive information on LULC for various European cities, including İzmir.

However, the model requires the shade value of the LULC classes, which can only be calculated if there is information on the tree cover area. In this case, tree cover density data was obtained from Copernicus to derive the shade values for the LULC classes. Additionally, the artificial classes were duplicated based on the existence of trees as treeless and treed, as this is an important factor in urban cooling (Figure 7). The K_c values for the various LULC classes were obtained from a previous study conducted by Allen et al[190], which provided valuable insights into the evapotranspiration rates of different LULC classes.

Table 3. Biophysical values for Urban Cooling model classes

Class Definition	LULC Code	Kc	Green Area (Yes:1, No:0)	Shade Factor			Albedo
				Tree Area (ha)	Plot Size (ha)	Shade	
Continuous urban fabric (S.L. : > 80%) (treeless)	1	0.01	0	0	2858.64	0	0.11
Continuous urban fabric (S.L. : > 80%) (treed)	2	0.29	0	151.35	2304.58	0.07	0.11
Discontinuous dense urban fabric (S.L. : 50% - 80%) (treeless)	3	0.01	0	0	317.07	0	0.11
Discontinuous dense urban fabric (S.L. : 50% - 80%) (treed)	4	0.15	0	547.28	2848.55	0.19	0.10
Discontinuous medium density urban fabric (S.L. : 30% - 50%) (treeless)	5	0.01	0	0	49.59	0	0.11
Discontinuous medium density urban fabric (S.L. : 30% - 50%) (treed)	6	0.21	0	184.53	580.93	0.32	0.10
Discontinuous low density urban fabric (S.L. : 10% - 30%) (treeless)	7	0.01	0	0	31.07	0	0.10
Discontinuous low density urban fabric (S.L. : 10% - 30%) (treed)	8	0.33	0	125.27	374.31	0.33	0.09
Discontinuous very low density urban fabric (S.L. : < 10%) (treeless)	9	0.01	0	0	79.78	0	0.10
Discontinuous very low density urban fabric (S.L. : < 10%) (treed)	10	0.33	0	149.27	411.79	0.36	0.09
Industrial, commercial, public, military and private units (treeless)	11	0.01	0	0	686.29	0	0.13
Industrial, commercial, public, military and private units (treed)	12	0.30	0	1113.77	5686.97	0.20	0.11
Construction sites (treeless)	13	0.01	0	0	60.81	0	0.13
Construction sites (treed)	14	0.26	0	9.97	295.18	0.03	0.12
Mineral extraction and dump sites (treeless)	15	0.01	0	0	93.77	0	0.13
Mineral extraction and dump sites (treed)	16	0.26	0	59.74	1322.41	0.05	0.12
Airports (treeless)	17	0.01	0	0	1.00	0	0.16
Airports (treed)	18	0.30	0	82.58	1248.84	0.07	0.13
Port areas (treeless)	19	0.01	0	0	7.05	0	0.11
Port areas (treed)	20	0.39	0	2.01	66.02	0.03	0.11
Fast transit roads and associated land (treeless)	21	0.01	0	0	4.20	0	0.09
Fast transit roads and associated land (treed)	22	0.25	0	75.67	578.46	0.13	0.09
Other roads and associated land (treeless)	23	0.01	0	0	2.31	0	0.13
Other roads and associated land (treed)	24	0.25	0	716.65	3748.75	0.19	0.10
Railways and associated land (treeless)	25	0.01	0	0	0.84	0	0.10
Railways and associated land (treed)	26	0.25	0	21.52	145.94	0.15	0.10

Table 3 (continued).

Class Definition	LULC Code	Kc	Green Area (Yes:1, No:0)	Shade Factor			Albedo
				Tree Area (ha)	Plot Size (ha)	Shade	
Isolated structures (treeless)	27	0.01	0	0	25.40	0	0.10
Isolated structures (treed)	28	0.20	0	37.43	99.31	0.38	0.08
Land without current use (treeless)	29	0.01	0	0	115.89	0	0.12
Land without current use (treed)	30	0.55	0	123.18	571.38	0.22	0.12
Green urban areas (treeless)	31	0.21	1	0	26.13	0	0.12
Green urban areas (treed)	32	0.48	1	656.87	1234.46	0.53	0.09
Sports and leisure facilities (treeless)	33	0.21	0	0	14.37	0	0.12
Sports and leisure facilities (treed)	34	0.54	0	103.72	346.28	0.30	0.10
Open spaces with little or no vegetation (beaches, dunes, bare rocks, glaciers)	35	0.19	1	14.73	312.42	0.05	0.11
Permanent crops (vineyards, fruit trees, olive groves)	36	0.68	1	1011.78	1772.43	0.57	0.08
Complex and mixed cultivation patterns	37	1.16	1	58.45	111.55	0.52	0.08
Arable land (annual crops)	38	0.67	1	2596.42	7956.17	0.33	0.09
Pastures	39	0.70	1	346.90	2506.24	0.14	0.11
Herbaceous vegetation associations (natural grassland, moors...)	40	0.95	1	14120.39	24965.28	0.57	0.07
Forests	41	1.33	1	24281.73	24281.73	1	0.04
Water	42	0.64	1	29.35	3440.45	0.01	0.09
Wetlands	43	1.25	1	8.70	940.10	0.01	0.07

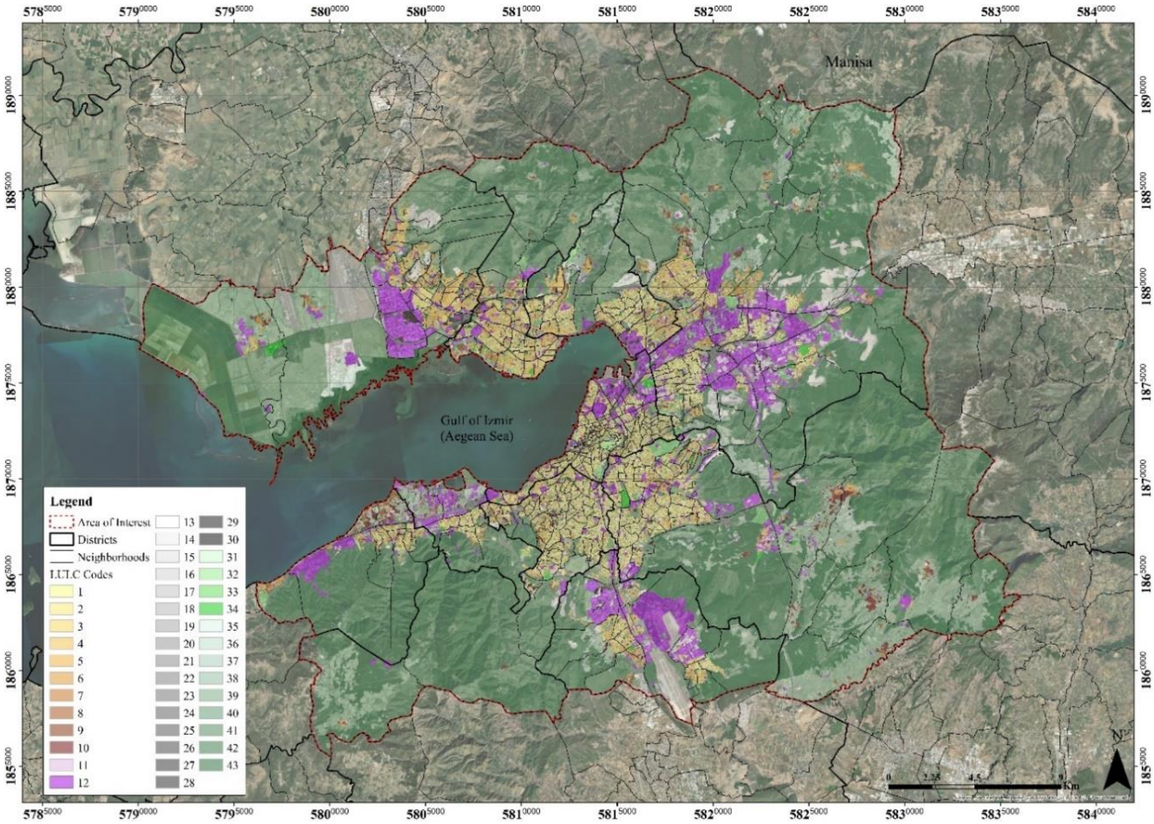

Figure 7. LULC map of Urban Cooling model

Evapotranspiration data is an important factor in the Urban Cooling model, as it allows us to estimate the amount of water evaporated and transpired by different LULC classes. This information is essential in determining the cooling potential of various areas. The data required for the model was sourced from the Consultative Group on International Agricultural Research- Consortium for Spatial Information website (CGIAR-CSI) and has a spatial resolution of 1km (Figure 8). The values range between 251 and 300, and this information is critical in determining the evapotranspiration rates of different LULC classes.

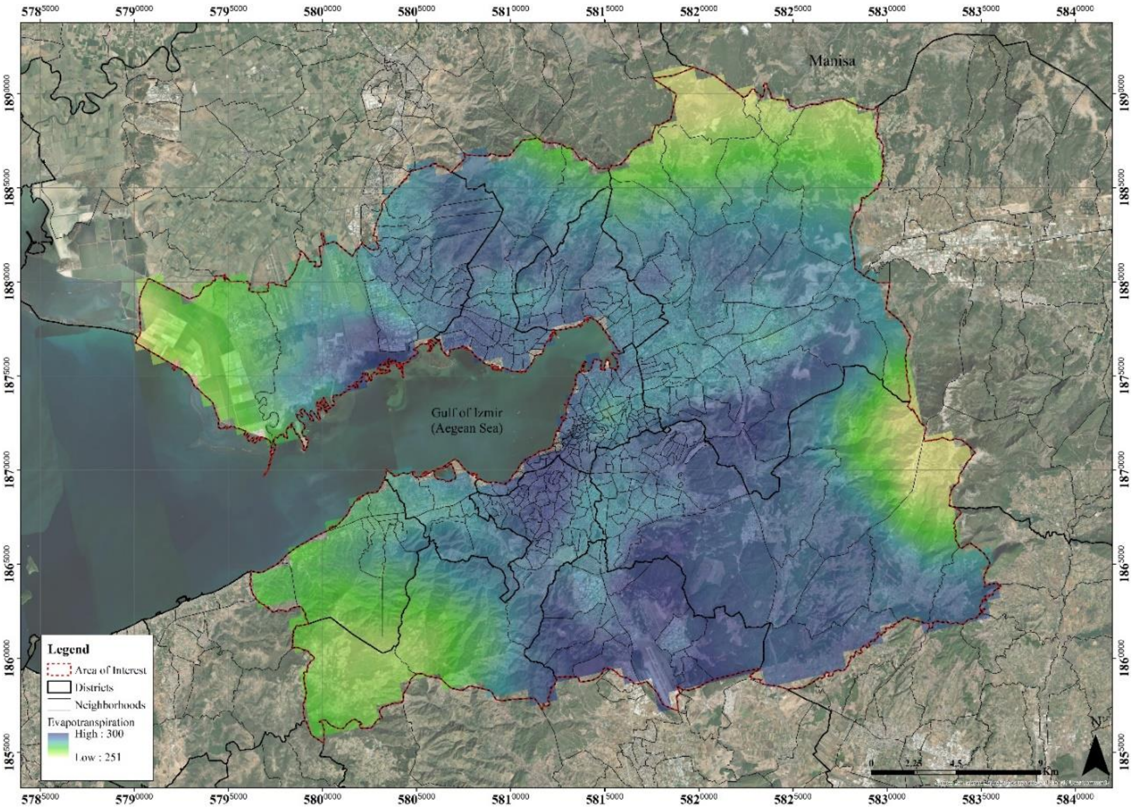

Figure 8. Evapotranspiration map of AOI

In the Urban Cooling model, the maximum cooling distance was determined based on studies conducted by Jaganmohan et al[191] and Quagliolo et al[192]. Since the average size of parks in İzmir was found to be 1.54 hectares, the cooling distance was set at 150 meters to account for the cooling effects of parks in the area.

The reference air temperature used in the Urban Cooling model is the temperature in rural areas where the urban heat island effect is not observed. This data was obtained from the nearest rural station to the city to ensure accurate and representative data for the model.

The UHI effect refers to the phenomenon where urban areas are significantly warmer than their surrounding rural areas. Various factors such as heat-absorbing building materials, lack of vegetation, and human activity causes this temperature difference. In the Urban Cooling model, the UHI effect data was obtained from the nearest meteorological station to account for the temperature difference in the city center compared to rural areas.

The air blending distance used in the Urban Cooling model is the radius over which the air temperature averages are calculated to account for wind effects. This variable is important to model the cooling effects of wind in urban areas accurately. The default value for this variable is set at 500 meters in the model, but it can be adjusted based on the specific conditions of the area being modeled.

Finally, the Urban Cooling Model of InVEST was run using the data prepared for İzmir (Figure 9)

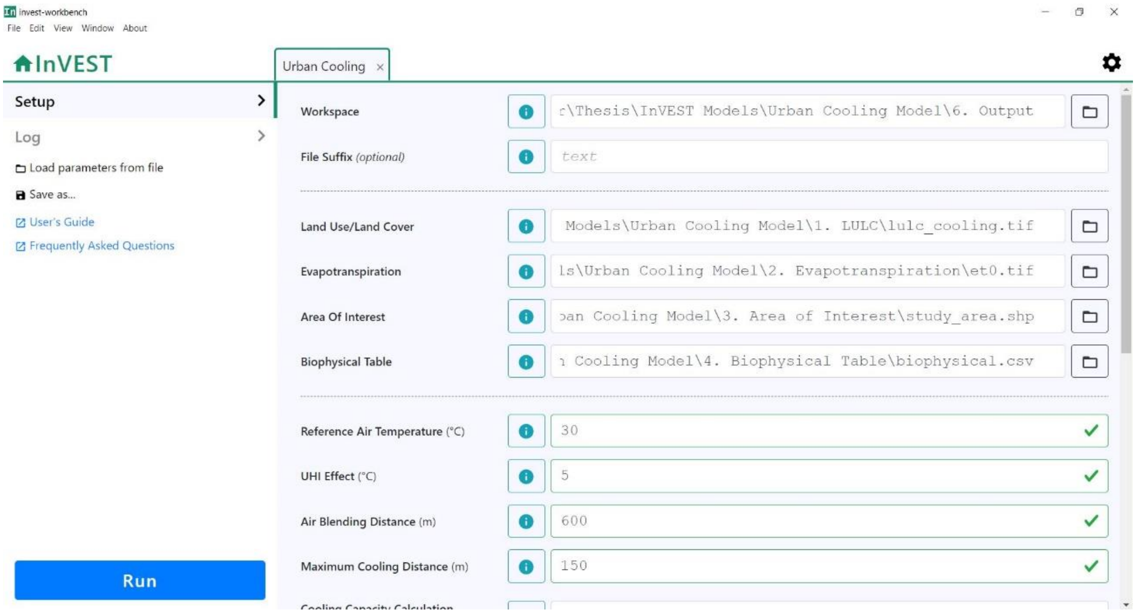

Figure 9. Urban Cooling model workbench

3.2.2. Urban Flood Risk Mitigation Assessment

Urban areas are at a higher risk of flooding due to the significant amount of impervious surfaces which prevent water infiltration into the ground[68,192–196]. CC has exacerbated this issue further, resulting in more frequent and intense precipitation events[17]. Consequently, there is an increasing need for effective flood risk assessment and mitigation strategies in urban areas. The "Flood Risk Mitigation Model" of InVEST is a popular hydrological tool used to analyze the retention of runoff and the amount of runoff during a rainfall event[62,192,194,197].

The model simplifies the infiltration process by considering various soil and land cover characteristics such as the drainage capacity of different soil types and the degree of impermeability of various surfaces[198]. The model utilizes the RCN matrix, which links LULC permeability with soil hydrological characteristics, to estimate runoff in different urban areas[199,200]. Accurately estimating runoff during a cloudburst in urban environments is challenging due to the complex and varying nature of the areas [201]. Several factors such as the quality and quantity of buildings, infrastructure quality and capacity, and the characteristics of the storm itself can affect an area's discharge capacity during a single rainfall event[202,203]. Modeling rainfall patterns in urban areas is a complex task that requires detailed information on rainfall event spatial and temporal distribution, as well as urban environment characteristics[196].

The process of estimating the runoff for each pixel in a given area involves considering the LULC type and soil characteristics of that pixel. The model uses the Curve Number method to make this estimation, which involves several equations. Firstly, Equation 8 estimates the runoff, Q, in millimeters for a particular pixel.

$$Q_{p,i} = \begin{Bmatrix} \dfrac{(P-\lambda S_{maxi})^2}{P+(1-\lambda)S_{max,i}} & if\ P > \lambda \cdot S_{max,i} \\ 0 & otherwise \end{Bmatrix} \tag{8}$$

Where, P is the design storm depth in millimeters, $S_{max,i}$ is the potential retention in millimeters, $\lambda \cdot S_{max}$ is the rainfall depth required to start the runoff. In this equation, λ is a constant value of 0.2 used for simplification purposes.

The potential retention, $S_{max,i}$, is calculated using Equation 9, a function of the curve number, CN. The curve number is an empirical parameter that depends on a particular pixel's LULC and soil characteristics, as defined by NRCS[204].

$$S_{max,i} = \frac{25400}{CN_i} - 254 \tag{9}$$

After estimating the runoff retention for each pixel, i.e. runoff retention index (RRI), using Equation 10, the model then calculates the runoff retention volume per pixel using Equation 11, which considers the pixel area in cube meters. The runoff retention volume per pixel is important in determining how much water the land retains and how much is lost as runoff. Additionally runoff (flood) volume in cube meters was calculated using Equation 12.

$$R_i = 1 - \frac{Q_{p,i}}{P} \tag{10}$$

$$R\_m3_i = R_i \cdot P \cdot pixel.area \cdot 10^{-3} \tag{11}$$

$$Q\_m3_i = Q_{p,i} \cdot pixel.area \cdot 10^{-3} \tag{12}$$

To use the Urban Flood Mitigation model of InVEST, five primary input data is required (Figure 10): watershed vector data, depth of rainfall, a land use land cover (LULC) map, a raster map of soil hydrologic conductibility, and biophysical values corresponding to each LULC class[187]. These inputs are crucial in determining the amount of runoff and the effects of land use on hydrological regimes.

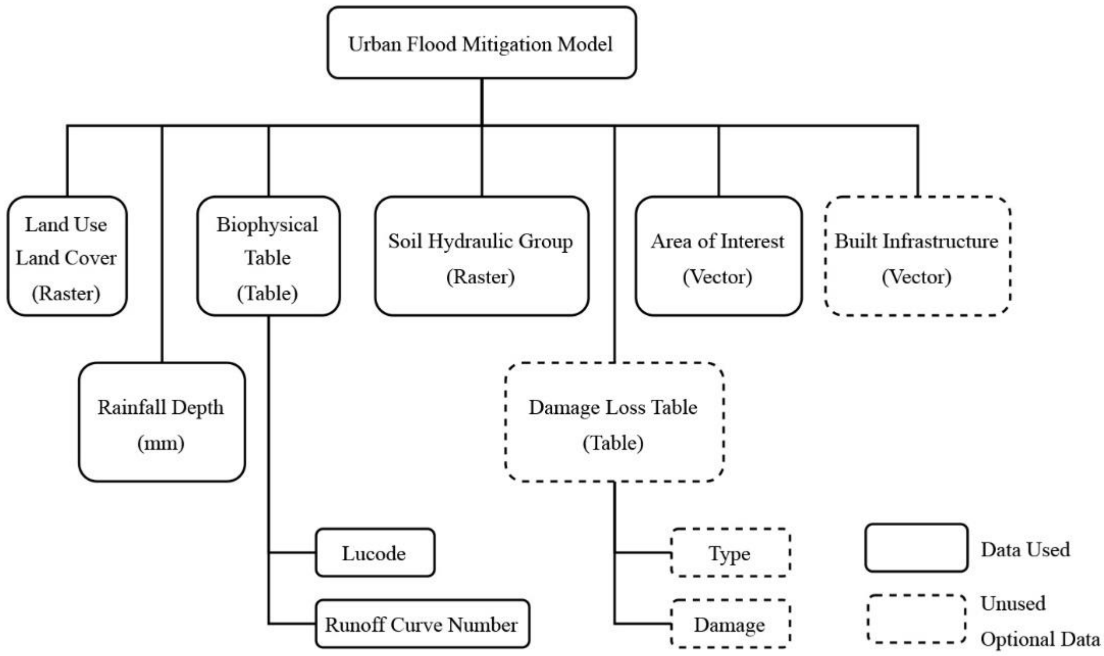

Figure 10. Input data of Urban Flood Risk Mitigation Model
(Adapted from Sharp[187])

Salata et al[196] used the InVEST model to evaluate the effects of a cloudburst event with a rainfall depth of 70mm on the retention of runoff and the amount of runoff in the affected area. This amount was chosen because it exceeded the minimum threshold for a cloudburst but was less than the rainfall recorded during a November 2020 event, which ranged from 42.1 mm to 147 mm in İzmir[205].

The LUCL classification scheme was utilized to classify land use based on imperviousness density, tree cover density, and the Urban Atlas 2018 dataset. Additionally, the HRL database was used to determine the degree of sealing per unit area, which provides information on the percentage and temporal change in soil sealing and characterizes sealed/impervious areas[206]. This characterization includes those in which an artificial, often impervious cover has replaced the original natural/semi-natural land cover or water surface[207].

The forest areas in the study were grouped according to their tree cover density, which ranged from 0% to 100%[208]. The dataset that provided information on the density of tree cover was used to categorize the forest areas. In addition, the green areas in urban settings, agricultural lands, and grasslands were classified using the Urban Atlas 2018 dataset, which was based on those areas' imperviousness and use. The imperviousness density, tree cover density, and urban atlas datasets were combined spatially to create a LULC classification of the run-off curve numbers on built and unbuilt land (Figure 11).

The final classification was obtained by employing four steps, which involved: (1) reclassifying the continuous imperviousness value to a discrete classification of urban areas, (2) reclassifying urban green areas, agricultural lands, and grasslands based on their imperviousness levels, (3) reclassifying the continuous forest value into three classes: poor, fair, and good, and (4) using the raster combine tool. The relationship between the categories of LULC and the runoff curve number is represented in Table 4.

Several factors influence the hydraulic conductivity of soil and its K_{sat}. These factors include the porosity and texture of the soil[209]. Clay soils, for example, tend to have lower conductivity than sandy and gravel soils[210]. Soils with high porosity and conductivity can quickly retain and move a large amount of water, allowing water to reach the aquifer rapidly, resulting in limited surface flow processes[211,212]. In contrast, soils with poor conductivity experience low infiltration, which results in high surface runoff rates (Table 5). As Freeze[213] noted, this can significantly affect the hydrological balance of an area, particularly during heavy rainfall events. As a result, it is crucial to have accurate and detailed maps of K_{sat} to ensure effective hydrological modeling and water management. Understanding the factors influencing K_{sat}, such as soil texture and porosity, can help make informed land use, water allocation, and flood risk management decisions.

