FLOOD VULNERABILITY ASSESSMENT USING GIS-BASED MULTI-CRITERIA DECISION ANALYSIS: A CASE STUDY OF KAYNARCA RIVER

by

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ABSTRACT

FLOOD VULNERABILITY ASSESSMENT USING GIS-BASED MULTI-CRITERIA DECISION ANALYSIS: A CASE STUDY OF KAYNARCA RIVER

Floods are a particularly destructive form of natural disaster that imposes substantial damage upon individuals, property, and the global economy. The growing frequency and magnitude of extreme weather events have a significant impact on flash floods. Urban areas tend to be more vulnerable to the hazards associated with flooding due to the high level of social and economic activity as well as the high population density. The assessment of flood vulnerability is an approach that draws on social and physical indicators and can aid urban areas in recognizing the possible threats linked to climate change. The present research employs a combined approach of Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) analysis methodologies to anticipate areas vulnerable to flooding in the Pendik district of Istanbul. The study utilizes various indicators, including age, educational attainment, building materials, year of construction, number of building floors, proximity to flood-prone areas, access to healthcare services, socio-economic status, and population density. In accordance with the research conclusions, a significant proportion of the study area exhibits varying degrees of vulnerability. Particularly, 19.37% of the area was characterized by a very low level of vulnerability, while 19.44% exhibited low vulnerability. A high level of vulnerability was identified in 25.60% of the area, whereas an extremely high level of vulnerability was found in 18.35% of the area. The findings of this research have the potential to provide valuable insights for urban planning and policymaking efforts aimed at mitigating the vulnerability of urban regions to flood hazards.

ÖZET

CBS TABANLI ÇOK KRİTERLİ KARAR ANALİZİ KULLANILARAK TAŞKIN KIRILGANLIĞI DEĞERLENDİRMESİ: KAYNARCA DERESİ ÖRNEĞİ

Taşkınlar, bireylere, mülklere ve küresel ekonomiye önemli zararlar veren, yıkıcı bir doğal afet şeklidir. Aşırı hava olaylarının artan sıklığı ve büyüklüğü, ani seller üzerinde önemli bir etkiye sahiptir. Kentsel alanlar, yüksek düzeyde sosyal ve ekonomik faaliyetin yanı sıra yüksek nüfus yoğunluğu nedeniyle sel ile ilişkili tehlikelere karşı daha kırılgan olma eğilimindedir. Taşkın kırılganlığının değerlendirilmesi, sosyal ve fiziksel göstergelerden yararlanan bir yaklaşımdır ve kentsel alanların iklim değişikliğiyle bağlantılı olası tehditleri tanımasına yardımcı olabilir. Bu araştırma, İstanbul'un Pendik ilçesinde sele karşı savunmasız alanları tahmin etmek için Analitik Hiyerarşi Süreci (AHS) ve Coğrafi Bilgi Sistemi (CBS) analiz metodolojilerinin birleşik bir yaklaşımını kullanmaktadır. Çalışma, yaş, eğitim düzeyi, yapı malzemesi, yapım yılı, bina kat sayısı, taşkına eğilimli alanlara yakınlık, sağlık hizmetlerine erişim, sosyo-ekonomik durum ve nüfus yoğunluğu gibi çeşitli göstergelerden yararlanmaktadır. Araştırma sonuçlarına göre, çalışma alanı değişen derecelerde kırılganlık sergilemektedir. Özellikle, alanın %19.37'si çok düşük düzeyde kırılganlık ile karakterize edilirken, %19.44'ü düşük kırılganlık sergilemiştir. Alanın %25.60'ında yüksek düzeyde kırılganlık tespit edilirken, alanın %18.35'inde çok yüksek düzeyde kırılganlık saptanmıştır. Bu araştırmanın bulguları, kentsel alanların sel tehlikelerine karşı kırılganlığını azaltmayı amaçlayan kentsel planlama ve politika oluşturma pratikleri için değerli bilgiler sağlama potansiyeline sahiptir.

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AHP	Analytical Hierarchical Process
CI	Consistency Index
CR	Consistency Ratio
ELECTRE	ÉLimination Et Choix Traduisant la REalité
F-AHP	Fuzzy Analytical Hierarchical Process
FEMA	Federal Emergency Management Agency
FR	Frequency Ratio
GIS	Geographic Information Systems
IMM	Istanbul Metropolitan Municipality
IPCC	Intergovernmental Panel on Climate Change
ISKI	Istanbul Su ve Kanalizasyon İdaresi
λ_{max}	Largest Eigenvalue
LULC	Land Use Land Cover
MacBETH	Measuring Attractiveness by a Categorical Based Evaluation Technique
M-AHP	Modified Analytical Hierarchical Process
MCDA	Multi Criteria Decision Analysis
MOORA	Multi-objective Optimization By Ratio Analysis
NBS	Nature Based Solutions
NGO	Non-Governmental Organisation
NIS	Negative Ideal Solution
OECD	Organisation for Economic Co-operation and Development
PCA	Principal Component Analysis
PIS	Positive Ideal Solution

PROMETHEE	Preference Ranking Organization METHod for Enrichment of Evaluations
RI	Random Index
ROC	Receiver Operating Characteristic
SES	Socioeconomic Status
SoVI	Social Vulnerability Index
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TUIK	Türkiye İstatistik Kurumu
UN	United Nations
UN-HABITAT	United Nations Human Settlements Programme
UNISDR	United Nations Office for Disaster Risk Reduction
VIKOR	VIsekriterijumskaoptimizacija i KOmpromisno Resenje
WMCCC	World Mayors Council on Climate Change
WSM	Weighted Sum Model

1. INTRODUCTION

From 1.5 billion people in 1975 to 3.5 billion people in 2015, the number of people living in cities has more than doubled in the last 40 years (Organisation for Economic Co-operation and Development (OECD), 2020). Furthermore, it is expected that the total number of urban populations will continue to experience substantial growth until the year 2050, with an estimated increase from 3.5 billion in 2015 to 5 billion in 2050, representing a growth rate of over 40% (OECD, 2020). Changes in land cover, including urbanization, deforestation, and agricultural practices, possess the capability to decrease evaporation rates and initiate decreased permeability. These shifts ultimately result in an increase in surface runoff and thereby contribute to the prevalence of inundation in urban areas (Chang & Franczyk, 2008). The issue of urban flooding has gained significant global attention in recent years, with projections indicating a heightened likelihood of flooding in the future due to multiple factors such as urbanization, climate change, and infrastructure degradation (O'Donnell & Thorne, 2020). Metropolitan regions are complicated ecosystems that support a significant populace, various facilities, and infrastructure, and often face challenges related to conflicts over adequate and dependable access to resources (Dookie & Gannon, 2022). Therefore, the issue of climate change and its associated consequences present a critical barrier to urban environments that are already facing challenging living conditions. Istanbul, the most populated city in Turkey and one of the most populous in the world, is indeed not immune from this threat.