Table 4. Biophysical values for Urban Flood Risk Mitigation model classes (Adapted from United States Department of Agriculture)

Cover description		**Curve numbers for hydrologic soil group**				**LULC Code**
		A	**B**	**C**	**D**	
Residential districts by average lot size	2 acres (12% imp.)	46	65	77	82	1
	1 acre (20% imp.)	51	68	79	84	2
	½ acre (25% imp.)	54	70	80	85	3
	⅓ acre (30% imp.)	57	72	81	86	4
	¼ acre (38% imp.)	61	75	83	87	5
	⅛ acre or less (town houses) (65% imp.)	77	85	90	92	6
Urban districts	Industrial(72% imp.)	81	88	91	93	7
	Commercial and business (85% imp.)	89	92	94	95	8
Impervious areas	Paved parking lots, roofs, driveways, etc. (excluding right of way)	98	98	98	98	9
Open space (lawns, parks, golf courses, cemeteries, etc.)	Poor condition (grass cover <50%)	68	79	86	89	10
	Good condition (grass cover >75%)	39	61	74	80	11
Row crops	Straight row (SR) Poor	72	81	88	91	12
Pasture, grassland, or range—continuous forage for grazing. [A]	Fair	49	69	79	84	13
Woods.[E]	Poor	45	66	77	83	14
	Fair	36	60	73	79	15
	Good	30	55	70	77	16

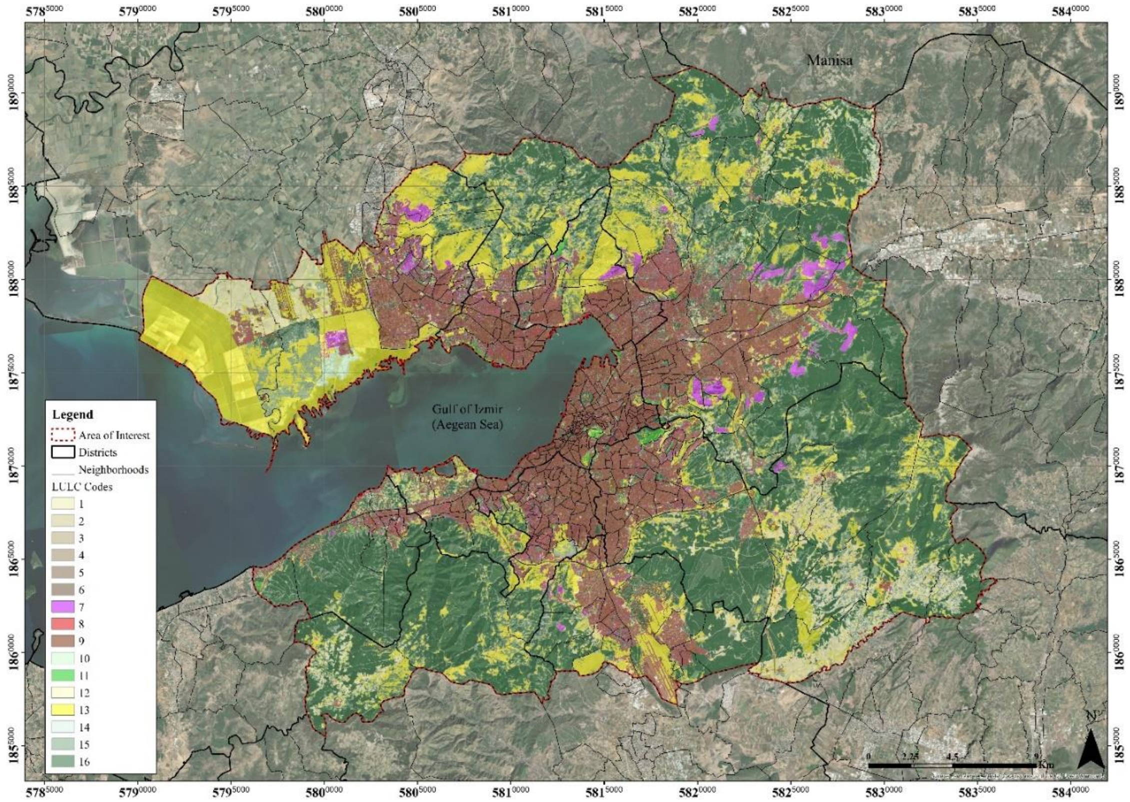

Figure 11. LULC map of Urban Flood Risk Mitigation model

Furthermore, it is important to note that K_{sat} can also be influenced by other factors, such as soil structure and macropores[210]. Soil structure, which refers to the arrangement of soil particles, can affect soil porosity and thus K_{sat}. Macropores, which are larger pores in the soil, can significantly increase K_{sat} by facilitating water[209]. Therefore, it is essential to consider these factors in addition to soil texture and porosity when assessing K_{sat}.

Table 5. Parameters related to the ability of soil to transmit water
(From Sharp et al., 2016)

	Group A	**Group B**	**Group C**	**Group D**
Saturated hydraulic conductivity of the least transmissive (soil depth 50 and 100 cm)	>40 m/s	[40;10] m/s	[10;1] m/s	<1 m/s

Table 6. Table for conversion of Hydrological Soil Classification

Geological Units	Soil Groups	Geological Units	Soil Groups	Geological Units	Soil Groups
Clastic rocks	A	Pyroclastic units	D	Granitoid	D
Lime soil	A	Granitoid	D	Clastic units	B
Sediment soil	A	Oligocene volcanic units	C	Schist	D
Terrestrial clastic units	B	Volcano-sedimentary units	C	Gneissoid	D
Lacustrine limestone	D	Flysch	D	Meta-granitoid	D
Marn	D	Nautical limestone	B	Metamophic units	B
Shale	D	Ophiolite-serpentinite-basalt	D	Clastic units	B
Rhyolite	C	Marble	B	Carbonate units	B
Basalt	C	Limestone	B	Quartzite	D
Dacite	C	Neritic limestone	B	Quartzit-schist	D
Andesite	C	Carbonate	B	Phyllite	D

A supplementary dataset was generated through raster reclassification, which utilized the Geological Unit to achieve better accuracy. The procedure for assigning a Hydrological Soil Classification according to the proposal made by Ross et al[214] is summarized in Table 6, while Figure 12 shows the classification results. Raster reclassification enabled the creation of a more detailed dataset, which was necessary to achieve greater precision in the Hydrological Soil Classification. The Geological Unit was utilized as a basis for the reclassification, as it provided a more accurate representation of the soil properties of the study area.

Ross et al[214] proposed a method for assigning a Hydrological Soil Classification, which was used in the study. This method considers various factors, such as soil texture, structure, and drainage, to classify the soils into four different hydrological units.

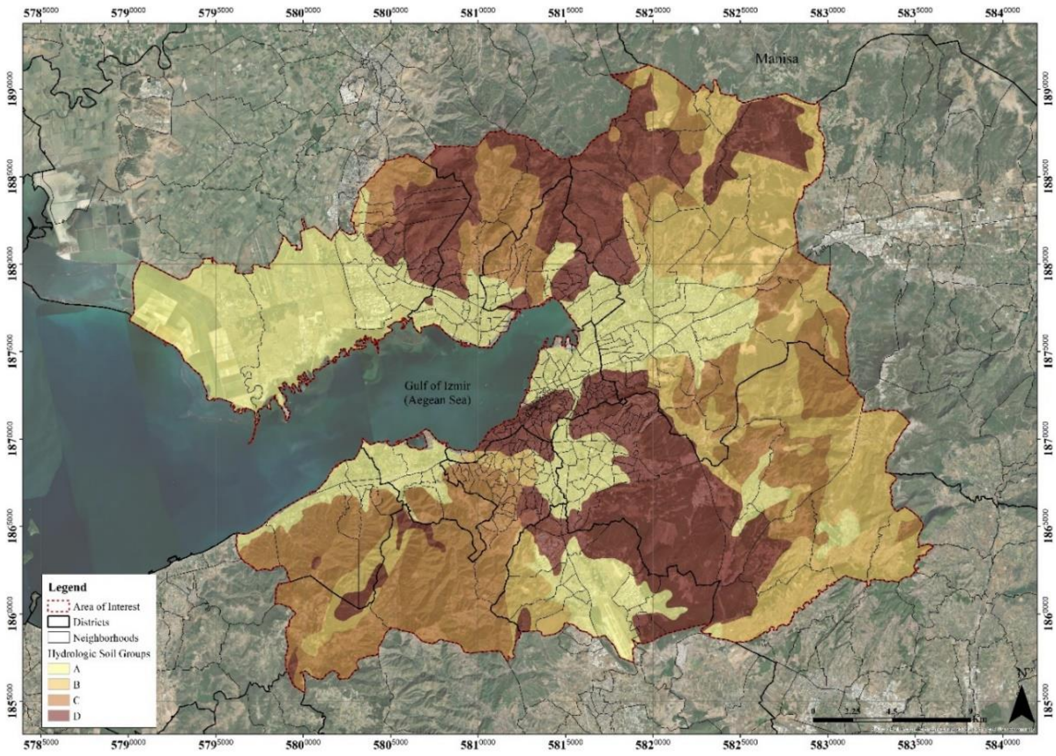

Figure 12. Groups of soil types according to their hydraulic conductivity (Adapted from Chamber of Geological Engineers of the Union of Chambers of Turkish Engineers and Architects)

Finally, the Urban Flood Risk Mitigation Model of InVEST was run using the data prepared for İzmir (Figure 13)

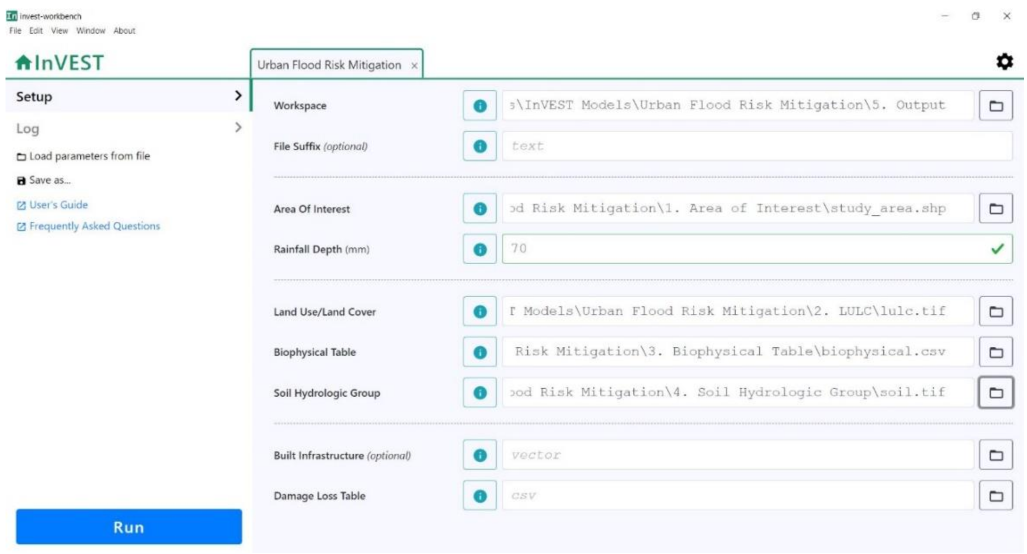

Figure 13. Urban Flood Risk Mitigation model workbench

3.2.3. Coastal Flood Risk Mitigation Assessment

Effective coastal management necessitates instruments that can evaluate the vulnerability of coastal regions to these hazards and aid in making decisions for sustainable coastal development. The “Coastal Vulnerability Model” of InVEST calculates a qualitative indicator of coastal exposure to erosion and inundation[187].

The Coastal Vulnerability model employs a geographical representation of seven bio-geophysical variables, namely relief, natural habitats, wind exposure, wave exposure, surge potential depth contour, geomorphology (optional), and sea level change (optional), to calculate the exposure index and coastal population density. As shown in Table 7, the model combines the evaluations of these factors at each coastline node to produce a coastal exposure index (CEI) spanning from extremely low to extremely high exposure using the methodology developed by Gornitz et al[215].

Table 7. Example ranking table of Coastal Vulnerability model
(From Sharp et al., 2016)

Rank	1 (very low)	2 (low)	3 (moderate)	4 (high)	5 (very high)
Geomorphology	Rocky; high cliffs; fjord; fiard; seawalls	Medium cliff; indented coast; bulkheads and small seawalls	Low cliff; glacial drift; alluvial plain; revetments; rip-rap walls	Cobble beach; estuary; lagoon; bluff	Barrier beach; sand beach; mud flat; delta
Relief	81 to 100 Percentile	61 to 80 Percentile	41 to 60 Percentile	21 to 40 Percentile	0 to 20 Percentile
Natural Habitats	Coral reef; mangrove; coastal forest	High dune; marsh	Low dune	Seagrass; kelp	No habitat
Sea Level Change	0 to 20 Percentile	21 to 40 Percentile	41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile
Wave Exposure	0 to 20 Percentile	21 to 40 Percentile	41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile
Surge Potential	0 to 20 Percentile	21 to 40 Percentile	41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile

Coastal Vulnerability model inputs include a digital elevation model representing the coastal area's topography, a point vector data containing observed storm wind speed and wave power values, a raster representing the population distribution, and a polyline with attributes on the local coastal geomorphology along the coastline. The model applies to both large, exposed, homogeneous coastlines and complex, diverse, sheltered coastlines. Variables include the rate or magnitude of sea level rise, the local bathymetry and topography, and the relative intensity of wind and waves generated by cyclones; they reflect natural variations in the biological and geomorphological properties of the region.

The primary output of the Coastal Vulnerability model is a geographical dataset displayed along the littoral of the coastal area of interest at user-specified intervals. The model's outputs may be applicable at different scales and dimensions depending on the granularity of the input data. Based on user- and model-defined criteria, the Coastal Vulnerability model assigns a score spanning from 0 (very low exposure) to 100 (extremely high exposure). The EI is computed for each coastal site using the model as the geometric means of all variable evaluations. Using the Coastal Vulnerability model, the exposure of coastal populations to hazards such as erosion and inundation can be investigated.

The model calculates the EI for each point as follows:

$$EI = \left(R_{Geomorphology}R_{Relief}R_{Habitats}R_{SLR}R_{WindExposure}R_{WaveExposure}R_{Surge}\right)^{1/7} \quad (13)$$

or more generally:

$$EI = \left(\prod_{i=1}^{n} R_i\right)^{1/n} \quad (14)$$

The variable R_i denotes the ranking of the i^{th} bio-geophysical factor utilized in the computation of EI.

The Coastal Vulnerability Model requires raster and vector input data, including landmasses, bathymetry map, WaveWatchIII data, habitat data, continental shelf contour, digital elevation model (DEM), human population, and sea level changes. Additionally, the model requires numeric input data, such as maximum fetch distance, elevation averaging radius, and population search radius (Figure 14).

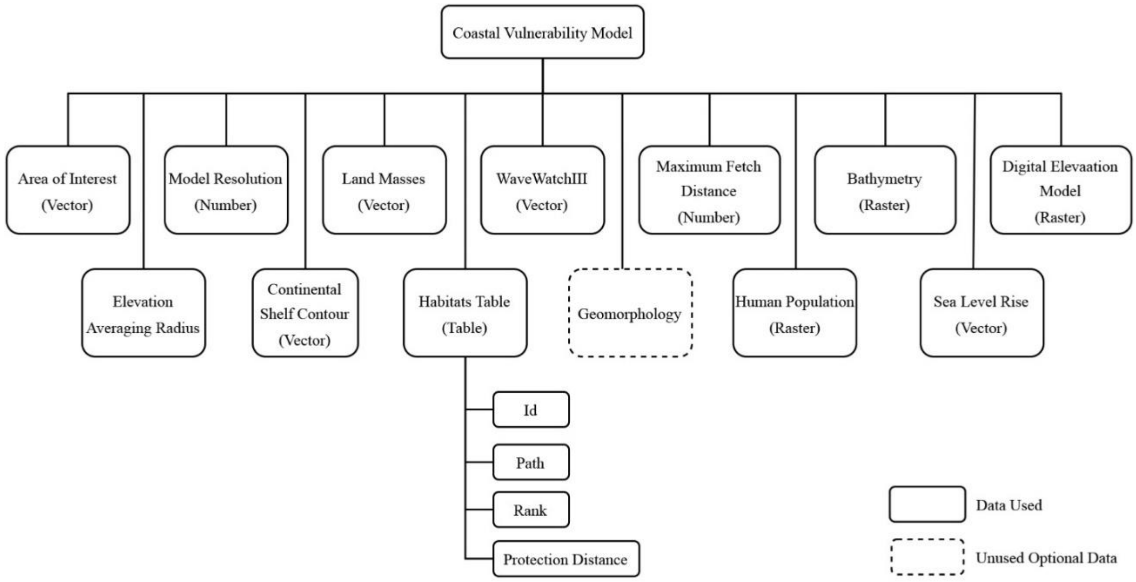

Figure 14. Input data of Coastal Vulnerability Model
(Adapted from Sharp et al[187])

The landmasses data used in the study is a map of all landmasses in and around the study region. This data was obtained from U.S. National Oceanic and Atmospheric Administration (NOAA).

WaveWatchIII data consists of gridded wind and wave data that represent storm conditions. However, the provided global data did not include information for the Gulf of İzmir. Therefore, wave and wind data required for the model were generated, as shown in Figure 15, from a study conducted by Özbahçeci, Kısacık and Ak[216]. A third-generation wave model, Simulated Waves Nearshore (SWAN), was utilized for wave modeling.

Figure 15. WaveWatch point location of the study

Habitat data is specified in the habitats table, which includes spatial data and parameters. However, no additional habitat categories were utilized in the study due to the absence of relevant data pertaining to the aquatic habitats of İzmir, except for the available seagrass data. The data was obtained from UNEP-WCMC[217].

Additionally, the bathymetry map, which has a resolution of 450 m, was acquired from the General Bathymetric Chart of the Oceans (GEBCO). Then, the continental shelf contour was determined using the bathymetry map, and contour lines were derived from the raster format bathymetry map. The continental shelf value contour, which is -200 m [218], was exported as a polyline shapefile. DEM data was obtained from Copernicus with a resolution of 25 m. Human population data is a map of total human population on each pixel. The Global Human Settlement Layer with a resolution of 100 m of European was utilized as the human population raster input.

Sea level rise data is a point vector data of sea level rise rates or amounts, which was derived from the Turkish National Sea Level Monitoring System (Türkiye Ulusal Deniz Seviyesi İzleme Sistemi, TUDES) measured at the Mentes (İzmir) station website.

The Coastal Vulnerability Model recommends setting numeric values of elevation averaging radius and population search radius as half of the model resolution. The model resolution was set as 50 m and the numeric values were set as 25 m. The maximum fetch distance, which refers to the maximum distance in meters to extend rays from shore points, was measured as 43,250 m.

The present study utilized a kernel density tool to generate a raster format map, as the model employed in this investigation provides a point vector output. This raster map was deemed necessary to synthesize the models' outputs to develop a multi-risk mitigation map.

The study identified low-lying urban areas, i.e., those located between 0-10 meters above sea level, as being particularly vulnerable to the risks posed by rising sea levels and sea surges[17]. To that end, kernel density techniques produced a coastal vulnerability map for the study area. The resultant raster map was then constrained by a 10-meter contour line (Figure 16) to effectively delineate the areas under threat.

Figure 16. 10-meter contour line

The Urban Cooling model and Urban Flood Risk Mitigation model yield capacity outputs that positively relate to reduction/mitigation, whereas the Coastal Vulnerability model produces a vulnerability output that negatively relate to reduction. As a result, the normalized values of the Coastal Flood Vulnerability model have been inverted to account for this difference.

$$X_{normalized} = [(X - X_{maximum}) \cdot (-1)] + X_{minimum} \tag{15}$$

Where X represents the output of the model.

It is worth noting that due to the lack of adequate geomorphology data, which is optional, it was not included in the model run. Nonetheless, the data and materials used in the Coastal Vulnerability Model of InVEST were carefully selected and prepared to ensure the reliability and accuracy of the model outputs. The utilization of reliable and accurate data inputs is crucial for Coastal Flood Risk Assessment and effective coastal management (Figure 17).

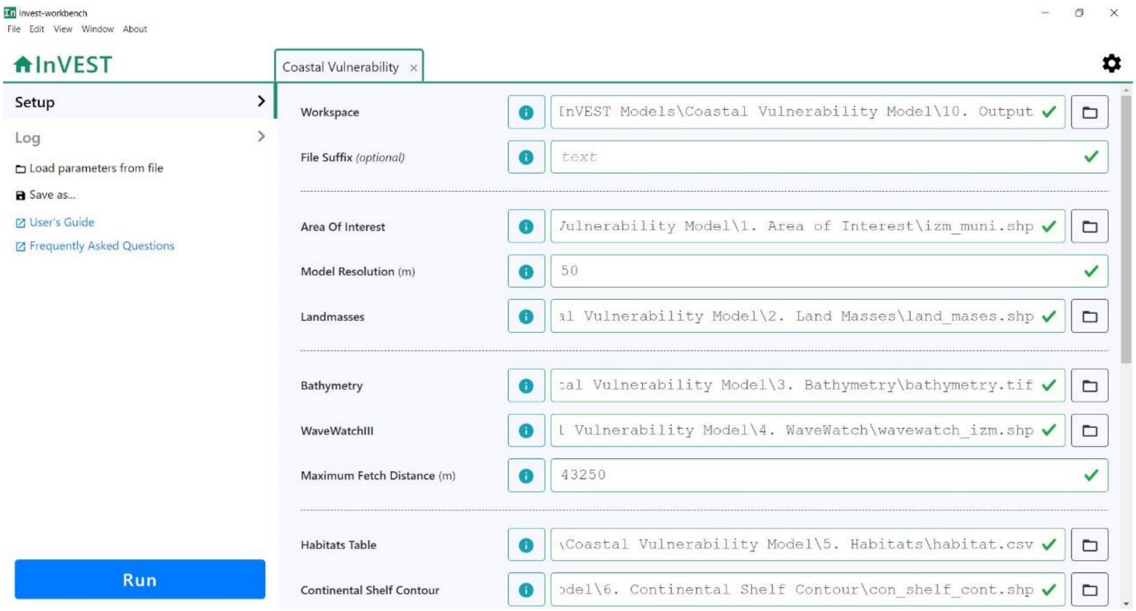

Figure 17. Coastal Vulnerability model workbench

3.2.4. Multi-Risk Mitigation Assessment of İzmir

A key step in minimizing the effects of environmental risks on urban areas is the evaluation of multi-risk mitigation methods. Three InVEST models were used in this work to calculate the heat mitigation index for various environmental concerns. These models produced outputs of HMI from the "Urban Cooling Model", RRI from the "Urban Flood Risk Mitigation Model", and coastal exposure index from the "Coastal Vulnerability Model".

The weighted sum tool in the ArcGIS environment was used to combine the output of each model. Weighted sum operation combines several raster maps, multiplying them by specified weights and summing together (Equation 16). As the data range vary for each model output, a range normalization is applied before weighted sum operation. The outputs of the three models were normalized for weighted sum operation using range normalization. However, equal weights (a weight of 1) was assigned to each risk since no information was available regarding which risk had priority in the literature. The total mitigation index, which indicated the cumulative influence of the three models in lowering the impact of environmental risks, was given a single value, X represents the output of the models, using the weighted sum tool.

$$X = \sum_{j=1}^{n} wjxij \tag{16}$$

Where w is the specified weight for input j and i is the input value.

In conclusion, this study's multi-risk mitigation evaluation highlights the value of combining several models to evaluate the efficacy of mitigation strategies. A thorough method of evaluating the total mitigation index is provided by using the weighted sum tool in the model output synopsis process. Urban planners and politicians may use the study's findings to guide their choices for environmental risk mitigation strategies.

3.3. Analysis of the Impact of Urbanization on Risk Reduction

A comprehensive analysis of the study area has been undertaken by examining 16 carefully selected sample locations to test the indicators to see the relation between urban morphology and ecosystem delivering capacity and to define urban planning parameters for the city to define the quantity and quality of NBS which are more suitable for AOI. These locations have been strategically chosen based on their period of establishment: Ottoman, Republican, Liberalization, and Contemporary, thereby enabling a detailed investigation of the urban evolution throughout İzmir's history (Table 8).

The total of 16 sample areas was selected in a way that includes best and worse scores of the risk mitigation index. These samples were chosen to represent different regions of the study area. The tiles were located so as to include only built-up land, excluding non-urban areas such as forests and open lands.

The division of İzmir's urban development into these specific periods was determined based on the year of urbanization in the region. The Ottoman period represents the areas developed before 1923, characterized by traditional settlement patterns and architectural styles. The Republican period encompasses 1923 and 1950 when urbanization and modernization efforts started to shape the city's landscape. The Liberalization period, spanning from 1980 to 2000, reflects an era of significant economic and social changes that influenced the urban form and land use patterns. Lastly, the Contemporary period includes developments since 2000, showcasing the latest trends in urban design, high-rise construction, and the transformation of İzmir's skyline. The spatial locations of the determined sample areas are presented in Figure 18.

In order to ensure a comprehensive analysis, four sample areas were carefully selected for each historical period, resulting in a total of 16 sample locations from residential districts. These areas were chosen with the objective of representing the characteristic urban elements and typologies of each respective period (Figure 19). For instance, the sample areas about the Ottoman period naturally encompass Kadifekale and Kemeraltı Bazaar, which hold significant historical value as the earliest settlement areas in İzmir. The sample areas for the Republican and Liberalization periods were chosen to capture the spatial expansion and diversification of the urban fabric, particularly along the İzmir Bay. Meanwhile, the Contemporary period is marked by the prevalence of high-rise structures, with the sample areas predominantly consisting of modern point-block buildings.

Table 8. Characteristics of the tiles

Period Name	Period	Period Code	Tile Code	District	Location/ Neighborhood
Ottoman	Before 1923	1	1.1	Konak	Kemeraltı-1
Ottoman	Before 1923	1	1.2	Konak	Kemeraltı-2
Ottoman	Before 1923	1	1.3	Konak	Kadifekale-1
Ottoman	Before 1923	1	1.4	Konak	Kadifekale-2
Republican	1923-1980	2	2.1	Konak	Alsancak
Republican	1923-1980	2	2.2	Konak	Güzelyalı
Republican	1923-1980	2	2.3	Bayraklı	Alpaslan
Republican	1923-1980	2	2.4	Karşıyaka	Bostanlı
Liberalization	1980-2000	3	3.1	Karabağlar	Yaşar Kemal
Liberalization	1980-2000	3	3.2	Bayraklı	Masuroğlu
Liberalization	1980-2000	3	3.3	Karşıyaka	Atakent
Liberalization	1980-2000	3	3.4	Çiğli	Egekent
Contemporary	2000-Present	4	4.1	Gaziemir	Gazikent
Contemporary	2000-Present	4	4.2	Bayraklı	Adalet
Contemporary	2000-Present	4	4.3	Çiğli	Ataşehir
Contemporary	2000-Present	4	4.4	Karşıyaka	Mavişehir

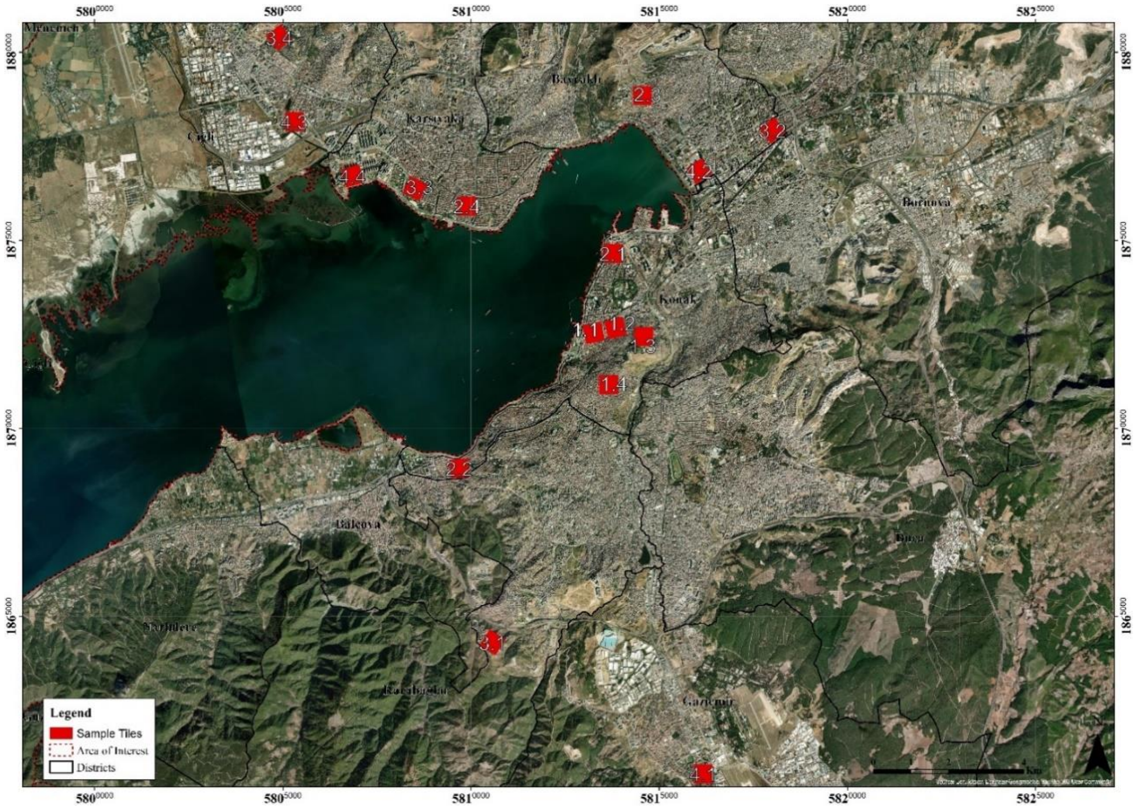

Figure 18. Locations of the tiles

A set of indicators were established to facilitate a comprehensive analysis of the sample areas, encompassing various dimensions of urban morphology and land use. The topographic indicators include average elevation (m) and average slope (%), providing insights into the physical characteristics of the study area. Built-up features such as the number of buildings, average building height, average building footprint (sqm), and built-up volume (%) offer valuable information about the intensity of urban development and the city's vertical growth. Additionally, LULC indicators were employed to assess the distribution of different land uses within the sample areas. These indicators include road area (%), residential area (%), industrial and/or commercial area (%), and green areas (%), providing insights into the functional aspects of urban development. Moreover, indicators related to the human and natural environment, such as impervious surface density (%), tree cover density (%), and grassland density (%), were utilized to analyze the environmental impacts and ecological aspects of the sample areas (Table 13). The values are average for each tiles and they were measured using ArcMap and several open access data from Copernicus such as Green Areas, Tree Cover Density, Imperviousness Density and Grassland.

Figure 19. Sample tiles and their periods

CHAPTER 4

RESULTS

4.1. Urban Cooling

In this section the results of Urban Cooling model were presented. The main output of the model is HMI map in raster form of the area. Other outputs are cooling capacity, average temperature value and average temperature anomaly maps which are vector maps for each neighborhood. The HMI values of the area change between 0.19 and 1 (Figure 20).

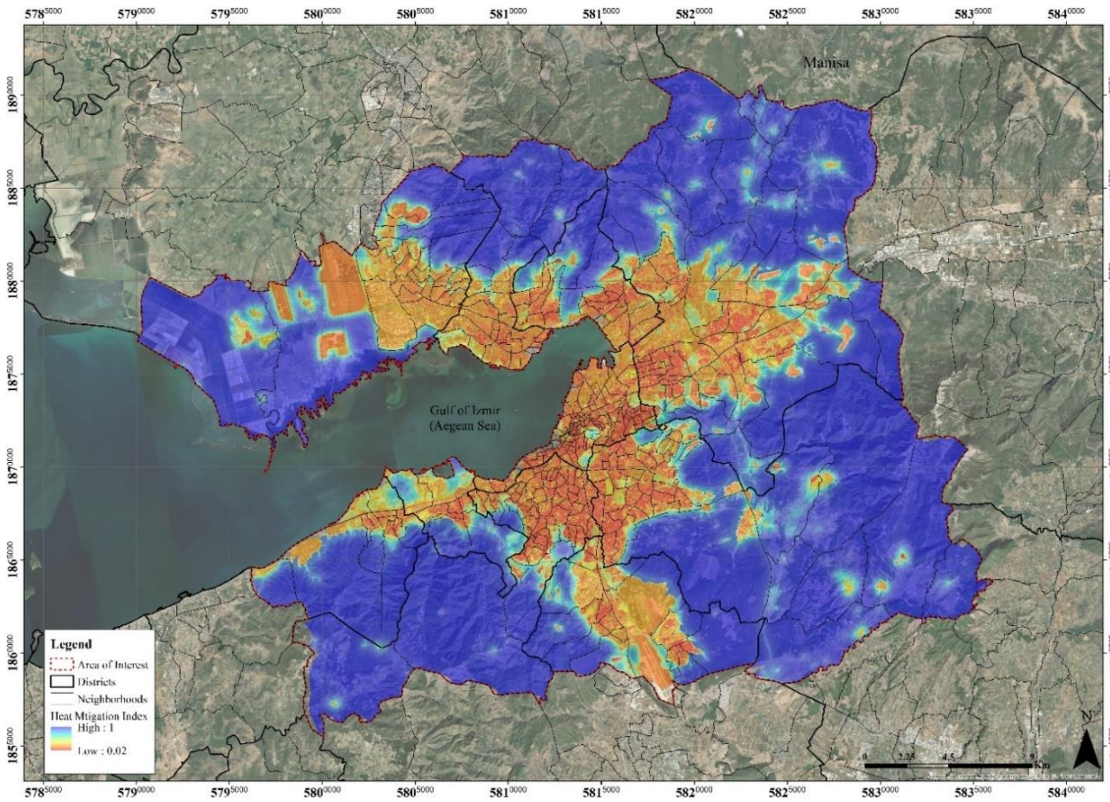

Figure 20. The map of heat mitigation index

Table 9 presents the results of an analysis of the cooling capacity, average temperature value and average temperature anomaly of ten districts in İzmir City. The average cooling capacity values for the districts range from 0.15 to 0.66, with Narlıdere having the highest value and Konak having the lowest. The average temperature value ranges from 30.76 ^{o}C to 34.11 ^{o}C, with Konak having the highest and Buca having the lowest.

The deviation of the present temperature from the mean temperature over a specified time period, known as the base period, is referred to as a temperature anomaly, which can be either positive or negative[17]. The average temperature anomaly ranges from 0.76 ^{o}C to 4.11 ^{o}C, with Konak having the highest anomaly and Balçova having the lowest.

Table 9. Results of Urban Cooling model

District	Average Cooling Capacity	Average Temperature Value (^{o}C)	Average Temperature Anomaly (^{o}C)
Balçova	0.42	32.04	2.04
Bayraklı	0.32	32.40	2.40
Bornova	0.50	31.33	1.33
Buca	0.56	30.76	0.76
Çiğli	0.28	31.35	1.35
Gaziemir	0.45	31.92	1.92
Karabağlar	0.54	31.05	1.05
Karşıyaka	0.47	31.41	1.41
Konak	0.15	34.11	4.11
Narlıdere	0.66	30.92	0.92
Mean	0.44	31.73	1.73
Stn. Dev.	0.15	0.98	0.98

The average cooling capacity across all neighborhoods was 0.22, with a standard deviation of 0.16. The neighborhoods with the highest average cooling capacity were 2. İnönü (0.75) in Narlıdere, Tırazlı (0.74) in Karabağlar, and Limanreis (0.72) in Narlıdere, while the neighborhoods with the lowest average cooling capacity were Yavuz Selim (0.05), Duatepe (0.05), and Yenigün (0.06) which are located in Konak (Figure 21).

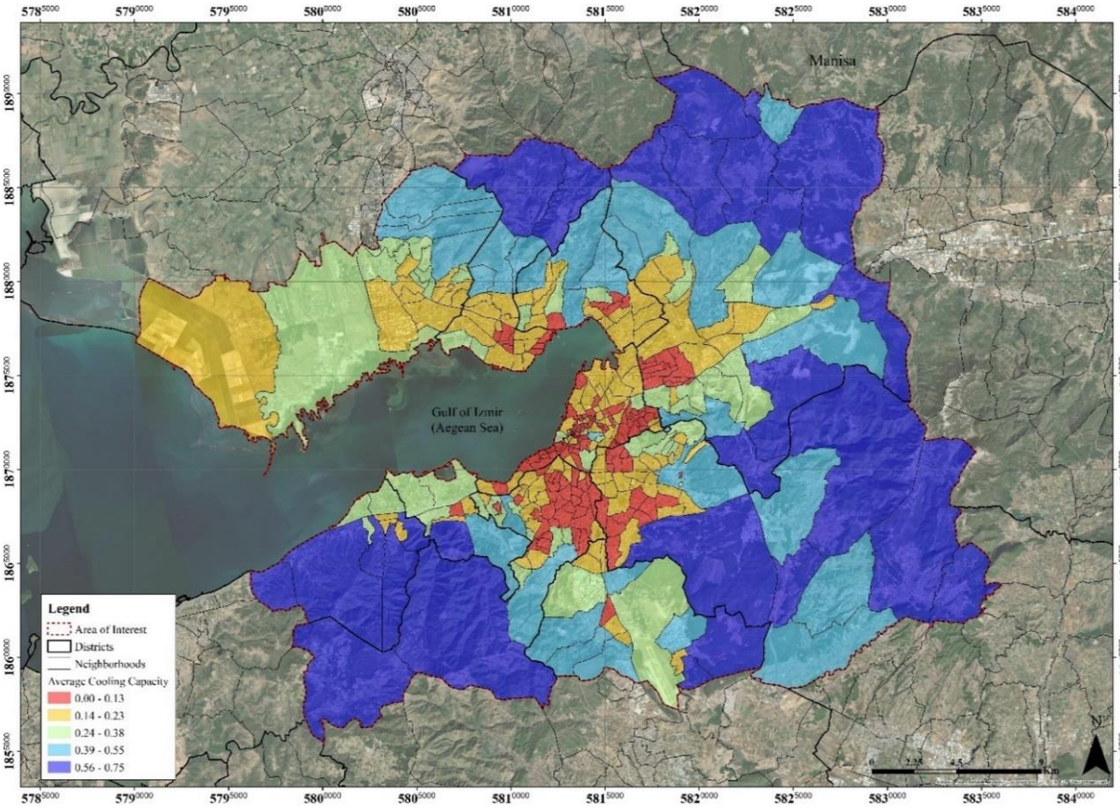

Figure 21. Average cooling capacity of the neighborhoods

The average temperature value across all neighborhoods was 33.35 ^{o}C with a standard deviation of 1.20. The neighborhoods with the highest temperature values were Uğur Mumcu (34.43 ^{o}C), Sarıyer (34.43 ^{o}C), and Bozyaka (34.43 ^{o}C) which are located in Karabağlar, while the neighborhoods with the lowest temperature values were Yamanlar (30.07 ^{o}C) in Karşıyaka, Tırazlı (30.08 ^{o}C) in Karabağlar, and Doğancılar (30.10 ^{o}C) in Buca (Figure 22).

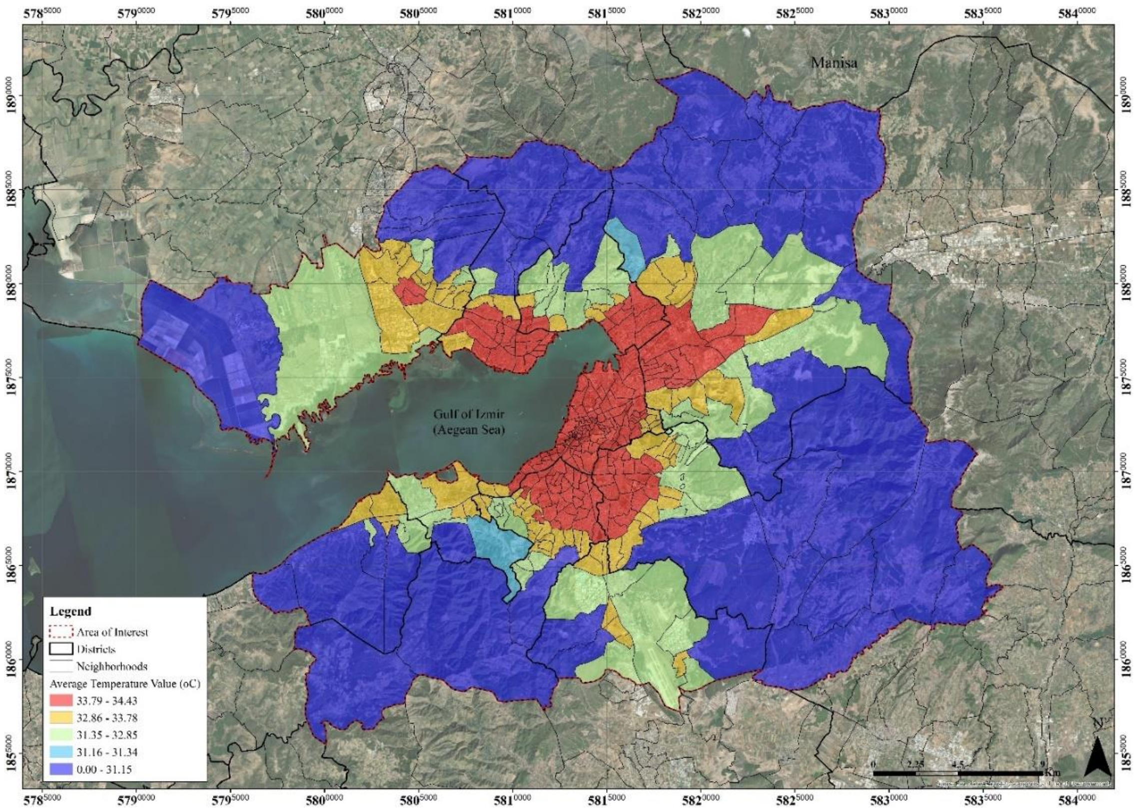

Figure 22. Average temperature (^{o}C) of the neighborhoods

The average temperature anomaly across all neighborhoods was 3.35 ^{o}C with a standard deviation of 1.20. The neighborhoods with the highest average temperature anomalies were Uğur Mumcu (4.43 ^{o}C), Sarıyer (4.43 ^{o}C), and Bozyaka (4.43 ^{o}C) which are located in Karabağlar, while the neighborhoods with the lowest average temperature anomalies were Yamanlar (0.07 ^{o}C) in Karşıyaka, Tırazlı (0.08 ^{o}C) in Karabağlar, and Doğancılar (0.10 ^{o}C) in Buca (Figure 23).

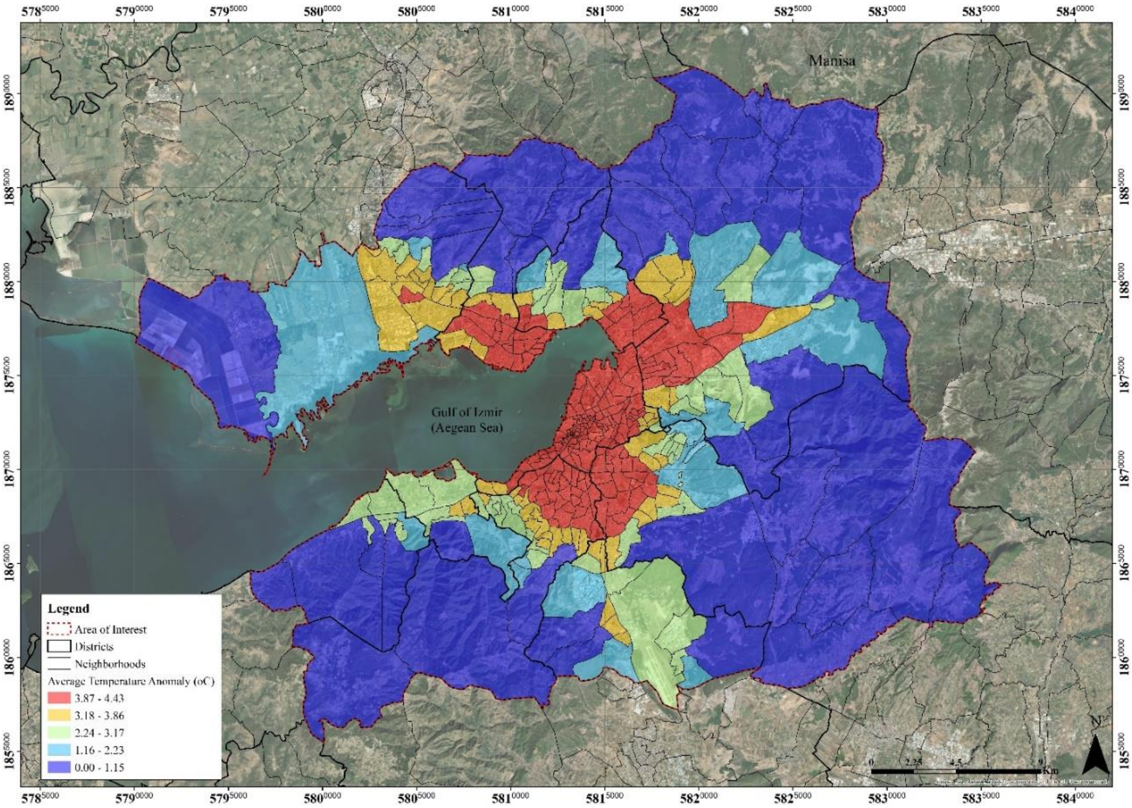

Figure 23. Average temperature anomaly (ºC) of the neighborhoods

4.2. Urban Flood Risk Mitigation

In this section the results of Urban Flood Risk Mitigation model were presented. The model gives the RRI, runoff retention in mm^3 and flood volume in mm maps in raster and vector formats for each neighborhood. The RRI values of the area change between 0.08 and 1 (Figure 24).

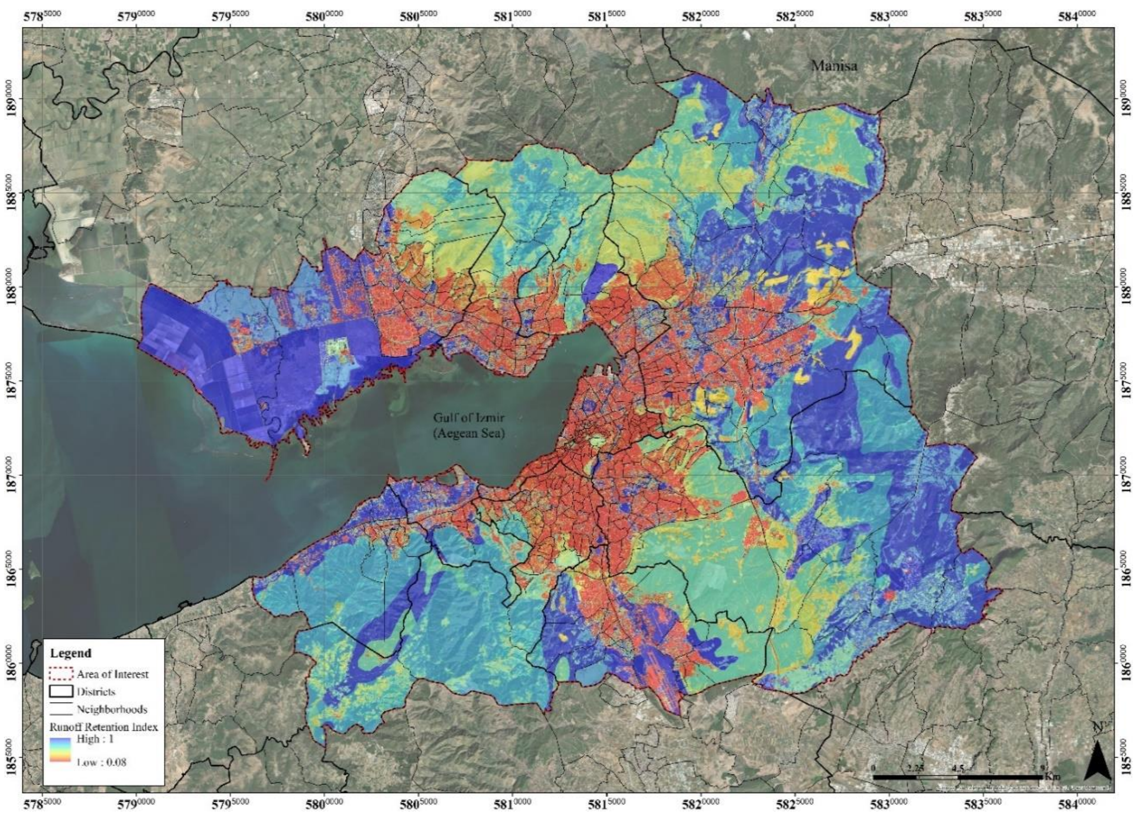

Figure 24. Runoff retention index

The Table 10 presents the results of an analysis of the RRI, runoff retention in mm^3 and flood volume in mm of ten districts in İzmir City. The average RRI for the districts range from 0.27 to 0.76, with Narlıdere having the highest value and Konak having the lowest. The runoff retention values range from 443,030.41 mm^3 to 10,575,856.23 mm^3, with Konak having the lowest and Bornova having the highest. The flood volume ranges from 506,593.74 mm to 5,522,268.48 mm, with Balçova having the lowest volume and Bornova having the highest.

The average RRI across all neighborhoods was 0.34 with a standard deviation of 0.20. The neighborhoods with the highest RRI were Sasalı Merkez (0.93) in Çiğli, Kırklar (0.88) in Buca, and Sahilevleri (0.87) in Narlıdere, while the neighborhoods with the lowest RRI were Altıntaş (0.10) in Konak, Dicle (0.10) in Buca, and Duatepe (0.10) in Konak (Figure 25).