The escalating risk of flooding and its potential consequences have led to an increasing demand for efficient flood vulnerability assessment tools that can aid decision-makers and urban planners in identifying vulnerable areas, prioritizing responses, and allocating resources. Consequently, the scientific community is experiencing a growing body of research on flood vulnerability, with numerous approaches being proposed to address this issue. The multi-criteria decision analysis (MCDA) approach is a methodology that involves the simultaneous evaluation and consideration of numerous criteria that may contribute to flood vulnerability. The utilization of Geographic Information System (GIS) tools enables the identification of flood vulnerability measures by performing an in-depth analysis of physical, social, economic, and ecological determinants. This approach facilitates the identification of hotspots in both urban and rural regions. This study endeavors to make a scholarly contribution to the existing literature on flood vulnerability by implementing a holistic approach. Specifically, it aims to adapt a relevant example of such efforts to the context of Istanbul.

1.1. Background and Motivation

Rapid population growth, changing climate, and insufficient urban planning practices significantly contribute to the increased risk of flooding in metropolitan regions around the world, especially in developing countries. Furthermore, the positioning of lots of urban centers in vulnerable areas, such as coastlines and floodplains, amplifies the consequences of flood hazards (Dookie & Gannon, 2022). Based on the most recent data provided by the Turkish Statistical Institute (TURKSTAT), Istanbul is home to an estimated 16 million individuals, which accounts for approximately 20% of the total population of the country (TURKSTAT, 2022). Moreover, Istanbul has earned a reputation as the most important city in Turkey, owing to its provision of essential industrial, economic, and social resources to the entire country. However, it is widely acknowledged that the city's vulnerability to disasters is a significant concern, owing to the rapid growth of its populace and the unplanned urbanization practices that have been practiced. Indeed, floods are a significant disaster that has occurred countless times throughout the history of Istanbul, resulting in substantial social and economic damage. The urban flood vulnerability of Istanbul is compounded by multiple factors, including poor urban planning and management, inadequate infrastructure, and environmental degradation.

The current body of literature has made minimal attempts to conduct a comprehensive evaluation of Istanbul's vulnerability to floods. This inadequacy stems from the absence of a comprehensive methodology that integrates both the physical and social aspects of vulnerability. The objective of this study is to address these gaps by utilizing a comprehensive methodology to assess the vulnerability of Istanbul to flooding. To provide a demonstration and rationale for the suggested methodology, the case analysis will center on the Kaynarca River situated in the Pendik region of Istanbul. Pendik, as a representative case of Istanbul's urbanization and internal migration patterns, is capable of acting as a model for comprehending the metropolis' vulnerability to flood events.

The principal aim of this study is to present a Multi-Criteria Decision Analysis (MCDA) method that utilizes Geographic Information Systems (GIS) to facilitate the recognition and ranking of flood risk indicators in the physical and social spheres. Through the utilization of GIS technology, this methodology presents a more precise and economical approach to evaluating Istanbul's vulnerability to flooding. Furthermore, it is anticipated that the results of this investigation will make a valuable contribution to the field of urban planning and disaster risk mitigation in Istanbul, augmenting the metropolis’ capacity to withstand flood occurrences. The research findings obtained from the analysis of Pendik can be utilized to develop effective policies and strategies for the wider Istanbul metropolitan region. Furthermore, the results of this endeavor could contribute to the scholarly discourse on evaluating flood vulnerability, particularly in urban regions characterized by intricate social and physical complexities. In conclusion, the outcomes of this investigation hold significant theoretical and practical consequences for urban planning and disaster risk mitigation endeavors in Istanbul, as well as in other regions.

1.2. Research Objectives and Questions

In Turkey, natural disasters such as floods and earthquakes have resulted in considerable damage to property and loss of life in recent years. As a result, both the government and society have started to acknowledge, albeit through challenging experiences, the seriousness of such events. However, scientific research and policy-making efforts focus almost exclusively on disaster risk and damage assessments.

Currently, in Turkey and Istanbul, the number of assessments that integrate social and physical vulnerability to river inundation is inadequate, and vulnerability discussions are frequently secondary. Istanbul, being the hub of economic, social, and cultural activities, is a focal point of discourse due to the high degree of urbanization pressure being experienced in its stream basins. Flood vulnerability is an area of research that attempts to identify the inclination of a society to be affected by disasters such as river flooding or sea level rise. With its emphasis on the human element, it surpasses conventional hazard and risk assessments and provides a social, economic, and physical picture of flooded areas.

The central objective of this research is to assess the vulnerability of urban areas in Istanbul to flooding, with a particular focus on the Kaynarca River basin situated within a context of significant urbanization. The study aims to examine the impact of urbanization pressures on the vulnerability of this stream basin to flooding events. By analyzing the specific conditions of this basin in relation to urbanization, the research seeks to gain a deeper understanding of the potential risks and challenges associated with flooding in rapidly developing areas of Istanbul. The findings of this study are intended to inform urban planning strategies and enhance the city's capacity for flood risk reduction and management in similar urbanized contexts. To achieve these goals, the research has identified specific objectives as follows:

- First, to identify flood vulnerability indicators and criteria through expert consultation and a literature review. This includes the quality of building stock, proximity to floodplains, population density, age, education level, etc.
- Second, to create a GIS-based MCDA framework to consider the identified indicators holistically and assess the flood vulnerability of one of the most urbanized watersheds in Istanbul.
- Third, to analyze results using descriptive statistics, spatial analysis and mapping techniques and present these results as a basis for potential policy-making processes.

Considering the research objectives stated above, the main question that this thesis is devoted to answering is:

- How can the physical and social flood vulnerability of Kaynarca River Basin in Istanbul be assessed, and what are the factors that contribute to this vulnerability?

1.3. Scope and Limitations

The present study puts forth an approach for evaluating the vulnerability of urban areas to flooding through the utilization of MCDA techniques and GIS tools. The selection of indicators was based on their relevance and the outcomes of the literature review. The study encompasses the geographic region of Kaynarca Stream situated in Pendik, Istanbul. Moreover, the present study is driven by an empirical investigation that draws on an expert questionnaire to assess the relative significance of indicators identified through a comprehensive review of the literature.

The availability and quality of the datasets used, which may have affected the validity of the analysis, were among the research's limitations. Furthermore, the research was constrained by the subjective evaluations and presumptions employed in the selection of indicators and assignment of weights. Likewise, the research was limited to metropolitan areas and may not be transferable to rural areas characterized by unique environmental, social, and economic contexts. Lastly, due to time limitations, the research concentrated on a certain type of MCDA methodology and did not explore or contrast alternative approaches that may possess diverse advantages and disadvantages such as Fuzzy Analytical Hierarchical Process (FAHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) and so forth. This could potentially limit the generalizability and applicability of the results.