Table 10. Results of Urban Flood Risk Mitigation model

District	Average Runff Retention Index	Average Runoff Retention (m^3)	Average Flood Volume (mm)
Balçova	0.65	929,638.36	506,593.74
Bayraklı	0.49	1,164,137.78	1,223,079.37
Bornova	0.66	10,575,856.24	5,522,268.48
Buca	0.69	9,898,786.26	4,454,140.24
Çiğli	0.74	6,804,605.99	2,377,874.99
Gaziemir	0.63	2,751,494.15	1,641,376.99
Karabağlar	0.63	4,369,846.96	2,541,316.78
Karşıyaka	0.56	1,974,228.88	1,556,403.28
Konak	0.27	443,030.41	1,169,832.77
Narlıdere	0.76	2,360,309.91	748,866.33
Mean	0.61	4127193.49	2174175.30
Stn. Dev.	0.14	3717088.93	1632155.77

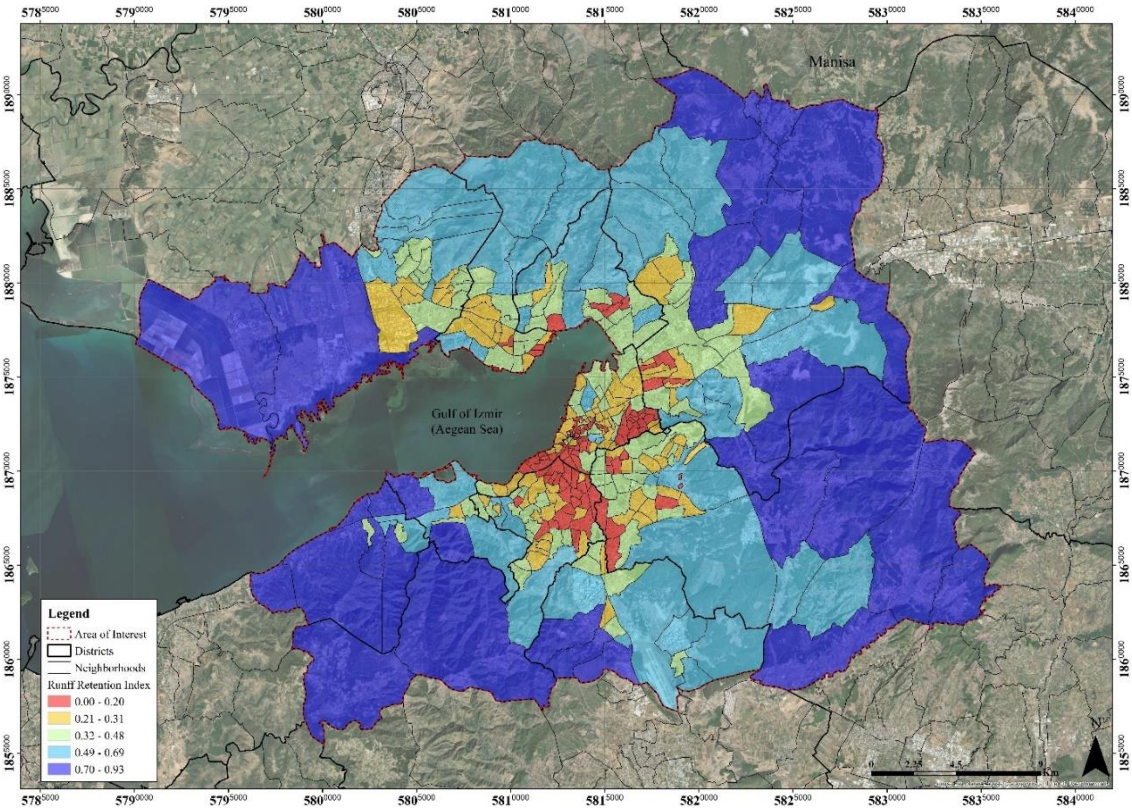

Figure 25. Runoff retention index of the neighborhoods

The average runoff retention across all neighborhoods was 107,483.59 mm^3 with a standard deviation of 335,487.54. The neighborhoods with the highest runoff retention were Kaklıç (2,620,806.97 mm^3) in Çiğli, Sasalı Merkez (2,615,571.49 mm^3) in Çiğli, and Kaynaklar Merkez (2,563,524.25 mm^3) in Buca, while the neighborhoods with the lowest runoff retention were Şehit Nedim Tuğaltay (97.99 mm^3), Bozkurt (109.89 mm^3), and Dayıemir (140.22 mm^3) which are located in Konak (Figure 26).

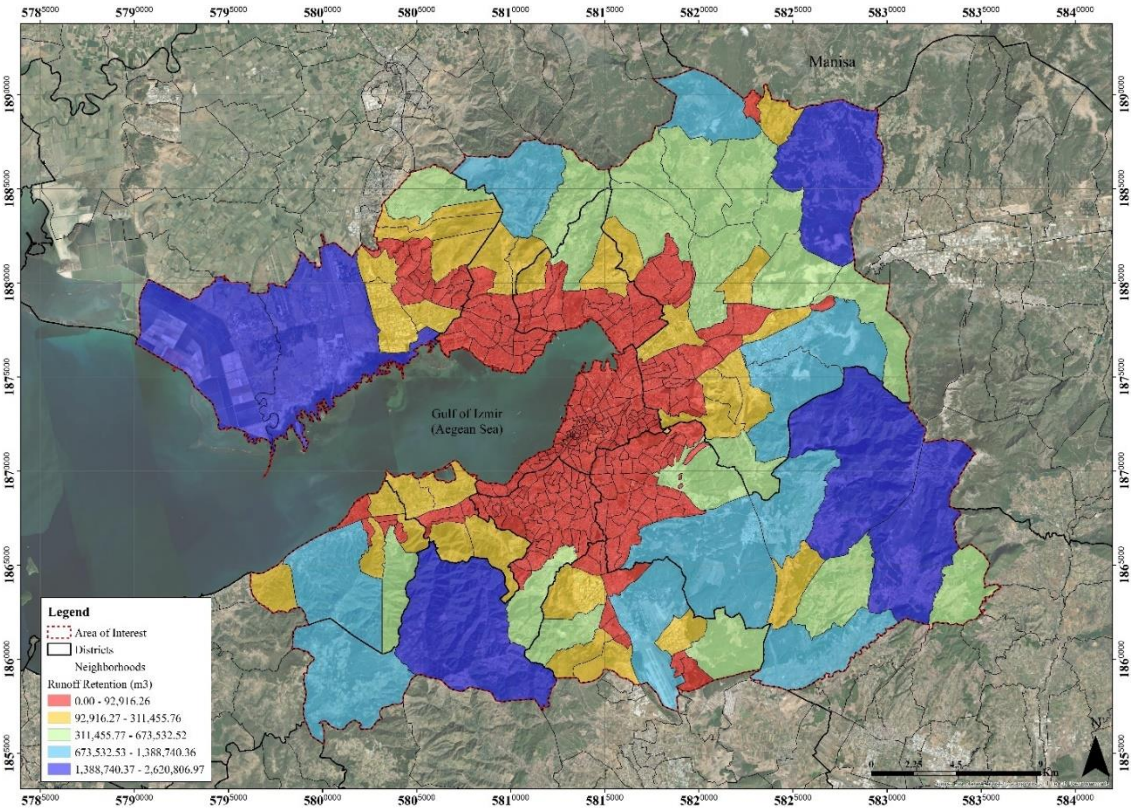

Figure 26. Runoff retention (m^3) of the neighborhoods

The mean flood volume across all neighborhoods was found to be 107,483.59 mm^3, accompanied by a standard deviation of 335,487.54. The neighborhoods exhibiting the highest flood volumes included Zafer in Buca (878,622.54 mm^3), Tırazlı in Karabağlar (698,545.13 mm^3), and Yakaköy in Bornova (540,663.56 mm^3). Conversely, the neighborhoods with the lowest flood volumes were Şehit Nedim Tuğaltay (546.01 mm^3), Odunkapı (633.48 mm^3), and Kahraman Mescit (661.86 mm^3), all of which are situated in Konak (Figure 27).

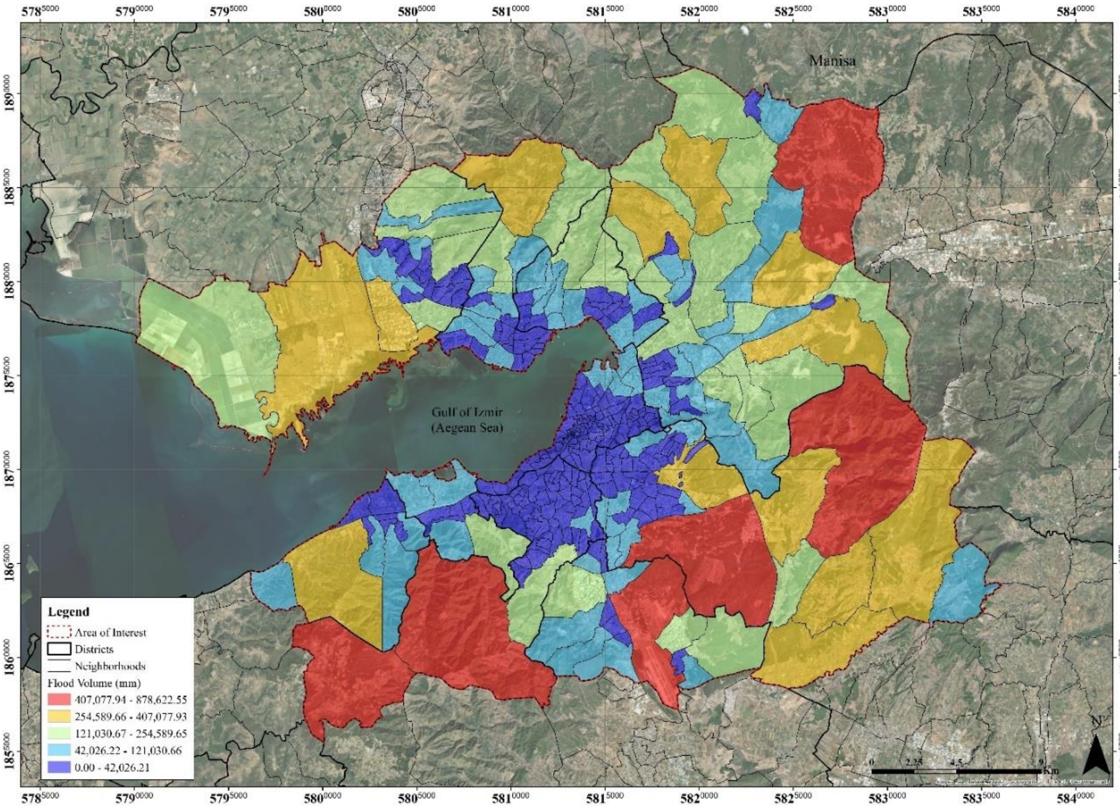

Figure 27. Flood volume (mm) of the neighborhoods

4.3. Coastal Vulnerability

This section presents the findings of the coastal vulnerability model, which generates a CEI to assess the vulnerability of neighborhoods to coastal hazards. The CEI values of the model were reversed to determine coastal flood risk mitigation index (CFRMI) values. The values of CFRMI are between 0.27 to 5 (Figure 28).

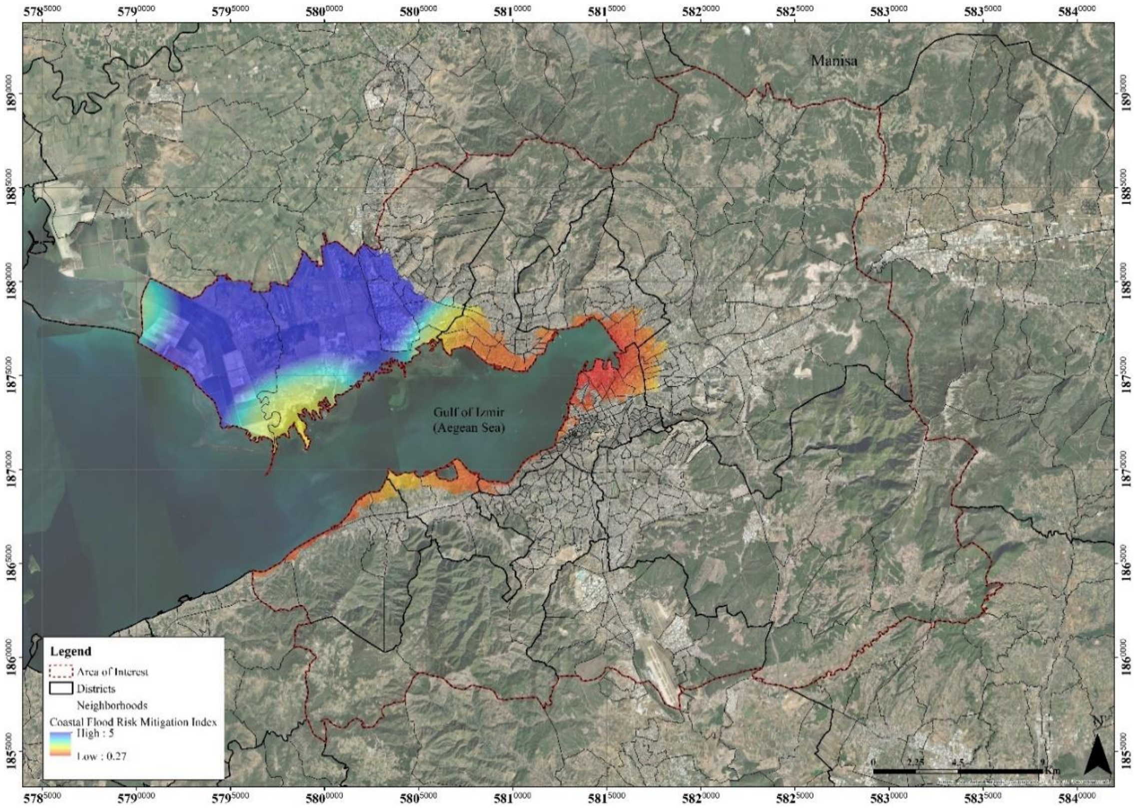

Figure 28. Coastal flood risk mitigation index

As shown in Table 11, the average CFRMI value of the area was calculated as 1.02 whit a standard deviation of 1.19. The results revealed that the highest CFRMI was found in Çiğli with a value of 4.41, indicating that this district is the most vulnerable to coastal hazards. On the other hand, Buca and Gaziemir had a CFRMI of 0.00, indicating that these districts are less susceptible to such hazards. The CFRMI of the remaining districts ranged between 0.52 and 1.04. Karabağlar and Bayraklı had the same coastal exposure index value of 0.68. The inland neighborhoods' values are not included in the calculations.

A thorough statistical analysis of the CFRMI values uncovered some noteworthy trends (Table 11). The minimum CFRMI value was 0.32, observed in Alsancak and Umurbey neighborhoods in Konak district. In contrast, the maximum value of 4.99 was found in Ahmet Efendi, Balatçık, Küçük Çiğli, and Yeni Mahalle neighborhoods in Çiğli district. The average CFRMI value was determined to be 1.24, with a standard deviation of 1.20 (Figure 29).

Table 11. Results of Coastal Vulnerability model

District	Average Coastal Flood Risk Mitigation Index
Balçova	1.01
Bayraklı	0.68
Bornova	1.04
Buca	0.00
Çiğli	4.41
Gaziemir	0.00
Karabağlar	0.68
Karşıyaka	1.04
Konak	0.52
Narlıdere	0.80
Mean	1.24
Stn. Dev.	1.20

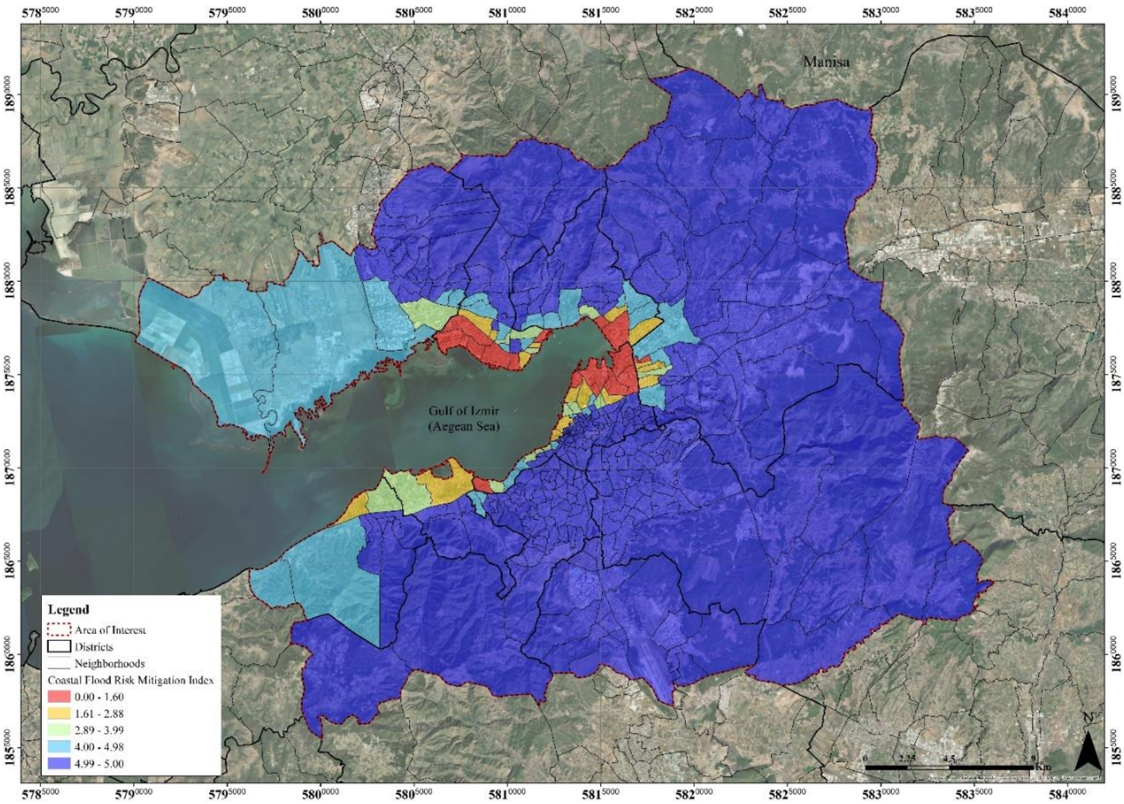

Figure 29. Coastal flood risk mitigation index of the neighborhoods

4.4. Multi-Risk Mitigation

This section presents the findings of the Multi-Risk Mitigation Index (MRMI), which was generated from Heat Mitigation Index (HMI), Runoff Retention Index (RRI), and Coastal Flood Risk Mitigation Index (CFRMI). As the indexes were normalized, the equally weighted sum product (MRMI) values range between 0 and 3 (Figure 30).

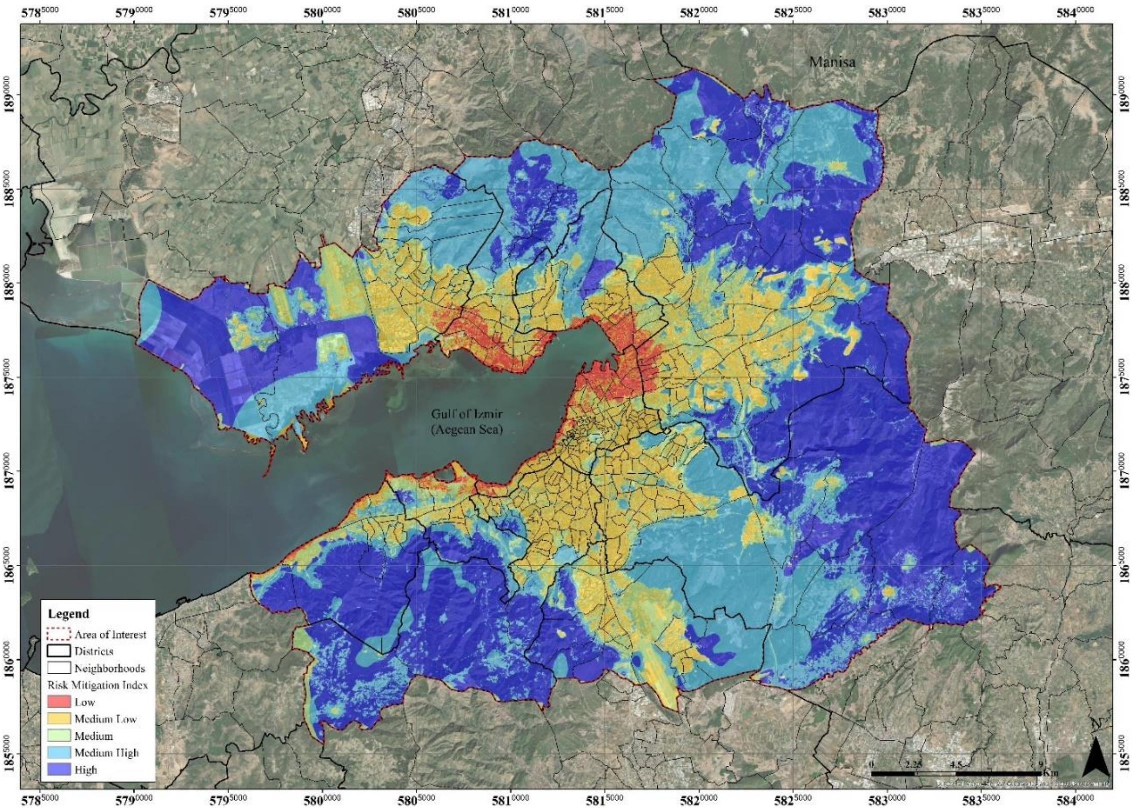

Figure 30. Multi-risk mitigation index of AOI

The MRMI data for İzmir's districts show a minimum score of 1.07 in Konak district, and a maximum score of 2.53 in Buca district (Table 12). The average score across all districts is 2.13, with a standard deviation of 0.37, indicating a relatively high level of variability in the level of response capacity to hazards across the districts. These statistical measures further reinforce the importance of taking a district-specific approach in multi-risk mitigation planning to address the varying levels of vulnerability and exposure to potential hazards across the region.

Table 12. Multi-risk mitigation index of the districts

District	Average Multi-Risk Mitigation Index
Balçova	2.06
Bayraklı	1.87
Bornova	2.38
Buca	2.53
Çiğli	2.36
Gaziemir	2.23
Karabağlar	2.39
Karşıyaka	2.12
Konak	1.07
Narlıdere	2.47
Mean	2.15
Stn. Dev.	0.43

The mean MRMI across all neighborhoods was 1.53, accompanied by a standard deviation of 0.51. The neighborhoods exhibiting the highest MRMI included Kırklar (2.84), Doğancılar (2.82), and Kaynaklar Merkez (2.82), all of which are situated in Konak. Conversely, the neighborhoods with the lowest MRMI were Umurbey (0.34) in Konak, Tersane (0.39) in Karşıyaka, and Alsancak (0.40) in Konak (Figure 31).

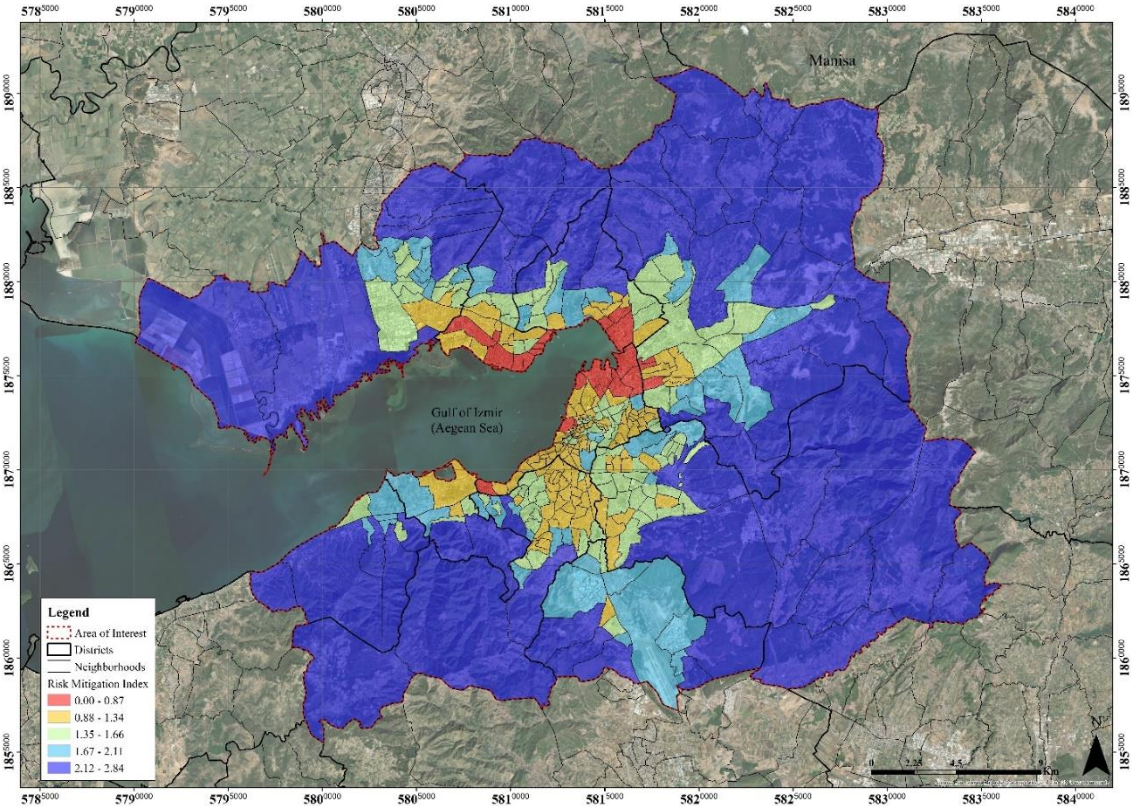

Figure 31. Multi-risk mitigation index of the neighborhoods

4.5. Relationship Between Urbanization and Risks

The data collection and analysis process involved a combination of online resources and field surveys. Land use analyses relied on internet-based platforms like Google Maps to gather information on LULC patterns and classifications. On the other hand, the numerical calculations for the remaining indicators were performed using the ArcMap software, which enabled the precise measurement and assessment of the selected parameters. The analysis of the data (Table 13) reveals a positive relation between MRMI and tree density as well as the proportion of green areas. Conversely, an inverse relationship is observed between imperviousness density and the risk reduction index. Tiles with the highest MRMI values (tile 4.1 with a value of 1.76) exhibit a green area ratio of 3.13% and a tree density of 8.72%, whereas tiles with the lowest MRMI values (tile 4.2 with a value of 0.43) have a green area ratio of 0.01% and a tree density of 1.78%.