Notwithstanding these constraints, the study provides significant and present-day insights into the vulnerability of Istanbul's urban areas to flooding. The findings of this research may provide a basis for the development of efficacious strategies aimed at reducing the vulnerability of the area to flooding and enhancing the adaptability of its populace.

1.4. Thesis Organization

This thesis is divided into four main sections to provide the readers with a solid understanding of the research topic being investigated. The first section begins with an overview of climate change and its impacts on urban areas, followed by a discussion of urban flood vulnerability indicators and the assessment techniques of flood vulnerability. The section then dives into GIS-based MCDA and discusses earlier research on flood vulnerability assessment in Istanbul, identifying literature gaps that the presented research aims to address.

The methodology chapter provides an overview of the study area, the sources of information that were employed, the flood vulnerability indicators, and the process utilized to produce the final indicator weights. The section then describes the selected MCDA approach and methodological techniques used to generate results. Beginning with descriptive statistics and data visualization, the Results and Analysis section presents the findings of this thesis. This is then followed by the presentation of the overall flood vulnerability map of the watershed as well as a rating of urban flood vulnerability indicators.

In the Discussion section, the outcomes and findings are interpreted and compared to existing literature. The section concludes with a discussion of the policy implications for urban flood management and planning in Istanbul, as well as limitations and potential research directions. The ultimate goal of this thesis is to give readers a thorough understanding of flood vulnerability in urban areas using a GIS-based MCDA perspective, as well as provide recommendations for improving flood management and planning in the city.

2. LITERATURE REVIEW

This section encompasses the inferences drawn from the literature review related to the concept of urban flood vulnerability, the extant research conducted in this field, and the methodologies advanced. The present section is partitioned into four subcategories, with each one specifically targeting one particular aspect of the research question. The initial subsection delves into the definitions and viewpoints concerning the notion of climate change and vulnerability to flooding within urban areas. The aim of this section is to furnish an in-depth understanding of the concept of flood vulnerability and its correlation with urban regions.

Indicators of urban flood vulnerability are addressed in the subsequent section. This subsection scrutinizes diverse physical and social indicators that have been identified in the literature and their application in evaluating flood vulnerability in urban areas. The objective of this section is to furnish an in-depth review of the diverse range of indicators that have been employed in previous research and their effectiveness in evaluating flood vulnerability.

In the third subsection, the use of GIS-based multi-criteria decision analysis in flood vulnerability assessment is discussed. This subsection investigates the relevance of this method to the assessment of flood vulnerability in urban areas and how it has been employed to identify areas at high risk of flooding. Finally, the fourth subsection presents a comprehensive overview of prior research endeavors pertaining to the evaluation of flood susceptibility in Istanbul. Additionally, it offers a summary of the key findings of these investigations, emphasizing their benefits and shortcomings.

2.1. Conceptual Framework on Urban Flood Vulnerability

2.1.1. Cities and Climate Change

Based on the most recent report by the Intergovernmental Panel on Climate Change (IPCC) (2022:13), global warming, reaching an increase of 1.5°C in the foreseeable future, would result "unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans". The report further suggests that surpassing this level of warming would end up resulting in some irreversible consequences (IPCC, 2022). The scholars highlight that climate change is intertwined with worldwide patterns, such as the inconsiderate consumption of natural resources and the escalating urbanization. Currently, a majority of the worldwide population resides in urban areas, and projections indicate that the percentage of urban dwellers will increase to over 70% by the year 2070 (United Nations (UN), 2019). In addition, the majority of global carbon dioxide emissions, exceeding 70%, are contributed by urban areas (Dasgupta et al., 2022). Climate change is causing significant changes in weather patterns, rising temperatures, sea-level rise, and more frequent and intense extreme weather events such as flooding, droughts, heatwaves, hurricanes, etc., and urban areas are particularly vulnerable to the impacts of climate change (Huq et al., 2007). Therefore, understanding the vulnerabilities of cities to climate change is crucial for developing effective strategies to mitigate and adapt to its impacts.

The word vulnerability derives from the Latin word *vulnus*, meaning 'wound' (Cuevas, 2011). In the context of climate change literature, vulnerability is the degree to which a person, a group, assets, or mechanisms are vulnerable to the consequences of hazards created by physical, social, economic, and environmental variables or procedures (United Nations Office for Disaster Risk Reduction (UNDRR), 2016). Several other definitions of vulnerability have been proposed in the literature. According to Cutter et al. (1993), vulnerability is a conceptual framework that gauges the degree to which a person or group experiences damage by a calamity, and it depends on the relationship between hazard and the societal characteristics of the affected populace. In addition to the aforementioned components, Füssel (2005) incorporated the notions of exposure, responsiveness, coping capacity, and criticality into the discussion of vulnerability, underscoring the non-existence of a singular optimal formulation of the phenomenon. Finally, the Sixth Assessment Report of the IPCC defines 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 a lack of capacity to cope and adapt" (IPCC, 2022:43). Both term's earliest uses and contemporary definitions converge on the idea that vulnerability arises from a tension between a system's exposure to harm and its ability to defend itself. Similarly, Kim and Chung (2013:302) define this relationship as a "dose-response" relationship, that is, the correlation between a hazard and adverse effects on a particular system.

The causal relationship between urbanization and human vulnerability to climate change is receiving increasing scrutiny from both the scientific and political spheres. The mainstream perspective indicates that countries experiencing rapid urbanization and economic metamorphosis encounter notable obstacles concerning their insufficient comprehension and the ability to tackle the adverse effects of climate change (Garschagen & Romero-Lankao, 2015). The report published by UN-HABITAT (2011), for instance, explores the variables that accelerate urban areas' contribution to climate change as well as the components that have rendered them vulnerable or resilient to it. Huq et al. (2007) gather the answer to the question of who is most at risk from the effects of climate change under the following three headings:

- Individuals who lack access to quality housing and drainage systems that can prevent flooding, those who are unable to relocate to less hazardous areas, and those who are unable to switch occupations if their jobs are threatened by climate change, i.e., groups whose livelihoods are exclusively dependent on agricultural activities.

- Secondly, groups such as infants and the elderly are more vulnerable to the negative effects of disasters due to their reduced physical or mental capacity to cope with extreme weather events.

- Lastly, individuals who are least equipped to manage the consequences of disasters, such as illness, injury, premature death, or loss of income or property, are also disproportionately affected.

The definition of Huq et al. (2007) supports the idea that the importance of a community's vulnerability to loss and damage from extreme climate change-induced events is a critical factor in determining the likelihood that such events will turn into a major disaster (IPCC, 2012). It is crucial to emphasize that the effects of even relatively minor events can be magnified by physical, ecological, and social factors that contribute to vulnerability and that these effects may be presented unevenly to certain groups of people. Therefore, discussions are centered around low-income countries and communities that do not have access to alternative solutions aimed at reducing risk, exposure, and vulnerability (IPCC, 2012).

Nevertheless, some scholars also argue that scholarly discourse has frequently emphasized the adverse consequences of urbanization while neglecting the potential of urban areas as a viable mechanism for addressing climate change (Garschagen & Romero-Lankao, 2015). Given the capacity of urban areas to accommodate a wide variety of services, institutions, and human capital, there is potential for the implementation of different methods, such as nature-based solutions (NBS), to mitigate and cope with climate change risks (Hobbie & Grimm, 2020). Moreover, alliances established in recent years, such as the World Mayors Council on Climate Change (WMCCC) and the C40 Cities Climate Leadership Group, confirm the idea that city leaders are far more willing than national politicians to take action to protect against threats and contribute to making a global difference (Rosenzweig et al., 2010).

There is an increasing trend among studies that emphasize vulnerability-led assessment over impact-led assessment (Kim and Chung, 2013). Therefore, research on the vulnerability of cities to climate change has been growing rapidly in recent years. There have been several studies that have examined the different dimensions of vulnerability in urban areas, including exposure, susceptibility, and resilience. These studies have used a range of approaches, from modeling the physical impacts of climate change on urban areas to examining the social and economic factors that contribute to vulnerability. The concept of vulnerability can be analyzed across various levels and scopes, depending on the specific concerns under consideration. This methodology can be employed to examine a singular matter, such as a building, or to evaluate a multifaceted entity, such as a metropolitan area (Barroca et al., 2006). Zarafshani et al. (2016:14), for instance, claim that "vulnerability assessments should shift away from a positivistic view that attempts to use quantitative indices to a mixed paradigm in which a combination of quantitative and qualitative measurements are used to assess vulnerability’’ and conclude that greater emphasis should be placed on the qualitative dimension of vulnerability.

2.1.2. Flood Vulnerability in Urban Area

Climate change possesses the capability to amplify the likelihood of flooding by means of multiple mechanisms, such as raised sea levels and storm surges from the sea, glacial lake outbursts, and intensified and prolonged rainfall (Huq et al., 2007). The event referred to as urban flooding involves the submergence of land or property within a built environment, predominantly in areas with high population densities (Safia Yusmah et al., 2020). The phenomenon of flood vulnerability is related to the degree of susceptibility, exposure, and coping capacity of individuals or a particular area to floods (Rehman et al., 2019).

The effects of flooding in urban areas are often a phenomenon where governance and urban planning should go hand in hand. The prevalence of impervious surfaces in metropolitan regions poses a challenge for the infiltration of precipitation into the ground, leading to a rise in surface runoff. The implementation of appropriate urban planning and governance strategies, such as the augmentation of green spaces, can effectively mitigate this issue. However, inadequately designed urban areas may not possess the capacity to accommodate such measures, thereby rendering them ineffective (Huq et al., 2007).

Over the past ten years, the quantity of studies on urban flood vulnerability has grown significantly (Cho & Chang, 2017). According to previous studies, flood vulnerability assessment is a critical step in identifying areas that are most at risk of flooding (Kienberger et al., 2014). While there is a consensus in the literature about the importance of vulnerability as a concept for understanding the impacts of climate change on cities, there are also different perspectives on how vulnerability should be measured. Examining the research on flood vulnerability in chronological order reveals that physical and socioeconomic approaches gained prominence in the 1990s, while spatial vulnerability assessments using remote sensing data and multispectral data gained prominence in the 2010s. After 2010, three-dimensional hydrological modeling in a GIS environment dominated scientific literature (Rehman et al., 2019).

To date, research on flood vulnerability assessment can be categorized into qualitative and quantitative approaches, with some studies utilizing a combination of both approaches. Quantitative approaches commonly employ numerical information, mathematical models, and statistical evaluation to evaluate the physical and social factors that influence flood vulnerability. Quantitative methods for evaluating flood vulnerability comprise GIS-based assessment, hydrological modeling, and statistical analysis of past incidents of floods. In contrast to quantitative approaches, qualitative methodologies employ subjective observations, expert opinions, and surveys to evaluate the social and cultural determinants that impact flood vulnerability.

2.2. Urban Flood Vulnerability Indicators

To date, various quantitative approaches have been employed in order to assess flood vulnerability. Nasiri et al. (2016) reviewed the most prevalent of these assessment techniques (curve method, disaster loss data method, computer modeling methods, and indicator-based methods) and concluded that the indicator-based approach provides a more thorough and precise portrayal of flood vulnerability. The indicator-based approach was adopted as the main assessment framework in this thesis. This section therefore aims to review previous research in the field of flood vulnerability analysis for the purpose of identifying the most known and accepted indicators.

An indicator or collection of indicators is typically characterized as statistics that quantitatively anticipate and synthesize the current characteristics of a system as well as provide data associated with it, for example, the child mortality rate in a region, the unemployment rate among adults, and the land use characteristics of a geographical area (Balica et al., 2010; Moreira et al., 2021). Similarly, Rehman et al. (2019) recommended assessing flood vulnerability using appropriate indicators such as environmental, economic and social vulnerability, categorizing it into various classes, such as degraded forest, land use poverty, age and gender. Throughout previous research, the deductive approach has been suggested as a general framework, and it has been stated that this method consists of the stages of comprehending the occurrence, identifying mechanisms, and selecting indicators (Balica et al., 2010).

Although indicator-based assessment frameworks for flood vulnerability are widely accepted and commonly used (Balica et al., 2010), a consensus on a common set of indicators has yet to emerge (Bigi et al., 2021). Furthermore, the inability to measure flood vulnerability clearly and accurately as a result of an absence of data and the geographical and social variability of vulnerability have mostly been determined to be the primary concerns with the indicator-based approach (Nasiri et al., 2016; Adger et al., 2004; Adger, 2006). Given the diversity and complexity of urban life, the evaluation of flood vulnerability in urban areas requires the consideration of an array of criteria. Similarly, it was underlined that a single indicator cannot be used to assess flood vulnerability and that multiple indicators must be turned into quantifiable features to gain an all-encompassing portrait of the flood vulnerability phenomenon (Balica et al., 2010). Correspondingly, it is essential to have a comprehensive understanding of the components that lead to flood vulnerability in order to decide on acceptable criteria for the assessment of flood vulnerability. On the other hand, it is also argued that the selection of indicators is determined mainly by the data that can be obtained and that the indicators overlap in the majority of research efforts (Moreira et al., 2021). Similarly, indicators and indicator sets often encounter challenges due to their subjectivity, bias, weighting, aggregation, normalization, and selection (Fekete, 2010).

The quantity of designated indicators is another subject that has been addressed in the literature. In the study conducted by Balica et al. (2010), the ultimate objective was to remove redundant or ineffective indicators from the flood vulnerability index and to present the index in a clear, flexible, and uncomplicated manner to be utilized by various stakeholders. In this study, seventy-one indicators pertaining to flood vulnerability were initially identified, and then the resulting index was transformed into a collection of twenty indicators for river basins using a three-step evaluation procedure, namely the derivative method, questionnaire application, and correlation method (Balica et al., 2010). In the review by Moreira et al. (2021), which analyzed 95 articles published on flood vulnerability since the year 2015, an average of 16 indicators were used, and the majority of the studies (58%) did not make any attempt to minimize the number of indicators.