Areas characterized by a higher presence of natural elements, such as trees and green areas (e.g., tile 3.2 and tile 4.4), demonstrate higher values of HMI and RRI compared to other areas. Furthermore, the findings highlight the significance of settlement location upon examining all risk reduction indexes. Despite the advantageous position of tile 4.4 in terms of mitigating urban flood and heat island risks, its CFRMI value is notably low (0.21) due to its current location (average elevation: 9.73m).

The results show that the indicators and the indices relationship for the whole tiles set is consistent in general. However, based on a single or few indicators compared to the indices some disparities are observed. Although tile 1.4 and tile 2.1 exhibit similar imperviousness density values (tile 1.4: 93.92, tile 2.1: 93.68), there is a significant disparity in their MRMI values (tile 1.4: 1.15, tile 2.1: 0.44). The difference in the situations can be explained by the fact that tile 1.4 has more residential areas and higher elevations compared to tile 2.1. Additionally, the buildings in tile 1.4 are typically two floors high and have a smaller area of 41.10 square meters, while the buildings in tile 2.1 are usually seven floors high and have a larger area of 146.56 square meters. Apart from human factors, it is important to note that tile 1.4 has a very low tree density of 0.03% and no green areas, whereas tile 1.2 has a tree density of 0.71% and a green area ratio of 0.13%. These observations suggest that when imperviousness remains constant, the number of floors, building footprint, and topographic height of buildings have a more pronounced influence on MRMI than the presence of natural elements. The low-risk mitigation index of Tile 1.4, which is close to the coast, indicates that when making site selection decisions, inland areas should be chosen regardless of the presence of green spaces and trees.

Table 14 provides valuable insights into the relationship between various factors and the indices related to heat mitigation, runoff retention, coastal flood risk mitigation, and multi-risk mitigation. The relationship between land use/urbanization standards and the occurrence of urban heat island, pluvial flood, and coastal flood events in İzmir are number of trees (tree cover density), imperviousness density, the size green areas, built up footprint, building height, and road ratio. Tree cover density, the extent of green areas, built-up footprint, and building height have a positive impact on ecosystem resilience and climate change adaptation, while imperviousness density and road ratio have a negative impact.

Table 13. Ecosystem delivery capacities of the tiles

Indicators	Ottoman Period Sample Tiles				Republican Period Sample Tiles			
	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4
Avg. Elevation (m)	7.15	15.79	99.43	134.16	9.92	10.97	134.92	10.98
Avg. Slope (%)	1.81	4.17	14.28	3.90	3.31	3.34	11.04	2.59
Number of Buildings	1292	1145	3227	2407	769	606	1165	338
Avg. Building Height	2	3	2	2	7	5	3	5
Avg. Building Footprint (m)	94.07	80.16	27.68	41.10	146.56	208.10	83.95	293.43
Built-up Volume (%)	0.19	0.22	0.14	0.16	0.63	0.50	0.23	0.40
Road (%)	7.78	11.42	21.90	22.12	18.26	15.09	19.25	7.63
Residential (%)	7.62	9.34	57.93	59.82	30.50	58.73	55.28	61.37
Industrial and/ or Commercial (%)	81.38	79.40	17.64	15.73	47.25	21.67	0.31	21.35
Green Areas (%)	1.25	0.00	2.15	0.00	0.13	0.22	0.00	0.00
Impervious Density (%)	95.51	71.94	85.87	93.92	93.68	82.89	86.12	82.49
Tree Cover Density (%)	0.29	2.16	1.18	0.03	0.71	2.67	0.45	0.97
Grassland Density (%)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Weighted Avg. HMI	**0.09**	**0.10**	**0.07**	**0.04**	**0.08**	**0.10**	**0.08**	**0.10**
Weighted Avg. RRI	**0.13**	**0.27**	**0.15**	**0.11**	**0.15**	**0.22**	**0.15**	**0.29**
Weighted Avg. CFRMI	**0.49**	**1.00**	**1.00**	**1.00**	**0.20**	**0.94**	**1.00**	**0.12**
Weighted Avg. MRMI	**0.72**	**1.37**	**1.22**	**1.15**	**0.44**	**1.27**	**1.22**	**0.51**
Indicators	Liberalization Period Sample Tiles				Contemporary Period Sample Tiles			
	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4
Avg. Elevation (m)	116.97	13.95	10.16	82.16	136.67	6.71	8.28	9.73
Avg. Slope (%)	5.88	2.73	2.49	8.23	4.24	1.65	1.69	2.76
Number of Buildings	37	310	149	87	67	24	121	72
Avg. Building Height	13	6	2	10	4	8	6	12
Avg. Building Footprint (m)	635.13	264.80	371.83	371.05	641.06	636.62	406.46	489.66
Built-up Volume (%)	0.24	0.39	0.09	0.26	0.14	0.10	0.24	0.34
Road (%)	10.02	15.07	11.08	7.18	16.54	8.95	10.71	4.91
Residential (%)	75.63	30.52	56.00	61.83	72.80	22.82	56.70	64.75
Industrial and/ or Commercial (%)	0.00	12.68	20.00	8.24	8.62	63.53	5.07	6.03
Green Areas (%)	1.81	3.82	3.63	10.56	3.13	0.00	3.65	19.55
Impervious Density (%)	64.00	76.00	43.70	43.83	55.49	84.69	59.92	36.00
Tree Cover Density (%)	3.77	4.11	10.57	5.07	8.72	1.78	3.09	13.78
Grassland Density (%)	0.02	0.00	0.01	0.00	0.00	0.00	0.01	0.01
Weighted Avg. HMI	**0.18**	**0.13**	**0.23**	**0.18**	**0.17**	**0.18**	**0.18**	**0.33**
Weighted Avg. RRI	**0.21**	**0.36**	**0.64**	**0.31**	**0.59**	**0.22**	**0.49**	**0.71**
Weighted Avg. CFRMI	**1.00**	**1.00**	**0.11**	**1.00**	**1.00**	**0.04**	**0.73**	**0.21**
Weighted Avg. MRMI	**1.39**	**1.50**	**0.97**	**1.50**	**1.76**	**0.43**	**1.40**	**1.25**

Correlation results are color-coded with negative values in red and positive values in green, considering 0 (no correlation) as the threshold. As the values move away from 0, the colors transition from light to dark to represent the strength of the correlation.

Regarding the HMI, the results indicate that a higher percentage of green areas and dense tree cover is strongly correlated with a higher HMI. Specifically, the correlation coefficients for Average Building Footprint and HMI is 0.736, %Green Areas and HMI is 0.802, and for %Tree Cover Density and HMI is 0.890. These findings align with the well-established understanding that vegetation reduces urban heat by providing shade, evaporative cooling, and mitigating the urban heat island effect. Creating space can be achieved by increasing building height (and thus building footprints) to increase the quantity of trees and green areas.

Conversely, more impervious surfaces, such as concrete and asphalt, show a strong negative correlation with the HMI. The correlation coefficient for %Impervious Density and HMI is -0.879. This emphasizes the need to reduce impervious surfaces and promote permeable alternatives to improve heat resilience in urban areas.

Table 14. Correlation of indicators and indexes
(**: Correlation is significant at the 0.01 level, *: Correlation is significant at the 0.05 level.)

Indicators	**HMI**	**RRI**	**HMI/ RRI**	**CFRMI**	**MRMI**
Avg. Elevation (m)	-0.255	-0.230	-0.243	**0.642****	0.481
Avg. Slope (%)	-0.302	-0.348	-0.325	**0.526***	0.300
Number of Buildings	**-0.675****	**-0.575***	**-0.625****	0.349	-0.051
Avg. Building Height	**0.633****	0.229	0.431	-0.133	0.092
Avg. Building Footprint (m)	**0.736****	0.563*	**0.649****	-0.252	0.153
Built-up Volume (%)	-0.148	-0.151	-0.150	-0.118	-0.215
Road (%)	**-0.673****	-0.427	**-0.550***	0.477	0.148
Residential (%)	0.307	0.344	0.325	0.215	0.431
Industrial and/ or Commercial (%)	-0.291	-0.348	-0.320	-0.319	**-0.534***
Green Areas (%)	**0.802****	**0.660****	**0.731****	-0.142	0.320
Impervious Density (%)	**-0.879****	**-0.860****	**-0.870****	0.061	**-0.509***
Tree Cover Density (%)	**0.890****	**0.924****	**0.907****	-0.227	0.377
Grassland Density (%)	0.565*	0.343	0.454	0.091	0.355

Moving on to the RRI, the analysis shows a strong negative correlation between impervious surfaces and RRI percentage. The correlation coefficient for %Impervious

Density and RRI is approximately -0.860. This indicates that areas with higher impervious surfaces have reduced capacity to retain rainwater, leading to increased runoff and potential flooding issues.

On the other hand, a strong positive correlation is observed between the density of tree cover and the RRI. The correlation coefficient for %Tree Cover Density and RRI is approximately 0.924. This suggests that areas with a higher density of trees and vegetation possess a greater capacity to retain rainwater, contributing to effective stormwater management and reducing the risk of flooding.

Since coastal flood risk is related to locations of the settlements, HMI and RRI were correlated to achieve planning decisions. Examining the HMI/RRI provides further insights into the relationship between heat mitigation strategies and runoff retention. This combined index aims to assess the overall effectiveness of mitigating heat-related issues and managing runoff in a given area.

Upon analyzing the results, several notable trends can be observed. Notably, the values range between -0.869 and 0.907, indicating a diverse range of effectiveness in addressing heat and runoff concerns. It is important to focus on the values that fall within the reasonable range of -0.4 to -1 and 0.4 to 1, as they represent the most significant impacts. Starting with the positive values, the highest recorded value is 0.907, corresponding to the Tree Cover Density. This indicates a substantial positive impact, suggesting that areas with a higher density of trees are more successful in mitigating heat and managing runoff. Such regions are likely to experience improved cooling effects and enhanced water retention due to abundant vegetation cover. Following closely behind is the Green Areas percentage with a value of 0.731. Similar to the Tree Cover Density, this result suggests that including significant green spaces contributes positively to heat mitigation and runoff management efforts. These areas are likely to provide natural cooling and stormwater absorption capabilities, benefiting the overall resilience of the region.

On the other end of the spectrum, the most negative value is -0.869, representing the Impervious Density. A high impervious density implies a significant proportion of impermeable surfaces such as roads, buildings, and pavements. The negative value indicates that regions with extensive impervious cover struggle in terms of heat mitigation and runoff retention. Such areas might experience increased heat island effects and heightened runoff, leading to potential flooding risks and reduced resilience.

The CFRMI analysis indicates varying effectiveness levels in mitigating coastal flood risks. The index range falls within reasonable values, with the correlation coefficient for average elevation and CFRMI being 0.642. This positive correlation suggests that higher elevations provide natural protection against flooding, reducing overall risk.

In terms of the MRMI, the analysis reveals several correlations between the index and different factors. A positive correlation of 0.481 is identified between the MRMI and average elevation. This suggests that higher elevations are associated with improved capabilities in mitigating multiple risks. A negative correlation of -0.509 is also found between the MRMI and impervious density. This indicates that areas with lower coverage of impervious surfaces exhibit enhanced multi-risk mitigation capabilities. Furthermore, a positive correlation of 0.377 is identified between the MRMI and tree cover density. This suggests that areas with a higher density of tree cover demonstrate improved multi-risk mitigation capacities.

In conclusion, the analysis of the various indices highlights the importance of incorporating green spaces, reducing impervious surfaces, preserving and expanding tree cover, and considering elevation in urban planning and development. These factors play crucial roles in enhancing heat mitigation, runoff retention, coastal flood risk mitigation, and multi-risk mitigation, ultimately contributing to creating sustainable and resilient cities. Policymakers and urban planners can leverage these insights, such as the correlation coefficients greater than approximately +- 0.4, to inform decision-making processes and develop strategies that promote the well-being and resilience of urban environments.

Table 15 is an illustration of the association that may be drawn between the tiles which have the most and the least ecosystem delivery capacity and risk reduction measures. The indicators that come out as positively correlated with MRMI are colored blue, while the values that come out as negatively correlated are colored orange. Additionally, Strong correlation is shown. Accordingly, higher ecosystem delivery capacity is represented with darker blue whereas lighter orange represents lack thereof.

Samples demonstrating predominantly positive correlations with the MRMI, accompanied by a minority of indicators indicating negative correlations, are indicative of heightened ecosystem delivery capacities within the geographical areas represented by tiles 3.2 and 4.1. In contrast, tiles 2.1 and 4.2 are associated with samples displaying the lowest ecosystem delivery capacities, positioned in the converse direction.

Table 15. Tiles which have the largest and the smallest ES capacities

Tiles	2.1	3.2	4.1	4.2
Avg. Elevation (m)	9.92	13.95	136.67	6.71
Avg. Slope (%)	3.31	2.73	4.24	1.65
Number of Buildings	769	310	67	24
Avg. Building Height	7	6	4	8
Avg. Building Footprint (m)	146.56	264.80	641.06	636.62
Built-up Volume (%)	0.63	0.39	0.14	0.10
Road (%)	18.26	15.07	16.54	8.95
Residential (%)	30.50	30.52	72.80	22.82
Industrial and/ or Commercial (%)	47.25	12.68	8.62	63.53
Green Areas (%)	0.13	3.82	3.13	0.00
Impervious Density (%)	93.68	76.00	55.49	84.69
Tree Cover Density (%)	0.71	4.11	8.72	1.78
Grassland Density (%)	0.00	0.00	0.00	0.00
Weighted Avg. HMI	**0.08**	**0.13**	**0.17**	**0.18**
Weighted Avg. RRI	**0.15**	**0.36**	**0.59**	**0.22**
Weighted Avg. CFRMI	**0.20**	**1.00**	**1.00**	**0.04**
Weighted Avg. MRMI	**0.44**	**1.50**	**1.76**	**0.43**

CHAPTER 5

DISCUSSION

The impact of current urbanization on calculated risk reduction will be examined in this chapter. Based on the findings identified during the analysis, planning standards are presented regarding the implementability of NBS in a performative manner.

5.1. An Approach to Adaptive Design

To effectively address the challenges posed by CC, urban areas must undergo a resilience transformation. This necessitates the integration of ES, NBS, and PBP. To optimize resource allocation and enhance the performance of the solutions, it is crucial to focus interventions on regions that are most vulnerable.

Contemporary and Liberalisation urban areas pose distinctive challenges and opportunities for a resilience transformation. Given their young buildings, making a radical transformation is economically infeasible. Nonetheless, improving the urban climate resilience of these areas is possible through the revitalization of underutilized spaces and their integration into the green-blue system. Policy measures, such as air corridor assessments, green space expansion, and increased urban tree coverage, can support the resilience of high-rise building zones. Revitalizing underutilized spaces and incorporating them into the green-blue system through measures such as assessing air corridors, expanding green spaces, and increasing urban tree coverage contribute to the resilience of high-rise building zones.

Urban areas dating back to the Ottoman period include urban conservation areas like Kemeraltı Bazaar and areas with haphazard urbanization around Kadifekale. When intervening in delicate areas like Kemeraltı Bazaar, it is essential to conduct a rigorous expert examination. Radical urban transformations may also be unsuitable for Kemeraltı Bazaar. However, the neighborhoods located north and south of Kadifekale are considered suitable for urban transformation or the assessment of urban ecosystems. These regions, characterized by low-rise buildings and a dense urban fabric, offer the potential for interventions that preserve the neighborhoods' core characteristics while promoting open spaces and green systems.

The Republican urban areas in İzmir represent a unique opportunity for integrating ES into urban systems. Unlike sensitive urban conservation areas like Kemeraltı, which require careful preservation, or modern constructions built after 2000 that incorporate sustainability measures, the structures in these areas lack the same qualities and ecosystem delivery capacity. However, this presents a potential for transformation and improvement.

In order to effectively address the challenges posed by climate change and enhance adaptation strategies, a hierarchical shift must be initiated, transitioning from the city scale to the building scale. This paradigmatic change requires a holistic approach that encompasses urban planning, design, and construction practices at various levels. At the city scale, comprehensive strategies need to be formulated to mitigate the impacts of climate change, such as implementing resilient infrastructure, adopting sustainable land-use policies, and promoting alternative transportation systems. Furthermore, at the neighborhood and building scales, innovative architectural and engineering solutions should be employed to improve energy efficiency, enhance insulation, and integrate renewable energy sources. By orchestrating this multi-faceted transformation from macro to micro levels, cities can develop a robust framework that fosters climate resilience, reduces carbon emissions, and facilitates adaptive measures, ultimately leading to sustainable and livable urban environments.

The traditional planning approach, which places greater emphasis on grey elements such as roads and buildings, while organizing infrastructure components like utilities and public facilities to establish functional and habitable communities, frequently lags in addressing challenges related to urban cooling, runoff reduction, and coastal flood mitigation. To create exemplary urban areas guided by contemporary planning approaches (Figure 32), it is essential to adopt a systematic and scientifically grounded planning methodology when dealing with these regions. This approach should involve comprehensive assessments of the existing urban fabric, identifying areas of improvement and potential interventions that can enhance ES and overall resilience.

Figure 32. Illustration of climate adaptive city planning approach
(Adapted from Ballard[219])

The provided visualization, as illustrated in Figure 32, underscores the critical importance of incorporating natural elements, including flow accumulation, topography, soil composition, natural vegetation, and the analysis of blue and green infrastructure systems within the existing urban fabric, as fundamental considerations when devising new settlement designs. Neglecting to grasp the intrinsic attributes of the given landscape prior to implementing impermeable and rigid urban elements, such as road networks and edifices, culminates in an inherent clash between human habitation and the surrounding natural milieu, thereby exacerbating the challenges associated with urban resilience in the face of climate change[219].

Nevertheless, by according precedence to the integration of ES and the judicious configuration of open and green spaces attuned to the presence of water resources and their hydrological dynamics, it becomes plausible to foster the development of urban living environments that synergistically coexist with their natural surroundings. Effectuating such harmonious cohabitation necessitates a deliberate endeavor to formulate a comprehensive framework that holistically encompasses the provision of ES and their seamless integration within the spatial design and planning of urban landscapes. By embracing this approach, the prospect of cultivating urban areas that embrace ecological sustainability and facilitate a harmonious equilibrium between urban dwellers and the encompassing natural ecosystems can be envisaged.

One of the key factors that stand out in terms of urban cooling, flood control and the urban-nature relationship in cities is the decision-making process regarding the location of open and green spaces (Figure 33). The distribution and configuration of green spaces in cities have a direct impact on surface runoff reduction[220]. Similarly, these green spaces can significantly contribute to mitigating urban heat island effects.

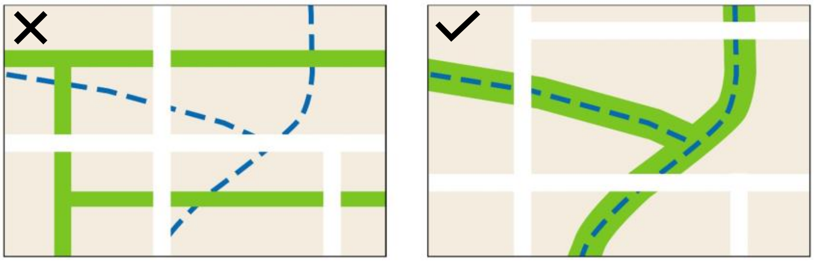

Figure 33. Illustration of green and open space design
(Green: open and green space system, blue: flow accumulation).

It is important to consider the topography and spatial distribution of green spaces for effective urban heat mitigation. Green infrastructure elements strategically placed along the flow direction and near coastal areas (estuaries) not only help impede surface runoff but also assist in reducing urban heat island effects. These elements are more effective than those situated closer to the water source (headwaters) and at higher elevations. Therefore, a well-planned network of green spaces, including both small-scale dispersed areas and larger clusters, can enhance both flood control and urban heat mitigation efforts.

In the context of urban flood management, the consideration of flow accumulation holds considerable importance. Nonetheless, a study conducted by Arslan and Salata[221] highlights that while flow accumulation indeed carries significance, the hydrological permeability of soil types exerts a substantially greater influence. When assessing the placement of urban green spaces in terms of flood control, it is well-established that soil permeability surpasses both topography and the quality of green areas in terms of its impact. The strategic clustering of green areas on soil groups characterized by high hydrological permeability enhances cities' infiltration capacity and mitigates flood risks. Hence, it can be inferred that the most effective approach to prevent urban floods lies in the implementation of planning strategies that harmonize with the natural soil composition, thus aligning with ES. By deliberately clustering green areas on soil types distinguished by high hydrological conductivity and, conversely, avoiding such pairings, an intricate design scheme can be established to develop the most resilient urban districts against flooding events.

Moreover, it is vital to consider building arrangements and adhere to city planning standards to create sustainable and resilient urban areas. The integration of these elements is crucial for ensuring efficient land use, optimized infrastructure networks, and the preservation of natural resources. Building arrangement plays a significant role in determining the overall functionality and aesthetics of a city, as well as its environmental impact.

As mentioned before, the presence of trees and green spaces, the degree of imperviousness, and the extent of built-up areas are fundamental urban planning parameters that necessitate careful consideration when addressing runoff management, particularly with regard to UHM strategies. These parameters play a crucial role in shaping sustainable and resilient urban environments. In the context of designated transformation zones, such as the Republican Period areas, these parameters assume even greater significance as they become central to the focus of urban design and planning efforts.

The research conducted by Cheng et al[222], has shed light on the benefits of integrating high-rise buildings within urban areas while maintaining a stable population density (Figure 34). Such architectural interventions provide opportunities for the inclusion of climate-resistant elements, such as green spaces and tree planting, thereby enabling the allocation of space on the ground for their implementation. The introduction of high-rise structures not only facilitates increased vertical development but also allows for the preservation and enhancement of natural elements, which are pivotal for mitigating the adverse effects of climate change in urban environments.

The preference lies with arrangements characterized by higher buildings, less site coverage, and more open space compared to those with lower buildings and higher site coverage. Such arrangements are considered preferable. Higher buildings provide opportunities for increased solar facade installation, vertical gardens, green facades. Furthermore, reduced site coverage enables the preservation of open spaces, facilitating natural ventilation and providing recreational areas for residents.

Randomness in the horizontal layout is strongly advocated. Traditional urban planning has favored uniform arrays of building blocks. However, arranging building blocks in scattered layouts is more desirable when the same amount of usable floor area is considered. Several advantages arise from scattered layouts, such as increased exposure to sunlight, minimized shading effects, and enhanced aesthetic appeal.

Figure 34. Building arrangements for climate adaptive cities
(Adapted from Cheng et al[222])

Furthermore, the utilization of appropriate NBS is of utmost importance in addressing the diverse range of hazards encountered by urban areas, with a particular emphasis on climate change adaptation. NBS assume a pivotal role in this regard. The research conducted by Biasin et al[223] emphasizes the identification of numerous beneficial NBS and their relevance to various associated circumstances. The NBS were categorized into distinct classes in order to facilitate analysis and facilitate comparisons. One such class is green roofs, which encompasses both intense and extensive green roofs. The assessment took into consideration various potential benefits associated with the two climate hazards under investigation (Table 16). Each NBS was assigned a numerical value ranging from 0 which indicating no discernible effect to 3 which indicating a significant impact[223].

Maximizing the performance of a given area necessitates the strategic employment of diverse NBS tailored to address specific problems. To this end, the development of an open and green space system that is intricately aligned with the urban and natural attributes of the area can significantly enhance the derived benefits from ES. An effective approach to achieving this outcome involves adopting the PBP methodology. An integral aspect of implementing NBS involves the identification and selection of suitable solutions that are appropriate for the different urban morphological periods exhibited by an area. Recognizing that each urban environment possesses distinct characteristics, it becomes evident that the resolution of various issues demands the adoption of tailored and site-specific planning and design decisions. Consequently, a comprehensive understanding of the local context is essential for devising effective strategies and choosing appropriate NBS.