As a local phenomenon, flood vulnerability is affected by local characteristics such as local construction techniques, the living conditions of communities, and the diversity of the population. That is why, in flood vulnerability literature, indicators that are specific to the study area can be found. Research highlights the partiality and context-dependence of current approaches as well as indicator choices, and it is claimed that the need for customized instruments for assessing flood vulnerability is growing since the indicators that are crucial for one region may not be crucial for other regions due to factors such as differentiated urbanization patterns or population dynamics. On the basis of this need, Barroca et al. (2006) developed a customizable software interface that presents potential vulnerability parameters and their interactions and made this instrument accessible to various stakeholders (economists, urban planners, local administrators, etc.). It has been concluded that local-specific indicators can be effectively chosen for each case study using their instrument (Barroca et al., 2006).

Relevant literature has pointed out the significance of determining suitable indicators capable of providing proper insights into the factors that lead to flood vulnerability. These studies vary in terms of the identification of the criteria. Indicators of flood vulnerability can be classified into two primary categories: social and physical indicators. Social indicators correspond to the vulnerability of the inhabitants residing in the area, such as their level of income, educational status, occupational status, and ability to access resources, whereas physical indicators directly relate to the physical characteristics of an area, such as topography, land use, and building type.

2.2.1. Social Indicators of Flood Vulnerability

The social dimensions of vulnerability are often addressed to determine and comprehend if certain individuals, groups, or communities are more sensitive and vulnerable to the consequences of natural disasters (Chakraborty et al., 2020). The term social vulnerability refers to the characteristics of a society, such as its demographic structure, living conditions, overall health, and other characteristics of individuals and communities. It is difficult to assess the level of exposure and vulnerability of residents to flood hazards due to the complex nature of urban systems, including the diversity of social interactions and the distinctive characteristics of each society (Cho & Chang, 2017). Similarly, Cutter et al. (2003) argue that the social vulnerability dimension has not been adequately addressed in the relevant literature. This is due to the difficulty of measuring socially stimulated vulnerabilities, which are challenging to evaluate since they require an in-depth comprehension and investigation of the socio-ecological aspects of the region (Cho & Chang, 2017).

Researchers highlight the significance of social vulnerability indicators in flood risk management, particularly in the process of allocating resources to mitigate flood damage (Lee, 2014). Likewise, in order to further guide disaster risk management efforts, knowing which groups are more vulnerable to being impacted by floods and where they reside is essential (Mason et al., 2021). Social determinants of flood vulnerability include social inequality, a lack of economic and political authority, and a lack of resources that limit the ability of vulnerable groups to avoid hazardous areas (Blaikie et al., 2014).

Numerous empirical studies have generated social vulnerability indexes specific to floods. Cutter et al. (2003) were among the first to develop methodologies for assessing social vulnerability. They identified several indicators related to economic and demographic characteristics of inhabitants and infrastructure density, then combined them into an index called the Social Vulnerability Index (SoVI) (Cutter et al., 2003).

One of the most widely used social vulnerability indicators is age, with the elderly and very young often being disproportionately affected by floods. The findings of the study by Tellman et al. (2020), which aims to validate social indicators based on the outcomes of 11,629 non-coastal past flood events throughout the United States between 2008 and 2012, indicate that counties with a larger percentage of elderly (over 65 years old) and a smaller percentage of the population under 5 years old are significantly correlated with a higher number of flood fatalities. Morimoto (2019) emphasized that isolated individuals and people aged 65–74 increase vulnerability and drew attention to the importance of early warning systems and various transfer mechanisms to ensure the safety of these groups. Similarly, it has been argued that the population over the age of 75 and between the ages of 0 and 9 should be included in this planning (Morimoto, 2019). Aldrich and Benson's (2007) study seem to support the idea that the physical, mental, and perceptual limitations of the elderly that may limit their ability to cope with floods make them a more dependent group on the support of others in disasters. Nonetheless, it is noted that age does not serve as the sole key determinant and that particular groups having similarities to the elderly require the same degree of assistance regardless of their chronological age. For instance, people with lower physical power also have relatively low thresholds for enduring the consequences of flooding, and some research suggests that disabled individuals or those with additional responsibilities, such as women who handle child care, are also associated with higher rates of death and injury during floods (Fekete, 2010).

Several studies have pointed to the significant correlation between income level and social vulnerability to floods. For instance, Fekete (2010) stated that families with low incomes and people who live alone may have a lower capacity to protect themselves during hazards. In a study conducted in the Dutch province of Zeeland, it was determined that the first six of the fifty districts with the highest social vulnerability scores are located in Zeeland's most populous municipality, Terneuzen. The relatively large number of low-income households was claimed to be one of the reasons why Terneuzen scored the lowest (Kirby et al., 2019). If data is available, the occupational status factor has also been shown in research to be associated with the economic component of social vulnerability, alongside income. A study of 200 adults surveyed after the 1984 Kentucky flood, for instance, highlighted the relatively high rates of psychosomatic symptoms experienced by men of lower occupational status (Phifer, 1990). Furthermore, lower land values and house rents in flood-prone areas were documented to impact the site selection of informal sectors and workers employed in these fields (Twinomuhangi, 2021).

Educational attainment is another indicator of social vulnerability, which is additionally positively linked with flood preparedness and response. According to Paul and Routray (2010) educational level of individuals is another indicator of social vulnerability, which is additionally positively linked with flood preparedness and response. Paul and Routray's (2010) research emphasize that educational level is related to the capacity to comprehend flood forecasts and warnings, suggesting that illiterate household heads or those with primary school education remain far behind educated people in understanding flood forecasts. Similarly, a population with a higher literacy rate may also perform better in the face of floods as they are more inclined to implement flood-resilience precautions prior to and during the event (Salazar-Briones et al., 2020; Chakraborty & Mukhopadhyay, 2019; Chen et al., 2013). The social vulnerability of illiterate women is doubled since, in certain communities, education is strictly tied to gender roles. Several cultures still pose greater obstacles for females to receive a formal education than males due to social practices such as child marriages, especially in less developed countries (Ferdous & Mallick, 2019). However, the other aspect of the debate is the economic damage experienced by low-income families as a consequence of the flood, which also pushes these parents to marry off their daughters at an early age, producing a vicious cycle that renders women 'the most vulnerable of the vulnerables' (Ferdous & Mallick, 2019).

Gender has also been suggested as a social vulnerability determinant, with floods and other natural disasters disproportionately targeting women. The gender dimension itself is often viewed as an intersection of feminist political ecology, environmental justice, and vulnerability studies and focuses on whether disasters are gender neutral or not. The reasons why women are relatively more vulnerable in disaster situations include their economic and social dependence on men, their greater domestic workload, their limited mobility, and their caregiving responsibilities (Singh, 2020). According to shared perception, women are more vulnerable during and after a disaster due to gender discrimination and gender roles (Singh, 2020; Ferdous & Mallick, 2019; Islam, 2017). Contrary to generally held perception, some research suggests that gender itself is not an indicator of vulnerability but rather a combination of social as well as institutional conditions such as women's level of income, class, and occupational status. In a survey of women who had experienced flooding in Lagos, it was found that a majority of the women agreed that the flood was gender neutral (Ajibade et al., 2013). However, while women in high-income groups were affected by floods equally to men, researchers also indicated that women in lower economic levels were more affected by the flood due to factors such as their caregiving, cleaning, and cooking responsibilities and shelter problems after the disaster, as well as being faced with gender discrimination and privacy concerns (Ajibade et al., 2013).

Conventional vulnerability assessments frequently fail to recognize that certain vulnerable groups are disproportionately impacted by floods, such as refugees, immigrants, and minorities. Research on hazards and environmental justice (EJ) shows that disadvantaged and marginalized populations are often extremely vulnerable to threats and natural hazards (Collins, 2010). Due to the diversity of indigenous cultures and the existence of linguistic barriers, ethnic diversity is considered one of the factors complicating disaster crisis management. Cities with a substantial immigrant population are considered to be more at risk since it is difficult to coordinate efforts among different ethnic backgrounds in the event of an emergency, which is deemed to be one of the obstacles to minimizing flood impacts (Eini et al., 2020). A study of the United States, for instance, found that a disproportionate number of racial minorities reside in flood-prone areas, along with a higher proportion of mobile homes (Tate et al., 2021). On the other hand, immigrants and refugees have to reside in the most vulnerable areas of cities, as their low income limits their mobility and choice of place to live.

As a research gap, it has been noted that social indicators that increase people's vulnerability are commonly included in the indexes, whereas indicators of coping and adaptive capacity are not employed as frequently (Moreira et al., 2021). It has been emphasized that measuring coping capacity at larger scales and across diverse populations is a difficult process due to the difficulty of measuring the complexity of interconnections between social networks and institutions and potential data limitations (Tellman et al., 2020). However, a few notable exceptions exist. The research of Chen et al. (2021), for instance, downscaled the discussion from the community level to the individual level and surveyed 10 distinct affordable housing communities established along China's largest river. The results show that in the Shangfang area, which has the highest exposure, despite the severe water accumulation, the residents have a strong awareness of preventing flooding; in other words, the research reflected a positive relationship between exposure and adaptability (Chen et al., 2021).

All in all, the social indicators used to quantify flood risk are as diverse as the notion of social vulnerability itself. Social vulnerability can be determined by numerous factors, including the person’s income, degree of education, social networks, gender, age, ethnicity, and health condition. Nevertheless, the efficacy of these factors in various settings may differ, and additional studies need to be conducted to produce more context-specific measurements of social vulnerability.

2.2.2. Physical Indicators of Flood Vulnerability

Physical and environmental vulnerability indicators are often used interchangeably and encompass conditions external to socioeconomic processes that impact vulnerability. In recent years, the impact of climate change on urban flood vulnerability has grown into a main consideration, as changing weather patterns and increased precipitation can substantially raise the likelihood of flooding in urban areas.

Studies generally correlate the physical vulnerability component with the exposure dimension and include the hydrological indicators in their analysis. The elements or assets in a particular area are considered to be ‘exposed’ to the possibility of flooding (Balica et al., 2012). The majority of studies have used hydrologic computational methods to model flood runoff in order to provide flood risk assessment information on the probability of flood occurrence, severity of the event, and location. In an urban flood vulnerability study conducted by Eguaroje et al. (2015), seven distinct physical vulnerability criteria were examined, namely, mean annual rainfall, soil type, slope, land use, drainage density, relief, and drainage order level, and their analysis concluded that the mean annual rainfall factor contributes more to flooding. In a way similar to this, Blistanova et al. (2016) used hydrological, geological, and physio-geographical factors as inputs in their research and evaluated the Bodva basin based on five distinct factors: precipitation regime, slope of the basin, land use characteristics, soil type, and total basin area.

Together with social parameters, Nguyen et al. (2019) have included physical indicators in their index, namely, households in a flooded area, flood water depth, proximity of the village to the river, flood frequency (per 10 years), and farmland in a flooded area, and they concluded that the areas with high vulnerability had both a high risk of inundation and a low resistance to it. Moreover, the number of households residing in the floodplain has been revealed to be the factor that increases exposure the most (Nguyen et al., 2019). Some argue that each individual in the floodplain with immediate access to shelters and health services would significantly lessen the effects of catastrophes and prevent the further spread of possible water-borne diseases (Mitra et al., 2022; Chakraborty & Mukhopadhyay, 2019).

In some studies, physical vulnerability is also referred to as structural vulnerability, and factors such as the use of inappropriate construction materials, open sewage systems, and garbage accumulation are additionally included in this category (de Brito et al., 2018). Similarly, structures made of porous materials, like wood or brick, may be more vulnerable to flood damage as they can absorb the water and weaken or become unstable (Hussain et al., 2021). Also, older buildings that were not constructed or planned to endure floods may be more vulnerable to risks (Wing et al., 2020; Fatemi et al., 2020). It is anticipated that since a building’s foundation strength directly relates to its weight, and as buildings with more stories are likely to weigh heavier, it will be more difficult for floodwaters to carry these structures away. Thus, the vulnerability would diminish as the number of stories increased (Usman et al., 2021).

Several other physical vulnerability indicators may only be measured or appear at the moment of a disaster event, according to a different perspective. These indicators include the number of authorized personnel assigned to disaster coordination, the efficacy of flood protection measures, and the quality of disaster management organizations or institutions (Messner & Meyer, 2006; Penning-Rowsell & Wilson, 2006). Table 2.1 wraps up several indicators from selected flood vulnerability assessment research.

Table 2.1. Indicators related to the assessment of flood vulnerability in selected studies.