Table 16. The assessment of performance in the context of NBS
(From Biasin et al[223])

Nature-Based Solutions	Runoff Retention	Heat Island Reduction	Environmental Co-Benefits	Total Score
Forested green areas	1.9	3	2.3	7.2
Rain gardens	1.6	1.5	1.7	4.8
Urban gardens	1.2	2	1.6	4.8
Green roofs	1	1.5	1	3.5
Green facades	0.1	1	0.7	1.8
Roadside trees and green paths	1.6	3	2.2	6.8
Green rails	1	2	1	4
Green urban furniture	1	2	1	4
Permeable surfaces	0.7	0	0.7	1.4
Rainwater harvesting	0.1	0	0.5	0.6
Infiltration basins	1.6	1.5	2	5.1
Infiltration trenches	1	0	1.2	2.2
Retention ponds	1.6	1.5	2.1	5.2
Restoration of rivers for the control of infiltrations	1.2	0	1.6	2.8
Creation of floodplains and riparian forests	2.8	2	3	7.8

Table 17 provides a comprehensive compilation of NBS options that are well-suited to address diverse urban morphological periods. This approach not only ensures optimal performance but also acknowledges the intricate interplay between urban and natural elements, enabling the harmonious integration of NBS into the urban fabric. The Ottoman era is characterized by a delicate and densely populated urban fabric, resulting in the need to prioritize areas focused on protection. In contrast, the Republican period offers more favorable conditions for urban transformation due to various factors. The existing buildings in the Ottoman areas may not possess modern architectural features, and the capacity of the ecosystem to support sustainable development is currently at its lowest. Consequently, interventions aimed at revitalizing these areas can be executed by utilizing the available leftover urban areas without resorting to extensive urban transformation efforts during the periods of Liberalization and Contemporary. For NBS definitions, please see appendix B.

Table 17. Relation of nature-based solutions to morphological periods

NBS	Application Scale		Related Issue			Morphological Period			
			UHI	**Pluvial Flood**	**Coastal Flood**	**Otm.** (Before 1923)	**Rep.** (1923-1950)	**Lib.** (1980-2000)	**Con.** (2000-Present)
Cool corridors	City		■				■		
Cycle and Pedestrian Green Route	City		■	■	■		■	■	■
Detention basins	City		■	■			■		
Flood warning systems	City			■	■	■	■	■	■
Floodplain restoration	City		■	■	■	■	■	■	■
Green infrastructure networks	City		■	■	■		■		■
Heat-aware landscaping	City		■			■	■	■	■
Living shorelines	City				■		■		■
Mangrove reforestation	City		■		■		■		
Natural ventilation	City		■	■			■	■	■
Urban Carbon Sink	City		■	■			■		■
Water features	City		■			■	■	■	■
Bioretention systems	District	Ground	■	■			■		■
Channel naturalization	District	Ground		■		■	■	■	■
Coastal wetland restoration	District	Ground			■	■	■	■	■
Cool microclimates	District	Ground Facade Roof	■	■			■		■
Green Filter Areas	District	Ground	■	■			■		■
Green Resting Areas	District	Ground	■	■		■	■	■	■
Parklet	District	Ground	■	■		■	■	■	■
Rain gardens	District	Ground	■	■			■		■
Tree-lined streets	District	Ground	■	■			■	■	■
Trees Renaturing Parking	District	Ground	■	■		■	■	■	■
Urban forestry	District	Ground	■	■			■		
Cool pavements	Local	Ground	■			■	■	■	■
Cool roofs	Local	Roof	■				■	■	■
Dune restoration	Local	Ground			■	■	■	■	■

Table 17 (continued).

NBS	Application Scale		Related Issue			Morphological Period			
			UHI	**Pluvial Flood**	**Coastal Flood**	**Otm.** (Before 1923)	**Rep.** (1923-1950)	**Lib.** (1980-2000)	**Con.** (2000-Present)
Energy efficient buildings	Local	Ground Facade Roof							
Green dams and levees	Local	Ground							
Green Noise Barriers	Local	Ground Facade							
Green roofs	Local	Roof							
Heat-resistant materials	Local	Ground Facade Roof							
Living walls	Local	Facade							
Permeable pavements	Local	Ground							
Pollinator Roofs	Local	Roof							
Pollinator Walls	Local	Facade							
Rainwater harvesting	Local	Ground Facade Roof							
Retention ponds	Local	Ground							
Solar shading	Local	Facade							
Tide gates and flood barriers	Local	Ground							
Urban agriculture	Local	Roof							

By following the systematic approach, specifically designed to implement NBS within the urban planning system, the city of İzmir can effectively integrate the ecosystem-based approach into its urban planning practice. This integration holds the potential to significantly enhance the city's capacity for climate change adaptation. By strategically incorporating NBS principles, such as green infrastructure, natural water management, and biodiversity conservation, İzmir can create resilient and sustainable urban environments that mitigate the impacts of climate change while promoting ecological balance and enhancing the overall well-being of its residents.

5.2. Climate Change Adaptation Planning Parameters

Following the establishment of the correlation, additional analyses were undertaken involving various indicators, namely Tree Cover Density, Imperviousness Density, Green Areas, Built-up Footprint, Number of Buildings, and Road characteristics. These indicators were selected based on their significant correlation with risk mitigation. It is noteworthy that the Built-up Footprint and Number of Buildings indicators do not exhibit proportional data. In order to address this issue, calculations involving the Footprint Ratio (FR) and Floor Space Index (FSI) were carried out.

To elaborate, the study employed an urban sample area measuring 250,000 square meters as a standardized parcel for analysis. This parcel-based approach facilitated the necessary calculations, which were subsequently expressed as percentages. The calculation of the FR involved employing Equation 17, while Equation 18 was utilized for the computation of the FSI These calculations served to provide a comprehensive understanding of the spatial distribution and characteristics of the urban landscape, contributing to the assessment of risk reduction strategies.

$$FR = \frac{Floor\ area\ of\ the\ buildings}{Plot\ area} \times 100 \tag{17}$$

$$FSI = \frac{Total\ floor\ area\ of\ all\ floors\ of\ the\ buildings}{Plot\ area} \times 100 \tag{18}$$

An analysis has been conducted on the measurement values of various indicators pertaining to climate change in the province of İzmir, with the aim of establishing parameters for effective climate change adaptation planning. This process involved considering the measurements obtained from samples (Table 13) and correlation results (Table 14). Consequently, a set of parameters has been generated, encompassing five distinct categories from vulnerable to resilient (Table 18). Measurements are divided into five assessment groups from high to low: vulnerable, moderately vulnerable, neutral, moderately resilient, and resilient. Correlation results are used to determine whether indicators have a positive or negative effect on risk reduction and to determine their impact levels.

Table 18. Parameters for climate change adaptation planning in İzmir

Impact Indicators	Impact Level	Vulnerable	Moderately Vulnerable	Neutral	Moderately Resilient	Resilient	Balanced
Tree Cover Density	6	0-1%	1-2%	2-5%	5-10%	+10%	10%
Imperviousness Density	5	+90%	80-90%	60-80%	35-60%	0-35%	50%
Green Areas	4	0-1%	1-3%	3-5%	5-10%	+10%	3%
Footprint Ratio (%)	3	0-0.2%	0.2-0.5%	0.5-0.15%	0.15-0.25%	+0.25%	0.25%
Road	2	+20%	15-20%	10-15%	5-10%	0-5%	16%
Floor Space Index	1	0-0.2%	0.2-0.6%	0.6-1.5%	1.5-%3%	+3%	1%

The impact level of 6 assigned to the Tree Cover Density indicator signifies its substantial role in evaluating vulnerability and resilience. Higher percentages of tree cover density, particularly above 10%, indicate a more resilient environment with abundant vegetation and greenery. In contrast, lower percentages, such as 0-1% or 1-2%, suggest vulnerability due to limited tree cover.

With an impact level of 5, the Imperviousness Density indicator reveals the extent of surfaces that impede water infiltration, such as pavement and buildings. High percentages, above 90% or 80-90%, indicate high vulnerability to environmental impacts, as the lack of permeable surfaces can lead to issues like urban heat islands and stormwater runoff. Conversely, lower percentages below 35% reflect more resilient areas with greater permeability.

Assigned an impact level of 4, the Green Areas indicator assesses the availability of green spaces within the area. Higher percentages, such as 5-10% or above 10%, indicate a greater presence of parks, gardens, and natural areas, contributing to environmental resilience and overall quality of life. Conversely, lower percentages, like 0-1% or 1-3%, suggest limited green spaces and potential vulnerability.

The impact level of 3 underscores the significance of the FR indicator in evaluating vulnerability and resilience. A lower footprint ratio percentage, such as 0-0.2% or 0.2-0.5%, signifies a smaller built-up area relative to the total land area, indicating a more vulnerable environment. Conversely, higher percentages above 0.25% indicate larger footprints and potential resilience.

With an impact level of 2, the presence of roads is considered a moderately influential indicator. Higher percentages, like 20% or above, suggest a greater extent of road infrastructure, which may contribute to vulnerability due to factors such as traffic congestion and air pollution. On the other hand, lower percentages below 5% indicate areas with fewer roads and potentially greater resilience.

The FSI indicator holds the lowest impact level of 1, implying a relatively lower influence on vulnerability and resilience assessments. Higher percentages, such as 3% or above, indicate a more built-up area relative to the available land, potentially leading to increased resilient areas. Conversely, lower percentages, like 0-0.2% or 0.2-0.6%, suggest a less dense built environment and potential vulnerability.

In the pursuit of creating a climate-resilient city in İzmir, it is essential to prioritize certain parameters that contribute to the overall environmental and urban resilience. To create balanced urban catchement in terms of green, gray distribution, it is essential to define correct parameters. These parameters were derieved from the tile which has the most ES delivery capacity (tile 4.1). The establishment of a climate-resilient city in İzmir necessitates adherence to specific criteria, namely a FR of 0.25% and a FSI of 1%. The study reveals a Tree Cover Density of 10%, an Imperviousness Density of 50%, Green Areas comprising 3%, a Road Coverage Ratio of 16%, and a FR of 50%. These specific indicators play a crucial role in facilitating sustainable urban development in İzmir and enhancing the city's resilience to the impacts of climate change, both of which are key objectives for the municipality.

CHAPTER 6

CONCLUSION

The present study has utilized PBP as a conceptual framework to tackle the obstacles associated with CC adaptation in the region of İzmir. The study aimed to evaluate the susceptibility of urban ecosystems to the effects of CC, with a specific focus on UHI, pluvial floods, and coastal floods. This was achieved by employing principles of planning by PBP during the analysis of various areas and risks, as well as planning recommendations. The research inquiries focused on examining the correlation between land use and urbanization standards and climate-related occurrences, assessing their impact on ecosystem susceptibility, and exploring the incorporation of ecosystem-based strategies into urban planning and design as a means to bolster CC adaptation.

The study shows that İzmir's urban ecosystems are vulnerable to CC impacts like UHI effects, urban pluvial floods, and coastal floods. The PBP approach helps identify vulnerable areas in the city and guides policymakers and stakeholders in developing tailored adaptation strategies. The study provides important findings and suggestions for adapting to CC, particularly focusing on ES in İzmir. The methodology highlights the importance of urban configurations with taller structures, reduced land usage, and more open areas, supporting the implementation of solar panels, vertical gardens, and green facades. Decreased site coverage preserves open spaces, promotes natural airflow, and provides recreational areas. The thesis emphasizes the role of NBS in addressing CC challenges and urban hazards.

In conclusion, the PBP framework aids in examining different domains and potential hazards, highlighting the strategic integration of customized NBS for specific climate challenges. Through the utilization of a performance-based methodology, the examination of various indicators has facilitated the development of distinct parameters for evaluating vulnerability and resilience. The aforementioned parameters, which have been arranged in order of their influence, furnish decision-makers with a structured approach to determining the importance of actions and investments in the realm of CC adaptation planning.

6.1. Limitations

This study is subject to certain limitations, which may impact the comprehensive assessment of ecosystem services in both rural and urban areas.

A primary constraint is the data insufficiency, particularly LULC coverage, resulting in the study area being confined to ten specific districts. To achieve a more robust and detailed analysis of ecosystem services in natural lands and urban regions, it is recommended to encompass the entire province of Izmir within the study boundaries. By doing so, a more comprehensive understanding of the interplay between natural and urban environments can be achieved.

Furthermore, an important aspect that affects the accuracy of urban cooling capacity evaluations is the presence of water elements within the urban landscape. Cities, such as Izmir, which are situated near coastal regions, benefit from the cooling effects provided by the sea. Although the Urban Cooling Model utilized in this study does not directly incorporate water surfaces as input data, it is crucial to address this limitation. This can be accomplished by integrating water surfaces and their cooling capacities as specific LULC classes within the model.

To visualize the impact of incorporating the presence of the sea on urban cooling capacity, Figure 35 demonstrates that the coastal strip experiences a partial positive change. This underscores the significance of accounting for water elements in the cooling capacity calculation, particularly in coastal cities like İzmir.

Table 19 illustrates the impact of large water bodies, such as seas, on the HMI with an increase of up to 0.001. However, it is crucial to note that, based on the applied method, the presence of the sea does not exhibit a statistically significant effect on urban heat reduction. It is essential to highlight that in this particular analysis, the ventilation parameter was not considered; only the presence of water was taken into account. To enhance the model's effectiveness, future investigations should incorporate air movement patterns into the analysis.

In a similar vein, the InVEST Urban Flood Risk Mitigation model overlooks the slope factor. To gain insights into the influence of slope on urban floods, a more comprehensive approach is required, considering not only the slope parameter but also the analysis of areas where water accumulates based on slope characteristics. This can be accomplished by generating a flow accumulation map utilizing ArcGIS analysis tools. The resultant map can be synthesized with the Flood Volume (Q_mm), an output of the model, to create an urban flood vulnerability map.

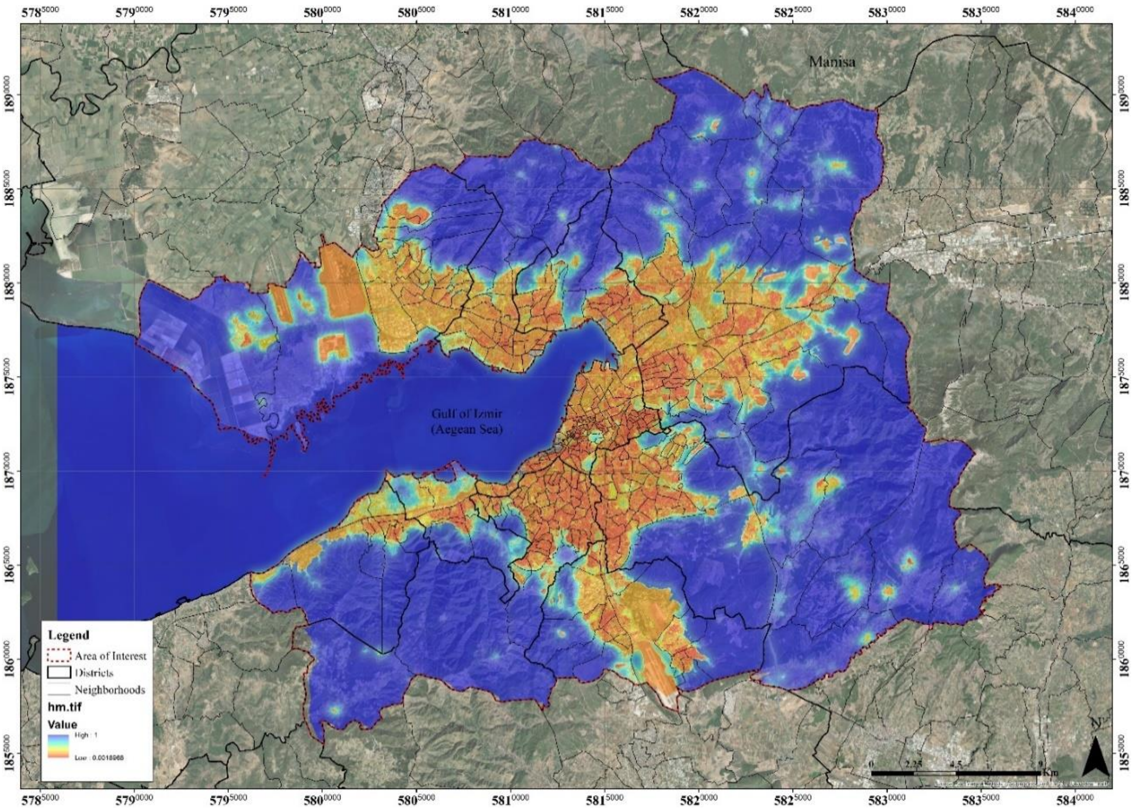

Figure 35. Heat mitigation index (sea included)

Table 19. Limitations of the models

Analyzes	Parameters	Mean (AOI)
HMI	Sea not Included	0.735
	Sea Included	0.736
Flood Volume (mm)	Flow Accumulation not Included	0.190
	Flow Accumulation Included	0.377

When evaluating this vulnerability map within the context of the AOI boundaries, the impact of flow accumulation on flood vulnerability becomes evident. Specifically, Table 19 demonstrates that the average flood volume increases from 0.190 to 0.377, indicating the significance of Flow Accumulation as a crucial data parameter in assessing urban flood vulnerability.

6.2. Future Studies

This study has provided valuable insights into the assessment of ecosystem services in both forested and urban areas of İzmir. However, there are several opportunities for future research that can further enhance the understanding of climate change adaptation and its implications for urban ecosystems.

One important direction for future research is to expand the geographical coverage of the study. Currently limited to specific districts within İzmir, future investigations should encompass the entire province, including diverse climate regions and urban landscapes. This broader approach will facilitate the identification of region-specific vulnerabilities and adaptation strategies, providing a more comprehensive understanding of the interplay between natural and urban environments.

Building upon the current study's reliance on existing climate data, future research should incorporate different climate change scenarios. By considering various climate projections for different future periods, researchers can assess the long-term effects of climate change on urban ecosystems. Understanding the variations in vulnerability and resilience over time will aid in the formulation of adaptive planning strategies with longer-term sustainability objectives.

Incorporating the role of human behavior in climate change adaptation is essential for effective urban planning. Future studies should explore the impact of public awareness, environment-friendly behavior, and community engagement on the success of adaptation strategies. Understanding the social dimensions of climate change adaptation can lead to more inclusive and community-oriented planning approaches.

Climate change can have significant implications for public health. Future studies should investigate the potential health effects of climate change in urban areas, including heat-related illnesses, vector-borne diseases, and respiratory issues. Understanding these health impacts will help prioritize and design adaptive strategies that safeguard the well-being of urban residents.

In conclusion, this study has laid a strong foundation for further research in the field of climate change adaptation and urban planning. By addressing the above-mentioned areas, future studies can contribute to more resilient and sustainable cities, fostering climate-resilient ecosystems and enhancing the quality of life for urban residents.

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APPENDIX A

Table 20. Output data of models by neighborhoods

District	Neighborhood	HMI	Avg. CC	Avg Temp. (ºC)	Avg. Temp. Anomaly (ºC)	RRI	Runoff Retention (m³)	Flood Volume (mm)	CFRMI	MRMI
Balçova	Bahçelerarası	0.42	0.28	33.06	3.06	0.64	153,466.89	86,367.13	0.82	1.31
Balçova	Çetin Emeç	0.81	0.51	31.34	1.34	0.65	311,455.76	168,688.27	5.00	2.46
Balçova	Eğitim	0.25	0.21	33.20	3.20	0.37	16,604.12	28,839.88	5.00	1.60
Balçova	Fevzi Çakmak	0.17	0.16	32.69	2.69	0.36	9,845.48	17,419.52	5.00	1.52
Balçova	İnciraltı	0.48	0.30	32.70	2.70	0.74	184,610.61	63,819.40	1.40	1.90
Balçova	Korutürk	0.29	0.26	32.67	2.67	0.50	42,224.72	41,726.28	5.00	1.78
Balçova	Onur	0.10	0.10	33.21	3.21	0.22	6,910.09	24,967.91	5.00	1.29
Balçova	Teleferik	0.86	0.64	31.11	1.11	0.73	204,520.67	74,765.35	5.00	2.59
Bayraklı	75. Yıl	0.34	0.21	32.53	2.53	0.40	4,165.27	6,145.73	5.00	1.73
Bayraklı	Adalet	0.18	0.18	34.08	4.08	0.32	43,038.78	90,353.24	0.55	0.54
Bayraklı	Alpaslan	0.08	0.08	33.43	3.43	0.13	3,067.44	20,214.56	5.00	1.20
Bayraklı	Bayraklı	0.19	0.14	33.92	3.92	0.32	7,981.95	17,001.05	0.55	0.70
Bayraklı	Cengizhan	0.38	0.28	32.77	2.77	0.40	27,419.90	41,327.11	5.00	1.77
Bayraklı	Çay	0.09	0.09	33.99	3.99	0.11	1,956.35	16,397.65	1.16	1.17
Bayraklı	Çiçek	0.12	0.11	33.90	3.90	0.14	3,889.69	23,900.31	0.66	1.24
Bayraklı	Doğançay	0.90	0.48	30.58	0.58	0.61	332,193.55	215,808.45	5.00	2.51
Bayraklı	Emek	0.17	0.17	34.01	4.01	0.32	16,978.36	35,927.64	1.02	1.47
Bayraklı	Fuat Edip Baksı	0.18	0.17	33.27	3.27	0.32	12,459.57	26,866.44	0.71	1.22
Bayraklı	Gümüşpala	0.15	0.11	33.63	3.63	0.19	9,948.30	43,671.71	0.85	1.26
Bayraklı	Körfez	0.71	0.45	32.01	2.01	0.61	109,157.04	71,092.97	5.00	2.30
Bayraklı	Manavkuyu	0.19	0.19	34.02	4.02	0.58	52,328.25	38,251.75	0.94	1.61
Bayraklı	Mansuroğlu	0.18	0.18	34.08	4.08	0.44	41,014.70	52,953.30	0.79	1.13
Bayraklı	Muhittin Erener	0.06	0.06	33.71	3.71	0.11	2,401.27	18,542.73	5.00	1.16
Bayraklı	Onur	0.20	0.17	32.76	2.76	0.27	17,535.26	47,564.75	5.00	1.45
Bayraklı	Org. Nafiz Gürman	0.35	0.27	32.82	2.82	0.39	38,820.30	60,544.71	5.00	1.73
Bayraklı	Osmangazi	0.19	0.17	33.89	3.89	0.40	40,728.25	60,701.76	1.11	1.52
Bayraklı	Postacılar	0.16	0.16	33.52	3.52	0.33	16,817.48	33,841.53	5.00	1.48
Bayraklı	R.Şevket İnce	0.73	0.42	31.62	1.62	0.61	210,037.85	134,551.12	5.00	2.33
Bayraklı	Soğukkuyu	0.24	0.23	33.96	3.96	0.61	33,152.84	21,139.16	5.00	1.84
Bayraklı	Tepekule	0.15	0.14	34.05	4.05	0.32	13,374.75	28,247.25	0.78	0.87
Bayraklı	Turan	0.71	0.47	32.44	2.44	0.62	92,916.26	57,275.75	0.77	2.09
Bayraklı	Yamanlar	0.25	0.20	32.82	2.82	0.35	32,754.31	60,758.70	5.00	1.59
Bornova	Atatürk	0.21	0.19	33.60	3.60	0.28	51,363.04	133,807.97	5.00	1.48
Bornova	Barbaros	0.12	0.12	34.28	4.28	0.30	9,961.40	23,246.60	1.05	0.95
Bornova	Beşyol	0.92	0.54	30.30	0.30	0.77	226,818.66	66,243.35	5.00	2.69

Table 20 (continued).