Authors & Publication Years	Physical Vulnerability Indicators	Social Vulnerability Indicators
(Abebe et al., 2017)	Land Cover, Slope, Elevation, Soil Drainage Class, Drainage Density, Rainfall Intensity	Population Density
(Blistanova et al., 2016)	Precipitation, Basin slope, Land use, Soil type, Catchment area	-
(Desalegn et al., 2021)	Slope, Elevation, Land use/land cover, Drainage density, Rainfall, Soil Types	-
(Eguaroje et al., 2015)	Annual Rainfall, Slope, Soil Types, Land use, Drainage Order level, Drainage Density	-
(Feloni et al., 2020)	Elevation, Slope, Aspect, Distance to channel network, Rainfall	-
(Fernandez et al., 2010)	Number of Buildings, Floors of buildings, Functions of buildings, Land use	Population, Age, Gender, Family number, Level of education, Literacy rate, Housing occupancy, Unemployment rate
(Hussain et al., 2021)	Precipitation, Slope, Distance to active channel, Land use/land cover	Dependent population, Independent population, Population density, Cultivated area, Uncultivated area, Unirrigated area, Irrigated area, Freshwater facilities, Forests
(Ibrahim et al., 2017)	Soil to Erosion Potential, Transportation Network, Shopping Market Locations, Irrigation Infrastructure	Population
(Murali et al., 2020)	Land use/land cover, Elevation, Past flood occurred regions	-
(Ouma & Tateishi, 2014)	Drainage, Elevation, Slope, Soil, Land Use	-

2.3. Multi-Criteria Decision Analysis

Making a decision involves intentionally weighing the advantages and disadvantages of each option to find the best way to move forward, taking into account all of the relevant information and potential consequences. It is noteworthy that the processes of ranking, selection, and sorting also fall within the classification of decision problems (Ishizaka & Nemery, 2013). According to Belton and Stewart (2002), every decision taken, sometimes explicitly and sometimes subconsciously, emerged as a result of a combination of many factors or criteria in a certain balance.

The complexity of this process has been widely acknowledged, referring to its multifaceted nature that encompasses the diverse viewpoints and distinct ideals held by decision-makers and all parties impacted by the consequent decisions (Marttunen & Belton, 2017). Environmental decision-making is also regarded as complex due to its reliance on a diverse range of knowledge domains, such as the natural and physical sciences, social sciences, politics, ethics, and various stakeholders (Huang et al., 2011; Linkov & Moberg, 2012; Cegan et al., 2017). The MCDA methods are widely recognized as the primary decision-making approaches that consider multiple criteria during the decision-making process and are considered a viable approach for effectively integrating diverse and disparate components (Cegan et al., 2017; Taherdoost & Madanchian, 2023).

Over the past few decades, various authors have developed and enhanced MCDA methodologies. Numerous MCDA techniques have been developed, each possessing unique characteristics. The literature contains diverse classifications of these methods as well as their implementations (De Montis et al., 2004; Triantaphyllou, 2000). The most commonly used MCDA approaches are:

1. The Weighted Sum Model (WSM) is a prevalent and time-honored approach in the field, and the process entails assigning weights to individual criteria and subsequently aggregating the weighted scores of each available option (Triantaphyllou, 2000).

2. AHP, which was introduced by Saaty in 1980, facilitates the determination of the relative importance of criteria and optimal options by utilizing priority vectors derived from pairwise comparisons (Saaty, 1980).

3. The Elimination Et Choix Traduisant la Réalité (ELECTRE) method, known as one of the outranking methods, aims to identify the set of alternatives that dominate other options while remaining non-dominated by any other options. ELECTRE is a MCDA technique that enables decision-makers to identify the optimal option based on various criteria while minimizing conflicts and maximizing benefits (Dahbi et al., 2020).

4. TOPSIS, which was proposed by Hwang and Yoon (1981), is considered one of the most employed MCDA techniques. The approach entails assessing each option by determining its proximity to both the positive ideal solution (PIS) and the negative ideal solution (NIS), which is referred to as the worst solution. The PIS is the solution that maximizes the benefits of the criteria, whereas the NIS is the solution that minimizes the negative aspects. The TOPSIS procedure emphasizes the alternatives by assessing how closely they are located to the PIS and their distance from the NIS (Hwang & Yoon, 1981; Çelikbilek & Tüysüz, 2020).

5. PROMETHEE was initially introduced by Brans in 1982 and subsequently expanded upon by Vencke and Brans in 1985 (Oubahman & Duleba, 2021). The approach is mainly recognized for its straightforwardness and capacity to evaluate data from diverse sources. The PROMETHEE method facilitates the simultaneous comparison of data that were initially presented in varying units and scales (Soldati et al., 2022). In order to enhance the efficacy of the model, it is suggested to integrate PROMETHEE with weighing techniques such as AHP (Oubahman & Duleba, 2021).

The aforementioned MCDA methodologies are prevalent in the field; however, there are several others, including MacBETH, MOORA, and VIKOR, each with their own unique benefits and drawbacks. While scholars acknowledge the favorable progress in the exploration of novel MCDA techniques and the refinement of established algorithms, they highlight the insufficient emphasis placed on the cautious selection of these methods for specific decision-making scenarios and caution against the potential consequences of utilizing an unsuitable approach, which may compromise the quality of the resulting recommendations (Bczkiewicz et al., 2021). Therefore, it is significant to choose an appropriate MCDA method in order to achieve efficient outputs.

The MCDA has been extensively adopted in the context of flood vulnerability assessments, particularly in the process of assigning weights to indicators. It is assumed that if practitioners and experts are involved in creating an index that they find useful, it is more likely that they will trust its results (Oulahen et al., 2015). On the other hand, in order to identify optimal policy alternatives, MCDA methods have been effectively employed in the past (Kim & Chung, 2013). Upon examination of various methods, it has been asserted that the Analytic Hierarchy Process (AHP) is the most utilized MCDA method in studies related to flood vulnerability (Moreira et al., 2021). Table 2.2 presents several similar studies that have employed MCDM techniques for flood vulnerability assessment.

Table 2.2. The selected studies using MCDA approaches.

Reference	Study Area	Country	Number of Criteria	Adopted Method(s)
Lee et al. (2015)	Han River	Korea	24	VIKOR
Vignesh et al. (2021)	Kanyakumari	India	10	AHP
de Brito et al. (2018)	Lajeado and Estrela	Brazil	11	AHP, ANP
Hadi et al. (2017)	Kedah State	Malaysia	4	AHP, Rank Sum
Ganji et al. (2022)	Aq’Qala county	Iran	18	AHP
Morea & Samanta (2020)	Kemp-Welch Catchment	Papua New Guinea	9	AHP
Feloni et al. (2019)	Attica region	Greece	9	AHP, FAHP

2.3.1. Analytical Hierarchical Process (AHP)

The Analytic Hierarchical Process (AHP) is a method for making decisions involving multiple criteria that are subjective and incompatible (Ishizaka & Labib, 2009). The AHP method was developed by Saaty (1980) and is utilized to evaluate the qualitative as well as quantitative multi-criteria factors that are taken into consideration in decision-making scenarios. As a frequently used

MCDA strategy in flood literature, AHP assists researchers in dealing with complex decisions in structuring flood-causing factors; however, it should be noted that this method aims to aid the decision makers in comprehending the decision problem rather than making the right decision (Ouma & Tateishi, 2014).

Pairwise comparisons are fundamental to the use of the AHP (Saaty, 1987). Some authors point out that AHP allows for a hierarchical presentation of criteria, arguing that this has the advantage that it allows users to better focus on specific criteria and sub-criteria (Ouma & Tateishi, 2014). Moreover, the AHP methodology's potential to manage quantitative as well as qualitative information renders it an effective solution for certain prioritization issues that consider distinct criteria (Ouma & Tateishi, 2014).