District	Neighborhood	HMI	Avg. CC	Avg Temp. (ºC)	Avg. Temp. Anomaly (ºC)	RRI	Runoff Retention (m^3)	Flood Volume (mm)	CFRMI	MRMI
Bornova	Birlik	0.12	0.11	33.92	3.92	0.25	5,790.11	17,799.90	5.00	1.34
Bornova	Çamiçi	0.97	0.59	30.17	0.17	0.63	347,972.81	205,055.19	5.00	2.60
Bornova	Çamkule	0.79	0.45	31.67	1.67	0.65	201,999.69	108,310.32	5.00	2.44
Bornova	Çınar	0.12	0.12	34.24	4.24	0.20	3,335.14	13,128.86	0.84	0.46
Bornova	Çiçekli	0.95	0.68	30.31	0.31	0.85	391,543.68	70,666.34	5.00	2.79
Bornova	Doğanlar	0.14	0.14	33.98	3.98	0.29	54,988.75	132,443.27	5.00	1.42
Bornova	Egemenlik	0.42	0.31	32.48	2.48	0.45	163,140.26	199,858.78	5.00	1.86
Bornova	Eğridere	0.90	0.48	30.68	0.68	0.60	459,750.33	310,963.67	5.00	2.50
Bornova	Ergene	0.22	0.19	33.61	3.61	0.35	12,460.35	23,092.66	5.00	1.55
Bornova	Erzene	0.62	0.38	32.12	2.12	0.77	673,532.52	203,119.51	5.00	2.38
Bornova	Evka 3	0.46	0.33	32.49	2.49	0.61	172,159.19	111,081.83	5.00	2.06
Bornova	Evka 4	0.33	0.27	32.12	2.12	0.43	24,505.38	32,229.62	5.00	1.75
Bornova	Gazi Osman Paşa	0.09	0.09	34.24	4.24	0.21	8,420.63	31,773.38	1.10	0.94
Bornova	Gökdere	0.89	0.57	30.68	0.68	0.74	352,470.37	121,030.66	5.00	2.63
Bornova	Gürpınar	0.83	0.62	31.06	1.06	0.78	827,285.58	232,598.48	5.00	2.61
Bornova	Işıklar	0.40	0.30	32.91	2.91	0.49	121,794.01	127,035.01	5.00	1.88
Bornova	İnönü	0.15	0.15	33.20	3.20	0.25	30,097.49	89,462.52	5.00	1.39
Bornova	Karacaoğlan	0.21	0.20	33.98	3.98	0.41	71,247.93	102,835.09	5.00	1.60
Bornova	Karaçam	0.93	0.58	30.30	0.30	0.70	534,135.24	228,234.80	5.00	2.63
Bornova	Kavaklıdere	0.87	0.64	30.67	0.67	0.76	616,252.08	190,609.95	5.00	2.63
Bornova	Kayadibi	0.98	0.56	30.19	0.19	0.66	597,821.34	308,902.67	5.00	2.64
Bornova	Kazımdirik	0.19	0.19	34.00	4.00	0.44	160,495.12	201,390.92	0.94	1.44
Bornova	Kemalpaşa	0.66	0.52	31.69	1.69	0.65	756,416.44	404,085.69	5.00	2.30
Bornova	Kızılay	0.32	0.27	33.50	3.50	0.42	46,132.11	62,528.90	5.00	1.74
Bornova	Koşukavak	0.08	0.08	34.05	4.05	0.15	3,365.54	19,482.46	5.00	1.21
Bornova	Kurudere	0.96	0.72	30.19	0.19	0.79	729,914.43	196,010.62	5.00	2.72
Bornova	Laka	0.79	0.44	31.15	1.15	0.49	123,386.53	129,243.47	5.00	2.27
Bornova	Meriç	0.29	0.25	33.73	3.73	0.38	40,807.15	67,993.86	1.55	1.61
Bornova	Merkez	0.55	0.37	32.62	2.62	0.44	27,062.55	33,865.46	5.00	1.99
Bornova	Mevlana	0.15	0.15	33.98	3.98	0.35	37,219.72	70,027.29	5.00	1.48
Bornova	Naldöken	0.58	0.43	31.99	1.99	0.67	557,903.50	269,622.52	5.00	2.25
Bornova	Rafet Paşa	0.10	0.10	34.26	4.26	0.19	9,090.54	37,725.47	1.31	1.13
Bornova	Sarnıçköy	0.93	0.71	30.30	0.30	0.83	61,429.36	12,966.65	5.00	2.75
Bornova	Serintepe	0.23	0.20	33.49	3.49	0.26	6,597.05	18,518.96	5.00	1.48
Bornova	Tuna	0.10	0.10	34.16	4.16	0.18	7,537.53	35,309.47	1.18	0.76
Bornova	Ümit	0.33	0.27	33.47	3.47	0.56	117,086.90	93,697.11	5.00	1.87
Bornova	Yakaköy	0.95	0.60	30.31	0.31	0.77	1,804,392.49	540,663.56	5.00	2.71
Bornova	Yeşilçam	0.32	0.23	32.49	2.49	0.30	13,209.05	30,491.96	5.00	1.61
Bornova	Yeşilova	0.11	0.11	34.11	4.11	0.20	18,550.25	72,617.76	5.00	1.29
Bornova	Yıldırım Beyazıt	0.06	0.06	34.26	4.26	0.12	1,896.36	13,657.64	0.85	0.48
Bornova	Yunus Emre	0.17	0.17	34.08	4.08	0.35	36,499.66	68,199.35	5.00	1.50

Table 20 (continued).

District	Neighborhood	HMI	Avg. CC	Avg Temp. (ºC)	Avg. Temp. Anomaly (ºC)	RRI	Runoff Retention (m^3)	Flood Volume (mm)	CFRMI	MRMI
Bornova	Zafer	0.32	0.25	33.12	3.12	0.49	58,018.04	60,638.97	5.00	1.80
Buca	Adatepe	0.70	0.51	31.64	1.64	0.51	343,799.62	331,679.38	5.00	2.20
Buca	Akıncılar	0.19	0.19	34.22	4.22	0.33	16,152.40	33,421.60	5.00	1.50
Buca	Atatürk	0.15	0.14	33.53	3.53	0.23	10,143.62	34,670.39	5.00	1.35
Buca	Aydoğdu	0.52	0.35	32.08	2.08	0.39	44,120.48	70,049.52	5.00	1.90
Buca	Barış	0.12	0.12	34.18	4.18	0.23	7,217.70	24,772.30	5.00	1.33
Buca	Belenbaşı	0.95	0.50	30.24	0.24	0.68	631,954.10	297,960.92	5.00	2.63
Buca	Buca Koop	0.27	0.20	32.70	2.70	0.36	20,264.94	36,092.06	5.00	1.61
Buca	Buca OSB	0.29	0.10	32.64	2.64	0.11	320.47	2,605.53	5.00	1.39
Buca	Buca OSB	0.34	0.25	32.84	2.84	0.19	611.06	2,538.94	5.00	1.52
Buca	Buca OSB	0.46	0.20	31.74	1.74	0.20	6,587.90	25,808.10	5.00	1.65
Buca	Cumhuriyet	0.29	0.21	32.64	2.64	0.26	4,382.15	12,277.85	5.00	1.54
Buca	Çağdaş	0.29	0.28	32.88	2.88	0.37	5,881.38	9,861.62	5.00	1.66
Buca	Çaldıran	0.18	0.17	34.08	4.08	0.43	6,585.06	8,856.94	5.00	1.60
Buca	Çamlık	0.12	0.12	34.19	4.19	0.26	7,282.73	21,123.27	5.00	1.36
Buca	Çamlıkule	0.12	0.11	33.54	3.54	0.26	14,119.63	40,515.38	5.00	1.37
Buca	Çamlıpınar	0.18	0.12	33.21	3.21	0.30	11,403.80	27,096.20	5.00	1.46
Buca	Dicle	0.08	0.08	34.18	4.18	0.10	1,280.71	11,340.29	5.00	1.16
Buca	Doğancılar	0.98	0.58	30.10	0.10	0.87	579,568.37	90,317.62	5.00	2.82
Buca	Dumlupınar	0.19	0.19	33.94	3.94	0.55	12,758.06	10,425.94	5.00	1.72
Buca	Efeler	0.19	0.17	34.14	4.14	0.39	20,501.61	32,033.39	5.00	1.57
Buca	Fırat	0.20	0.16	34.13	4.13	0.42	35,457.96	49,116.05	5.00	1.60
Buca	Gaziler	0.20	0.19	33.46	3.46	0.27	6,407.06	17,567.95	5.00	1.44
Buca	Göksu	0.07	0.07	34.02	4.02	0.14	7,970.36	48,365.65	5.00	1.19
Buca	Güven	0.07	0.07	34.22	4.22	0.14	1,533.50	9,491.50	5.00	1.19
Buca	Hürriyet	0.20	0.15	34.11	4.11	0.38	17,598.11	29,322.89	5.00	1.56
Buca	İnkılap	0.19	0.18	34.21	4.21	0.42	19,751.74	27,386.26	5.00	1.59
Buca	İnönü	0.13	0.12	33.59	3.59	0.18	14,385.47	64,973.54	5.00	1.29
Buca	İzkent	0.29	0.24	33.00	3.00	0.29	6,329.62	15,258.38	5.00	1.57
Buca	Karacaağaç	0.95	0.49	30.22	0.22	0.72	871,215.60	345,020.43	5.00	2.65
Buca	Karanfil	0.21	0.19	33.07	3.07	0.34	4,190.00	8,039.00	5.00	1.54
Buca	Kaynaklar Merkez	0.98	0.70	30.11	0.11	0.84	2,563,524.26	501,397.95	5.00	2.82
Buca	Kırklar	0.97	0.62	30.15	0.15	0.88	1,934,174.21	262,509.82	5.00	2.84
Buca	Kozağaç	0.16	0.16	34.02	4.02	0.35	19,730.38	36,745.63	5.00	1.49
Buca	Kuruçeşme	0.23	0.19	32.42	2.42	0.22	13,114.59	46,840.41	5.00	1.43
Buca	Laleli	0.07	0.07	34.20	4.20	0.13	1,403.04	9,719.96	5.00	1.18
Buca	Menderes	0.16	0.16	34.03	4.03	0.36	12,868.47	23,160.53	5.00	1.50
Buca	Murathan	0.21	0.19	32.55	2.55	0.25	5,899.24	17,697.76	5.00	1.45
Buca	Mustafa Kemal	0.30	0.20	33.00	3.00	0.32	39,125.33	81,834.68	5.00	1.60
Buca	Seyhan	0.08	0.08	34.31	4.31	0.17	10,830.78	53,163.23	5.00	1.23

Table 20 (continued).

District	Neighborhood	HMI	Avg. CC	Avg Temp. (ºC)	Avg. Temp. Anomaly (ºC)	RRI	Runoff Retention (m^3)	Flood Volume (mm)	CFRMI	MRMI
Buca	Şirinkapı	0.43	0.32	33.15	3.15	0.37	19,366.03	33,224.98	5.00	1.78
Buca	Ufuk	0.48	0.29	33.50	3.50	0.42	50,051.61	70,180.39	5.00	1.88
Buca	Vali Rahmi Bey	0.17	0.17	34.08	4.08	0.44	15,751.68	19,822.32	5.00	1.60
Buca	Yaylacık	0.15	0.15	33.80	3.80	0.21	10,409.76	39,332.24	5.00	1.34
Buca	Yenigün	0.12	0.12	34.03	4.03	0.29	15,625.59	38,680.42	5.00	1.39
Buca	Yeşilbağlar	0.10	0.10	33.97	3.97	0.23	9,947.92	33,340.09	5.00	1.31
Buca	Yıldız	0.09	0.09	33.48	3.48	0.18	9,290.80	42,026.21	5.00	1.26
Buca	Yıldızlar	0.95	0.57	30.21	0.21	0.62	295,094.40	181,024.59	5.00	2.57
Buca	Yiğitler	0.10	0.10	34.23	4.23	0.16	4,474.57	22,853.44	5.00	1.25
Buca	Zafer	0.93	0.70	30.61	0.61	0.61	1,388,740.36	878,622.55	5.00	2.54
Çiğli	Ahmet Efendi	0.27	0.25	33.30	3.30	0.46	8,957.06	10,677.94	5.00	1.68
Çiğli	Ahmet Taner Kışlalı	0.24	0.23	33.16	3.16	0.34	10,492.22	20,601.79	5.00	1.56
Çiğli	Ataşehir	0.21	0.19	33.70	3.70	0.41	96,741.89	138,220.14	3.26	1.25
Çiğli	Atatürk	0.50	0.33	32.20	2.20	0.39	28,983.98	46,042.03	5.00	1.87
Çiğli	Atatürk OSB	0.23	0.20	33.28	3.28	0.27	126,482.67	338,660.39	4.75	1.43
Çiğli	Aydınlıkevler	0.22	0.22	33.65	3.65	0.33	15,889.53	32,396.47	2.50	1.43
Çiğli	Balatçık	0.33	0.26	33.55	3.55	0.53	113,159.32	99,185.68	5.00	1.85
Çiğli	Cumhuriyet	0.85	0.47	30.72	0.72	0.61	401,023.39	254,589.65	5.00	2.45
Çiğli	Çağdaş	0.26	0.25	33.66	3.66	0.47	11,779.06	13,532.94	5.00	1.71
Çiğli	Egekent	0.26	0.25	33.33	3.33	0.42	14,699.69	20,566.31	5.00	1.66
Çiğli	Esentepe	0.19	0.16	33.47	3.47	0.39	23,028.76	36,156.24	5.00	1.56
Çiğli	Evka-2	0.33	0.30	32.68	2.68	0.37	15,389.23	26,099.77	5.00	1.68
Çiğli	Evka-5	0.28	0.25	33.12	3.12	0.33	14,857.98	29,802.02	5.00	1.60
Çiğli	Evka-6	0.60	0.34	31.77	1.77	0.40	4,569.06	6,728.94	5.00	1.99
Çiğli	Güzeltepe	0.22	0.20	33.03	3.03	0.21	7,872.82	29,094.18	5.00	1.42
Çiğli	Harmandalı Gazi Mustafa Kemal Atatürk	0.80	0.45	31.00	1.00	0.59	165,086.96	116,698.04	5.00	2.39
Çiğli	İnönü	0.88	0.50	30.96	0.96	0.59	217,827.75	150,120.25	5.00	2.47
Çiğli	İzkent	0.50	0.35	32.48	2.48	0.44	20,286.59	25,976.41	5.00	1.92
Çiğli	Kaklıç	0.73	0.28	31.47	1.47	0.87	2,620,806.97	407,077.93	4.27	2.40
Çiğli	Köyiçi	0.27	0.25	33.69	3.69	0.55	17,932.99	14,449.01	5.00	1.80
Çiğli	Küçük Çiğli	0.16	0.16	33.86	3.86	0.22	15,717.87	57,012.13	5.00	1.36
Çiğli	Maltepe	0.18	0.17	33.75	3.75	0.26	8,049.28	23,247.72	3.22	1.23
Çiğli	Sasalı Merkez	0.94	0.21	30.32	0.32	0.93	2,615,571.49	208,172.30	4.55	2.75
Çiğli	Şirintepe	0.21	0.20	33.68	3.68	0.23	9,598.94	32,233.06	5.00	1.42
Çiğli	Uğur Mumcu	0.43	0.37	33.02	3.02	0.49	29,393.06	30,785.95	5.00	1.91
Çiğli	Yakakent	0.88	0.49	31.07	1.07	0.51	177,224.79	171,361.21	5.00	2.38
Çiğli	Yeni Mahalle	0.16	0.16	33.92	3.92	0.26	13,182.56	38,386.45	5.00	1.40
Gaziemir	Aktepe	0.36	0.16	33.17	3.17	0.35	26,258.34	47,990.66	5.00	1.70

Table 20 (continued).

District	Neighborhood	HMI	Avg. CC	Avg Temp. (ºC)	Avg. Temp. Anomaly (ºC)	RRI	Runoff Retention (m^3)	Flood Volume (mm)	CFRMI	MRMI
Gaziemir	Atatürk	0.76	0.64	31.70	1.70	0.56	73,862.28	59,130.72	5.00	2.31
Gaziemir	Atıfbey	0.14	0.14	33.49	3.49	0.33	18,240.58	36,786.43	5.00	1.46
Gaziemir	Beyazevler	0.51	0.43	32.76	2.76	0.48	76,757.12	82,548.89	5.00	1.99
Gaziemir	Binbaşı Reşatbey	0.22	0.21	33.63	3.63	0.26	9,536.84	26,863.17	5.00	1.47
Gaziemir	Dokuz Eylül	0.40	0.35	32.82	2.82	0.62	773,295.82	473,796.22	5.00	1.99
Gaziemir	Emrez	0.23	0.21	33.69	3.69	0.38	16,195.76	26,637.24	5.00	1.59
Gaziemir	Fatih	0.51	0.43	32.34	2.34	0.50	136,073.67	134,511.34	5.00	2.00
Gaziemir	Gazi	0.10	0.10	33.59	3.59	0.25	11,921.37	36,658.63	5.00	1.33
Gaziemir	Gazikent	0.21	0.21	33.33	3.33	0.58	17,780.16	12,998.84	5.00	1.77
Gaziemir	Hürriyet	0.94	0.69	30.41	0.41	0.66	482,729.95	243,940.04	5.00	2.60
Gaziemir	Irmak	0.82	0.49	30.98	0.98	0.79	358,474.07	93,158.97	5.00	2.61
Gaziemir	Menderes	0.25	0.19	32.95	2.95	0.46	23,148.68	27,615.32	5.00	1.70
Gaziemir	Sevgi	0.75	0.45	31.60	1.60	0.78	238,959.34	66,079.65	5.00	2.50
Gaziemir	Yeşil	0.88	0.55	30.76	0.76	0.80	213,009.55	54,390.44	5.00	2.67
Gaziemir	Zafer	0.56	0.37	32.22	2.22	0.56	275,250.60	218,270.43	5.00	2.11
Karabağlar	Abdi İpekçi	0.37	0.27	33.54	3.54	0.32	10,093.98	21,651.02	5.00	1.67
Karabağlar	Adnan Süvari	0.18	0.18	33.96	3.96	0.41	5,975.76	8,500.24	5.00	1.57
Karabağlar	Ali Fuat Cebesoy	0.13	0.13	34.14	4.14	0.21	8,002.26	30,112.74	5.00	1.32
Karabağlar	Ali Fuat Erden	0.28	0.23	32.98	2.98	0.41	6,509.17	9,296.83	5.00	1.67
Karabağlar	Arap Hasan	0.09	0.09	34.37	4.37	0.12	2,091.12	15,079.88	5.00	1.20
Karabağlar	Aşık Veysel	0.11	0.11	34.36	4.36	0.18	9,109.87	40,758.14	5.00	1.28
Karabağlar	Aydın	0.17	0.16	34.09	4.09	0.38	17,670.61	28,711.39	5.00	1.54
Karabağlar	Bahar	0.14	0.14	34.35	4.35	0.16	4,480.86	23,428.14	5.00	1.28
Karabağlar	Bahçelievler	0.14	0.14	34.37	4.37	0.16	6,039.96	31,200.04	5.00	1.29
Karabağlar	Bahriye Üçok	0.10	0.10	33.81	3.81	0.31	5,571.57	12,306.44	5.00	1.40
Karabağlar	Barış	0.09	0.09	34.38	4.38	0.20	4,394.58	18,054.43	5.00	1.27
Karabağlar	Basın Sitesi	0.15	0.15	34.20	4.20	0.22	8,693.06	31,164.94	5.00	1.35
Karabağlar	Bozyaka	0.08	0.08	34.43	4.43	0.15	4,096.31	23,469.69	5.00	1.21
Karabağlar	Cennetçeşme	0.23	0.18	32.23	2.23	0.36	11,451.03	20,804.97	5.00	1.57
Karabağlar	Cennetoğlu	0.10	0.10	34.36	4.36	0.14	2,515.45	15,747.55	5.00	1.22
Karabağlar	Çalıkuşu	0.12	0.12	34.33	4.33	0.16	4,077.33	21,598.68	5.00	1.26
Karabağlar	Devrim	0.35	0.23	33.39	3.39	0.34	18,121.11	34,504.89	5.00	1.68
Karabağlar	Doğanay	0.08	0.08	34.40	4.40	0.12	1,350.79	10,318.21	5.00	1.18
Karabağlar	Esenlik	0.09	0.09	34.37	4.37	0.11	956.73	8,087.27	5.00	1.17
Karabağlar	Esentepe	0.27	0.24	32.85	2.85	0.41	8,696.78	12,394.22	5.00	1.67
Karabağlar	Esenyalı	0.17	0.17	33.78	3.78	0.35	5,220.30	9,899.70	5.00	1.50
Karabağlar	Fahrettin Altay	0.29	0.24	33.04	3.04	0.41	18,540.80	27,029.21	0.68	1.67
Karabağlar	Gazi	0.08	0.08	33.58	3.58	0.24	4,836.12	15,505.88	5.00	1.30
Karabağlar	General Asım Gündüz	0.16	0.16	34.25	4.25	0.25	2,948.17	8,671.83	5.00	1.40

Table 20 (continued).

District	Neighborhood	HMI	Avg. CC	Avg Temp. (ºC)	Avg. Temp. Anomaly (ºC)	RRI	Runoff Retention (m³)	Flood Volume (mm)	CFRMI	MRMI
Karabağlar	General Kazım Özalp	0.18	0.13	32.84	2.84	0.22	2,880.06	9,943.94	5.00	1.39
Karabağlar	Gülyaka	0.09	0.09	34.41	4.41	0.17	3,469.43	16,487.57	5.00	1.25
Karabağlar	Günaltay	0.09	0.09	34.18	4.18	0.19	9,897.93	41,629.08	5.00	1.27
Karabağlar	İhsan Alyanak	0.13	0.08	33.68	3.68	0.18	5,292.72	23,925.29	5.00	1.29
Karabağlar	Karabağlar	0.08	0.08	34.42	4.42	0.14	3,605.63	22,574.37	5.00	1.20
Karabağlar	Kavacık	0.98	0.59	30.11	0.11	0.73	1,270,309.40	474,671.69	5.00	2.60
Karabağlar	Kazım Karabekir	0.13	0.13	34.38	4.38	0.21	4,396.50	16,316.50	5.00	1.32
Karabağlar	Kibar	0.07	0.07	34.02	4.02	0.16	2,569.32	13,285.68	5.00	1.21
Karabağlar	Limontepe	0.18	0.17	33.38	3.38	0.33	10,616.72	21,240.28	5.00	1.49
Karabağlar	Maliyeciler	0.16	0.16	33.76	3.76	0.30	5,729.53	13,331.48	5.00	1.44
Karabağlar	Metin Oktay	0.10	0.10	33.57	3.57	0.17	2,507.64	11,863.36	5.00	1.26
Karabağlar	Muammer Akar	0.57	0.38	32.53	2.53	0.53	24,961.08	22,043.92	5.00	2.09
Karabağlar	Osman Aksüner	0.13	0.13	34.25	4.25	0.18	2,563.29	11,562.71	5.00	1.30
Karabağlar	Özgür	0.07	0.07	33.41	3.41	0.22	5,330.52	18,455.48	5.00	1.27
Karabağlar	Peker	0.24	0.12	33.58	3.58	0.28	12,471.79	32,636.22	5.00	1.50
Karabağlar	Poligon	0.77	0.48	32.45	2.45	0.65	65,314.47	35,149.54	5.00	2.41
Karabağlar	Refet Bele	0.12	0.12	34.32	4.32	0.24	4,946.66	16,004.34	5.00	1.34
Karabağlar	Reis	0.09	0.09	34.39	4.39	0.14	1,681.29	10,694.71	5.00	1.21
Karabağlar	Salih Omurtak	0.21	0.18	33.49	3.49	0.35	15,590.95	28,754.05	5.00	1.55
Karabağlar	Sarıyer	0.07	0.07	34.43	4.43	0.14	2,664.81	15,871.19	5.00	1.19
Karabağlar	Selvili	0.12	0.12	34.37	4.37	0.22	5,462.95	19,338.05	5.00	1.32
Karabağlar	Sevgi	0.12	0.12	34.35	4.35	0.23	5,401.53	18,111.47	5.00	1.34
Karabağlar	Şehitler	0.48	0.34	33.00	3.00	0.47	10,940.36	12,306.64	5.00	1.94
Karabağlar	Tahsin Yazıcı	0.16	0.16	34.17	4.17	0.36	12,092.81	21,395.19	5.00	1.51
Karabağlar	Tırazlı	0.99	0.74	30.08	0.08	0.76	2,254,566.09	698,545.13	5.00	2.75
Karabağlar	Uğur Mumcu	0.07	0.07	34.43	4.43	0.13	2,125.38	14,772.63	5.00	1.17
Karabağlar	Umut	0.08	0.08	33.75	3.75	0.17	4,868.76	24,412.24	5.00	1.22
Karabağlar	Uzundere	0.85	0.46	31.05	1.05	0.66	368,288.23	193,608.81	5.00	2.51
Karabağlar	Üçkuyular	0.15	0.15	33.39	3.39	0.23	4,226.51	13,973.49	0.68	1.35
Karabağlar	Vatan	0.14	0.14	34.19	4.19	0.29	16,208.16	40,610.85	5.00	1.41
Karabağlar	Yaşar Kemal	0.48	0.31	31.57	1.57	0.40	22,195.14	33,356.86	5.00	1.87
Karabağlar	Yunus Emre	0.09	0.09	34.24	4.24	0.19	13,007.18	55,025.83	5.00	1.27
Karabağlar	Yurdoğlu	0.20	0.18	32.80	2.80	0.29	16,448.75	40,727.25	5.00	1.47
Karabağlar	Yüzbaşı Şerafettin	0.09	0.08	33.12	3.12	0.22	5,771.46	20,394.55	5.00	1.29
Karşıyaka	Aksoy	0.18	0.17	34.16	4.16	0.35	10,589.48	19,496.52	0.68	0.69
Karşıyaka	Alaybey	0.13	0.12	34.19	4.19	0.18	1,424.27	6,373.73	0.71	0.67
Karşıyaka	Atakent	0.34	0.29	33.81	3.81	0.69	30,030.42	13,705.59	0.81	1.05
Karşıyaka	Bahariye	0.15	0.15	34.19	4.19	0.33	7,865.41	15,969.60	0.80	1.35
Karşıyaka	Bahçelievler	0.17	0.17	34.13	4.13	0.34	20,619.14	40,042.86	0.96	1.25

Table 20 (continued).

District	Neighborhood	HMI	Avg. CC	Avg Temp. (ºC)	Avg. Temp. Anomaly (ºC)	RRI	Runoff Retention (m^3)	Flood Volume (mm)	CFRMI	MRMI
Karşıyaka	Bahriye Üçok	0.15	0.15	34.21	4.21	0.37	11,294.87	18,952.13	5.00	1.51
Karşıyaka	Bostanlı	0.20	0.18	34.06	4.06	0.36	32,804.73	57,782.28	0.73	0.60
Karşıyaka	Cumhuriyet	0.16	0.16	33.88	3.88	0.24	18,347.29	57,826.72	1.81	1.24
Karşıyaka	Dedebaşı	0.12	0.12	34.18	4.18	0.21	7,541.66	27,990.34	0.89	1.22
Karşıyaka	Demirköprü	0.13	0.13	34.17	4.17	0.22	3,106.57	10,704.43	0.88	0.75
Karşıyaka	Donanmacı	0.17	0.17	34.17	4.17	0.30	5,275.68	12,448.32	0.66	0.62
Karşıyaka	Fikri Altay	0.14	0.14	34.13	4.13	0.21	2,717.01	10,337.99	5.00	1.33
Karşıyaka	Goncalar	0.10	0.10	34.21	4.21	0.17	2,756.93	13,868.07	0.82	1.01
Karşıyaka	İmbatlı	0.18	0.18	34.07	4.07	0.36	11,887.07	20,865.93	5.00	1.53
Karşıyaka	İnönü	0.22	0.20	33.58	3.58	0.21	10,232.76	39,005.25	2.23	1.38
Karşıyaka	Latife Hanım	0.84	0.54	30.92	0.92	0.61	118,879.11	75,433.91	5.00	2.45
Karşıyaka	Mavişehir	0.39	0.31	33.34	3.34	0.64	67,950.72	38,372.28	1.27	1.22
Karşıyaka	Mustafa Kemal	0.56	0.38	32.38	2.38	0.44	52,229.71	67,792.30	5.00	1.99
Karşıyaka	Nergiz	0.11	0.11	34.21	4.21	0.22	3,167.63	11,196.37	0.78	1.16
Karşıyaka	Örnekköy	0.23	0.22	33.70	3.70	0.35	33,709.97	62,008.04	5.00	1.57
Karşıyaka	Sancaklı	0.98	0.61	30.13	0.13	0.67	449,626.95	221,246.06	5.00	2.64
Karşıyaka	Şemikler	0.17	0.17	34.01	4.01	0.27	21,472.05	58,810.96	1.36	0.90
Karşıyaka	Tersane	0.12	0.12	34.08	4.08	0.21	2,809.81	10,448.19	0.80	0.39
Karşıyaka	Tuna	0.18	0.12	34.19	4.19	0.14	1,389.57	8,270.43	1.18	0.77
Karşıyaka	Yalı	0.17	0.17	33.87	3.87	0.29	37,184.51	91,111.50	1.20	0.64
Karşıyaka	Yamanlar	0.99	0.61	30.07	0.07	0.67	809,607.92	391,165.14	5.00	2.66
Karşıyaka	Zübeyde Hanım	0.81	0.51	31.10	1.10	0.56	199,707.62	155,178.40	5.00	2.37
Konak	1.Kadriye	0.07	0.07	34.17	4.17	0.12	1,908.14	13,729.87	5.00	1.17
Konak	2.Kadriye	0.34	0.25	34.07	4.07	0.40	20,505.37	31,084.64	5.00	1.72
Konak	Akarcalı	0.14	0.14	34.19	4.19	0.20	3,063.63	12,406.37	5.00	1.32
Konak	Akdeniz	0.11	0.11	34.27	4.27	0.24	5,362.16	16,687.84	0.59	1.02
Konak	Akın Simav	0.11	0.11	34.39	4.39	0.18	1,429.52	6,480.48	0.76	0.99
Konak	Akıncı	0.10	0.10	34.24	4.24	0.22	838.37	2,948.63	5.00	1.30
Konak	Ali Reis	0.09	0.09	34.18	4.18	0.17	703.96	3,405.04	5.00	1.24
Konak	Alsancak	0.10	0.10	34.25	4.25	0.23	6,170.95	20,849.05	0.32	0.40
Konak	Altay	0.26	0.26	34.15	4.15	0.37	2,121.07	3,667.93	5.00	1.62
Konak	Altınordu	0.14	0.14	34.22	4.22	0.27	658.72	1,784.28	5.00	1.40
Konak	Altıntaş	0.07	0.07	34.34	4.34	0.10	677.05	6,308.95	5.00	1.15
Konak	Anadolu	0.07	0.07	33.91	3.91	0.13	819.26	5,592.74	5.00	1.18
Konak	Atamer	0.19	0.17	33.38	3.38	0.26	3,297.80	9,547.21	5.00	1.44
Konak	Atilla	0.08	0.08	34.33	4.33	0.13	1,992.80	13,932.20	5.00	1.19
Konak	Aziziye	0.12	0.12	34.16	4.16	0.15	1,339.36	7,326.64	5.00	1.25
Konak	Ballıkuyu	0.06	0.06	34.15	4.15	0.13	1,129.68	7,718.33	5.00	1.17
Konak	Barbaros	0.07	0.07	34.34	4.34	0.20	2,396.04	9,517.96	1.05	1.10
Konak	Boğaziçi	0.10	0.10	34.14	4.14	0.16	1,876.24	10,072.76	5.00	1.23
Konak	Bozkurt	0.11	0.11	34.23	4.23	0.13	109.89	723.11	5.00	1.23

Table 20 (continued).

District	Neighborhood	HMI	Avg. CC	Avg Temp. (ºC)	Avg. Temp. Anomaly (ºC)	RRI	Runoff Retention (m^3)	Flood Volume (mm)	CFRMI	MRMI
Konak	Cengiz Topel	0.33	0.30	33.99	3.99	0.43	15,579.90	20,876.10	5.00	1.74
Konak	Çahabey	0.12	0.12	34.27	4.27	0.11	199.52	1,585.48	5.00	1.21
Konak	Çankaya	0.10	0.10	34.33	4.33	0.17	4,306.29	20,669.71	0.62	1.02
Konak	Çınarlı	0.22	0.21	34.10	4.10	0.39	33,981.32	52,783.68	0.47	0.57
Konak	Çınartepe	0.35	0.20	33.08	3.08	0.30	6,468.68	15,112.32	5.00	1.64
Konak	Çimentepe	0.06	0.06	34.26	4.26	0.12	938.85	6,852.15	5.00	1.17
Konak	Dayıemir	0.12	0.12	34.23	4.23	0.11	140.22	1,126.78	5.00	1.22
Konak	Dolaplıkuyu	0.07	0.07	34.20	4.20	0.14	283.54	1,711.46	5.00	1.20
Konak	Duatepe	0.05	0.05	34.25	4.25	0.10	559.27	4,928.73	5.00	1.14
Konak	Ege	0.16	0.16	34.19	4.19	0.32	5,434.53	11,288.47	0.42	0.51
Konak	Emir Sultan	0.19	0.19	34.15	4.15	0.26	2,358.32	6,755.68	5.00	1.43
Konak	Etiler	0.12	0.12	34.23	4.23	0.21	2,496.66	9,123.34	0.63	1.24
Konak	Faik Paşa	0.13	0.13	34.22	4.22	0.31	1,072.52	2,392.48	5.00	1.43
Konak	Fatih	0.19	0.19	34.26	4.26	0.24	911.56	2,840.44	5.00	1.41
Konak	Ferahlı	0.08	0.08	34.15	4.15	0.19	5,214.79	22,365.22	5.00	1.25
Konak	Fevzi Paşa	0.16	0.16	34.23	4.23	0.21	391.36	1,491.64	5.00	1.35
Konak	Göztepe	0.19	0.17	33.93	3.93	0.30	11,488.75	26,437.25	0.61	1.25
Konak	Güneş	0.11	0.11	34.25	4.25	0.13	169.77	1,174.24	0.77	1.17
Konak	Güneşli	0.15	0.15	34.28	4.28	0.17	3,306.55	15,705.46	5.00	1.31
Konak	Güney	0.13	0.13	34.22	4.22	0.26	6,340.83	18,467.17	5.00	1.37
Konak	Güngör	0.10	0.10	34.29	4.29	0.12	223.42	1,680.58	5.00	1.20
Konak	Güzelyalı	0.13	0.13	33.71	3.71	0.20	5,128.18	20,323.83	0.60	0.96
Konak	Güzelyurt	0.09	0.09	34.26	4.26	0.17	629.75	3,003.25	0.74	0.69
Konak	Halkapınar	0.15	0.15	34.17	4.17	0.27	17,636.01	48,227.00	0.55	0.49
Konak	Hasan Özdemir	0.12	0.10	34.09	4.09	0.18	1,198.70	5,647.30	5.00	1.28
Konak	Hilal	0.17	0.17	34.22	4.22	0.47	11,157.02	12,691.98	0.53	1.40
Konak	Hurşidiye	0.07	0.07	34.25	4.25	0.20	487.61	1,892.39	5.00	1.26
Konak	Huzur	0.08	0.08	34.06	4.06	0.15	1,096.79	6,253.21	5.00	1.21
Konak	İmariye	0.54	0.39	34.02	4.02	0.56	9,740.74	7,514.26	5.00	2.10
Konak	İsmet Kaptan	0.15	0.15	34.25	4.25	0.32	7,104.16	14,882.84	0.53	1.11
Konak	İsmet Paşa	0.09	0.09	34.17	4.17	0.17	2,997.95	14,677.05	5.00	1.25
Konak	Kadifekale	0.25	0.20	34.09	4.09	0.32	5,631.61	12,246.39	5.00	1.55
Konak	Kahraman Mescit	0.13	0.13	34.24	4.24	0.21	171.14	661.86	5.00	1.32
Konak	Kahramanlar	0.12	0.12	34.22	4.22	0.22	2,665.30	9,437.70	0.47	1.30
Konak	Kemal Reis	0.09	0.09	34.39	4.39	0.14	878.17	5,344.83	5.00	1.22
Konak	Kestelli	0.09	0.09	34.24	4.24	0.14	250.87	1,590.13	5.00	1.21
Konak	Kılıç Reis	0.09	0.09	34.37	4.37	0.12	1,255.03	9,447.97	5.00	1.19
Konak	Kocakapı	0.15	0.15	34.22	4.22	0.29	3,975.49	9,730.51	5.00	1.42
Konak	Kocatepe	0.09	0.09	34.30	4.30	0.11	444.63	3,664.37	5.00	1.19
Konak	Konak	0.18	0.17	34.24	4.24	0.24	6,334.99	20,524.01	0.73	0.82
Konak	Kosova	0.15	0.12	34.09	4.09	0.22	1,310.95	4,688.05	5.00	1.35

Table 20 (continued).

District	Neighborhood	HMI	Avg. CC	Avg Temp. (°C)	Avg. Temp. Anomaly (°C)	RRI	Runoff Retention (m^3)	Flood Volume (mm)	CFRMI	MRMI
Konak	Kubilay	0.11	0.11	34.18	4.18	0.17	1,010.72	5,079.28	5.00	1.26
Konak	Kurtuluş	0.13	0.13	34.24	4.24	0.27	421.48	1,118.52	5.00	1.39
Konak	Küçükada	0.16	0.16	34.18	4.18	0.45	5,898.84	7,310.16	5.00	1.59
Konak	Kültür	0.15	0.15	34.23	4.23	0.34	11,449.16	22,633.85	0.45	0.94
Konak	Lale	0.15	0.15	34.09	4.09	0.28	5,489.19	14,040.81	5.00	1.41
Konak	Levent	0.08	0.08	34.19	4.19	0.14	1,626.13	10,238.87	5.00	1.20
Konak	Mecidiye	0.12	0.12	34.29	4.29	0.18	228.16	1,038.84	5.00	1.20
Konak	Mehmet Akif	0.13	0.08	33.66	3.66	0.15	1,202.75	6,826.25	5.00	1.27
Konak	Mehmet Ali Akman	0.19	0.19	33.56	3.56	0.39	14,021.69	21,713.31	0.62	0.76
Konak	Mehtap	0.09	0.09	34.18	4.18	0.21	2,482.54	9,389.46	5.00	1.28
Konak	Mersinli	0.19	0.19	34.14	4.14	0.28	23,386.32	59,878.70	0.76	0.58
Konak	Millet	0.08	0.08	33.67	3.67	0.14	2,141.00	13,665.00	5.00	1.20
Konak	Mimar Sinan	0.18	0.18	34.21	4.21	0.56	33,106.36	26,463.64	0.45	1.19
Konak	Mirali	0.12	0.12	34.20	4.20	0.15	287.41	1,623.59	5.00	1.26
Konak	Mithatpaşa	0.11	0.11	34.39	4.39	0.16	2,886.55	15,607.45	0.69	0.91
Konak	Murat	0.12	0.09	33.62	3.62	0.16	3,034.64	16,418.36	5.00	1.25
Konak	Murat Reis	0.10	0.10	34.39	4.39	0.16	3,575.60	19,412.40	5.00	1.24
Konak	Namazgah	0.19	0.19	34.24	4.24	0.31	1,078.95	2,407.05	5.00	1.49
Konak	Namık Kemal	0.21	0.21	34.24	4.24	0.32	1,162.86	2,498.14	5.00	1.52
Konak	Odunkapı	0.13	0.13	34.23	4.23	0.21	171.52	633.48	5.00	1.32
Konak	Oğuzlar	0.15	0.15	34.23	4.23	0.31	2,424.00	5,353.00	5.00	1.44
Konak	Pazaryeri	0.15	0.15	34.22	4.22	0.32	1,280.93	2,723.07	5.00	1.45
Konak	Piri Reis	0.11	0.11	34.38	4.38	0.13	1,046.00	6,969.00	5.00	1.22
Konak	Sakarya	0.09	0.09	34.23	4.23	0.17	475.96	2,310.04	5.00	1.24
Konak	Saygı	0.09	0.08	33.78	3.78	0.15	2,050.87	12,040.13	5.00	1.22
Konak	Selçuk	0.19	0.19	34.25	4.25	0.27	2,644.20	7,043.80	5.00	1.44
Konak	Sümer	0.17	0.17	34.23	4.23	0.23	314.37	1,043.63	5.00	1.39
Konak	Süvari	0.10	0.10	34.19	4.19	0.16	645.59	3,295.41	5.00	1.25
Konak	Şehit Nedim Tuğaltay	0.12	0.12	34.23	4.23	0.15	97.99	546.01	5.00	1.25
Konak	Tan	0.10	0.10	34.24	4.24	0.15	197.12	1,104.88	5.00	1.23
Konak	Tınaztepe	0.09	0.09	34.27	4.27	0.13	539.79	3,611.21	5.00	1.20
Konak	Trakya	0.07	0.07	33.93	3.93	0.12	632.06	4,785.94	5.00	1.17
Konak	Turgut Reis	0.12	0.12	34.38	4.38	0.22	1,990.69	7,095.31	0.84	0.95
Konak	Tuzcu	0.07	0.07	34.22	4.22	0.12	536.60	3,992.40	5.00	1.18
Konak	Türkyılmaz	0.12	0.12	34.24	4.24	0.22	237.33	854.67	5.00	1.32
Konak	Uğur	0.13	0.13	34.24	4.24	0.17	354.00	1,753.00	5.00	1.28
Konak	Ulubatlı	0.12	0.11	33.94	3.94	0.18	4,847.33	22,249.67	5.00	1.28
Konak	Umurbey	0.16	0.16	34.18	4.18	0.34	23,768.28	46,616.73	0.32	0.34
Konak	Ülkü	0.07	0.07	34.22	4.22	0.13	405.88	2,618.12	5.00	1.19
Konak	Vezirağa	0.46	0.35	34.01	4.01	0.50	4,143.83	4,088.17	5.00	1.95
Konak	Yavuz Selim	0.05	0.05	34.11	4.11	0.11	519.77	4,205.23	5.00	1.15

Table 20 (continued).

District	Neighborhood	HMI	Avg. CC	Avg Temp. (ºC)	Avg. Temp. Anomaly (ºC)	RRI	Runoff Retention (m^3)	Flood Volume (mm)	CFRMI	MRMI
Konak	Yeni	0.12	0.12	34.21	4.21	0.21	567.86	2,092.14	5.00	1.31
Konak	Yenidoğan	0.12	0.12	34.21	4.21	0.25	4,085.46	12,469.54	5.00	1.35
Konak	Yenigün	0.06	0.06	34.26	4.26	0.13	622.25	4,312.75	0.67	1.07
Konak	Yenişehir	0.15	0.15	34.20	4.20	0.28	10,484.08	27,532.93	0.61	0.93
Konak	Yeşildere	0.22	0.20	34.13	4.13	0.28	4,733.32	12,136.68	5.00	1.49
Konak	Yeşiltepe	0.23	0.23	34.24	4.24	0.31	4,696.71	10,591.29	0.80	0.88
Konak	Yıldız	0.14	0.14	34.23	4.23	0.15	160.51	917.49	5.00	1.27
Konak	Zafertepe	0.10	0.10	34.20	4.20	0.14	3,310.71	20,748.30	5.00	1.22
Konak	Zeybek	0.09	0.09	34.07	4.07	0.13	885.64	6,002.36	5.00	1.20
Konak	Zeytinlik	0.15	0.15	34.21	4.21	0.34	6,408.49	12,575.51	5.00	1.47
Narlıdere	2. İnönü	0.92	0.75	30.40	0.40	0.78	419,322.64	116,877.40	5.00	2.70
Narlıdere	Altıevler	0.33	0.31	33.05	3.05	0.79	74,366.80	19,468.20	0.67	1.43
Narlıdere	Atatürk	0.29	0.22	32.34	2.34	0.37	13,390.04	22,400.96	5.00	1.66
Narlıdere	Çamtepe	0.19	0.18	32.93	2.93	0.50	13,045.01	12,854.99	5.00	1.68
Narlıdere	Çatalkaya	0.29	0.26	32.51	2.51	0.41	13,517.55	19,592.45	5.00	1.69
Narlıdere	Huzur	0.88	0.72	30.60	0.60	0.77	1,177,627.93	345,299.21	0.46	2.58
Narlıdere	Ilıca	0.70	0.58	31.72	1.72	0.67	100,408.78	49,174.23	5.00	2.36
Narlıdere	Limanreis	0.87	0.72	30.68	0.68	0.77	255,937.98	76,065.03	0.71	2.49
Narlıdere	Narlı	0.81	0.64	31.11	1.11	0.72	134,501.33	53,301.69	5.00	2.52
Narlıdere	Sahilevleri	0.44	0.35	32.88	2.88	0.87	144,199.41	21,385.59	1.21	1.94
Narlıdere	Yenikale	0.17	0.17	33.11	3.11	0.53	13,992.43	12,446.57	5.00	1.68

APPENDIX B

Table 21. Nature-based solutions and their definitions

NBS	Definition	Application Scale	
Cool corridors	Designing pathways with shade structures and vegetation to create cool routes in urban areas.	City	
Cycle and Pedestrian Green Route	Cycle and pedestrian green route characterized by pathways that provide public health is part of the green networks in the city.	City	
Detention basins	Constructing basins to temporarily store and slowly release excess stormwater, reducing peak flows.	City	
Flood warning systems	Implementing early warning systems to provide timely information and alerts to residents in flood-prone areas.	City	
Floodplain restoration	Restoring natural floodplains and wetlands to provide storage and flood attenuation.	City	
Green infrastructure networks	Implementing a system of interconnected green spaces, including parks, green roofs, and permeable surfaces, to manage stormwater runoff.	City	
Heat-aware landscaping	Choosing heat-tolerant and drought-resistant plants for landscaping to minimize water consumption and maintenance needs.	City	
Living shorelines	Using natural materials like oyster reefs and marsh grasses to stabilize shorelines and reduce erosion.	City	
Mangrove reforestation	Planting and restoring mangrove forests along coastlines to provide coastal protection and enhance biodiversity.	City	
Natural ventilation	Incorporating design elements that allow for natural airflow and ventilation in buildings and urban spaces.	City	
Urban Carbon Sink	Urban carbon sink is the action covers planting trees across the city to maximize carbon sequestration around a new green corridor mainly.	City	
Water features	Incorporating water bodies like fountains and ponds to provide evaporative cooling and enhance aesthetics. Incorporating water bodies like fountains and ponds to provide evaporative cooling and enhance aesthetics.	City	
Bioretention systems	Constructing vegetated areas that collect and treat stormwater runoff, allowing it to infiltrate slowly.	District	Ground
Channel naturalization	Restoring or reconfiguring channels to a more natural state, enhancing their capacity to manage floodwaters.	District	Ground
Coastal wetland restoration	Restoring and preserving coastal wetlands to act as natural buffers against storm surges and coastal flooding.	District	Ground
Cool microclimates	Designing urban spaces with features that create cooler microclimates, such as shade structures and water misters.	District	Ground Facade Roof
Green Filter Areas	Green filter areas provide a visual barrier and pollution filter between roads or industrial operations and public space or walkways.	District	Ground

Table 21 (continued).

NBS	Definition	Application Scale	
Green Resting Areas	Green resting areas are green spaces projected for social recreation (resting, relaxation, observing nature, social contact).	District	Ground
Parklet	Parklet or pocket park provides opportunities for people to create small but important public spaces in their own neighborhoods.	District	Ground
Rain gardens	Creating depressions or shallow basins with native vegetation to capture and absorb rainwater.	District	Ground
Tree-lined streets	Planting trees along streets to provide shade and reduce heat radiation from paved surfaces.	District	Ground
Trees Renaturing Parking	The urban heat island effect will be abated in parking and arboreal areas by planting trees which improve the filtration of urban run-off and cooling capacity.	District	Ground
Urban forestry	Increasing the number of trees and vegetation in urban areas to provide shade and reduce surface temperature.	District	Ground
Cool pavements	Using reflective materials for pavements to reduce heat absorption and lower surface temperatures.	Local	Ground
Cool roofs	Installing roofs with reflective materials to reduce heat absorption and lower indoor temperatures.	Local	Roof
Dune restoration	Rebuilding and stabilizing sand dunes to act as natural barriers and absorb wave energy during storms.	Local	Ground
Energy efficient buildings	Implementing energy-efficient design principles and technologies to reduce heat generation and improve thermal comfort.	Local	Ground Facade Roof
Green dams and levees	Constructing vegetated structures along rivers and coastlines to provide flood protection while enhancing ecosystem services.	Local	Ground
Green Noise Barriers	Green noise barriers are designed to reduce the traffic noise that arrives at the residentials on the street.	Local	Ground Facade
Green roofs	The external upper covering of a building which the main objective is to favor the growth of vegetation keeping the habitability conditions.	Local	Roof
Heat-resistant materials	Using heat-reflective and insulating materials in construction to minimize heat transfer.	Local	Ground Facade Roof
Living walls	Installing vertical gardens on building facades to provide cooling and improve air quality.	Local	Facade
Permeable pavements	Using porous materials for sidewalks and roads to allow rainwater infiltration and prevent heat buildup.	Local	Ground
Pollinator Roofs	A green roof designed to attract biodiversity as a mean to compensate ecological habitat fragmentation.	Local	Roof
Pollinator Walls	Vegetated walls which can provide pollen to attract insect pollinator species. Useful in urban areas when open spaces are limited.	Local	Facade
Rainwater harvesting	Collecting rainwater for various uses, reducing stormwater runoff and alleviating pressure on drainage systems.	Local	Ground Facade Roof
Retention ponds	Constructing ponds to collect and temporarily store stormwater, allowing for gradual release and reducing downstream flooding.	Local	Ground

Table 21 (continued).

NBS	Definition	Application Scale	
Solar shading	Installing shading devices like awnings and louvers to reduce direct sunlight and heat gain in buildings.	Local	Facade
Tide gates and flood barriers	Installing gates and barriers to control tidal flow and prevent coastal flooding.	Local	Ground
Urban agriculture	Promoting rooftop gardens and community gardens to increase green spaces and reduce heat island effect.	Local	Roof