AHP has been widely utilized through studies on flood vulnerability assessment, illustrating successful results in the identification of the most vulnerable regions and assisting as a useful tool. The prevalent utilization of AHP is attributed to its straightforward implementation and naturally intuitive problem-solving strategy (Ishizaka & Labib, 2009). The integration of heterogeneous data is another key factor contributing to the widespread popularity of the method (Chen & Khan, 2013).

According to Ouma and Tateishi (2014), AHP exhibits versatile performance in urban flood studies and is defined as a beneficial tool in the processing of spatial data. They found that the most important factor in flood vulnerability is soil cover by reaching a consistency ratio of 0.09 in their studies using the AHP method (Ouma & Tateishi, 2014). Similarly, Hoque et al. (2019) adopted the AHP method to amalgamate several natural, social, and physical criteria for a flood vulnerability assessment in Bangladesh, and their findings conclude that the use of the AHP approach provides powerful results for weighting the set of indicators and supporting the spatial decision-making process. The study of Usman Kaoje et al. (2021), on the other hand, employed the AHP method in order to determine building-based flood vulnerability rather than an area-based assessment strategy by incorporating the perspectives of 31 experts in total.

Apart from the conventional AHP formulated by Saaty (1977), numerous novel methodologies have also been noticed in the relevant literature. A significant portion of these efforts focuses on the utilization of the current AHP framework by incorporating it with various models and procedures. For instance, Ali et al. (2019) employed the AHP methodology to determine the weight of the chosen flood vulnerability factors, and they subsequently utilized the Frequency Ratio (FR) model to establish the correlation between previous flood occurrences and the likelihood of future flooding, drawing from a sample of 200 flood points. Similarly, Albulescu et al. (2022) performed research on hydrological vulnerabilities in drainage basins located in northeastern Romania by employing a combination of the TOPSIS and AHP methodologies. The paper examines multiple variables such as the occurrence rate of hydrological events, the extent of coverage of hydrotechnical structures, land use patterns, topographical features, and aspects of the hydrological network. The study highlights the potential of utilizing the AHP-TOPSIS-based framework as a practical and adaptable research tool (Albulescu et al., 2022). Senan et al. (2023) conducted a study in the Western Ghats of India to identify areas vulnerable to flooding. The researchers used two methodologies, AHP and F-AHP, and concluded that both methods were effective. When receiver operating characteristic (ROC) analysis confirmed the identified regions, they asserted that the AHP methodology produced better results (Senan et al., 2022).

There are arguments that the AHP is accompanied by certain drawbacks in addition to its favorable outcomes. One potential issue refers to the extensive quantity of questions that a decision-maker must respond to, which may result in a complicated and fatigued process (Ishizaka & Labib, 2009). Another concern is mostly related to the inescapability of experts showing bias and subjectivity while assessing the criteria. Nefeslioğlu et al. (2013) put forward an alternative approach called Modified Analytic Hierarchy Process (M-AHP) to address this downside. The model was designed to ensure that the experts assigned a score for each criterion and refrained from generating a pairwise comparison matrix. Similar to the conventional AHP approach, attention was put on maintaining a consistency ratio of less than 10% (Nefeslioğlu et al., 2013). A further concern regarding the approach relates to its capacity to generate outcomes that may be less dependable, as it neglects to consider fuzziness and uncertainty (Ekmekçioğlu et al., 2021; Chen & Khan, 2013). Lastly, the methodology has faced criticism for the lack of clarity in the process of converting linguistic descriptions that are assigned to the precise numerical values that are utilized in the comparison matrix (Feizizadeh & Kienberger, 2017).

Chen and Khan (2013) highlight that the AHP places greater emphasis on prioritizing input factors based on their relative importance, although it does not provide a quantitative measure of importance among factors. The authors also contend that the uncertainty associated with criterion weights is the primary factor that impacts the final result, as opposed to problems in other elements of the methodology (Chen & Khan, 2013). In light of these limitations, the sensitivity analysis approach has become increasingly significant in scholarly discourse. In order to comprehensively grasp the ambiguities that arise from AHP and evaluate the uniformity of model outputs, researchers have frequently suggested the utilization of sensitivity analysis and uncertainty analysis of criteria weights and these approaches are deemed more favorable, particularly in cases where the results of MCDA have the objective to offer decision-making assistance (de Brito et al., 2019). Sensitivity analysis is recognized for offering satisfactory responses to "what if" questions as well as assisting to strengthen the dependability of the model by analyzing the robustness of the ideal decision under changes in indicators (Erkut & Tarımcılar, 1991:62). Additionally, it has been claimed that this tool can serve as an efficient way of assessing the endurance of the ultimate outcome in response to variations in the input information (Chen et al., 2009). Yahaya et al. (2010) suggest that the implementation of a sensitivity analysis can prove to be beneficial in cases where there exist uncertainties associated with the determination of the significance of various factors.

The insufficiency of sensitivity analysis endeavors in flood vulnerability research has been highlighted by scholars (Feizizadeh & Kienberger, 2017). Yahaya et al. (2010) conducted a sensitivity analysis on the weights derived from the AHP in a study of a river basin located in Nigeria. According to the authors' assessment, the sensitivity analysis did not result in any significant alteration in the order of the criteria (Yahaya et al., 2010). Another study conducted to examine the viability of utilizing a combined uncertainty and sensitivity analysis approach to reduce the related uncertainty in various aspects of vulnerability assessment (Feizizadeh & Kienberger, 2017). The study employed a variance-based global sensitivity analysis to gauge the sensitivity of decision makers and the authors concluded that their findings exhibit the effectiveness of the sensitivity analysis in reducing the ambiguity linked to GIS-MCDA models (Feizizadeh & Kienberger, 2017).

2.3.2. AHP-GIS Implementation Strategy in Urban Flood Vulnerability Assessments

AHP and GIS are frequently employed by multiple studies to facilitate the decision-making process. The amalgamation of two approaches in the domain of urban flood vulnerability assessments has been demonstrated to be a beneficial instrument for recognizing flood-prone regions and assessing their vulnerability to flooding. This section highlights research endeavors that employ the combined use of AHP and GIS, while expounding on the approach's details in the methodology section.

Malczewski (2006) claims that the combined use of GIS and MCDA has received considerable attention from the world of academia in recent years. Similarly, Fekete (2021) highlights the growing prevalence of GIS-based multi-criteria decision analysis in flood vulnerability assessment research in the past few years, owing to its capacity to combine multiple considerations and furnish a comprehensive assessment framework. In this combination, AHP is used to determine the relative importance of each criterion or alternative, while GIS is employed to map out the vulnerable areas and evaluate spatial connections as well as patterns of flood vulnerability. It has been claimed that the synthesis of AHP and GIS methodologies constitutes an efficient framework for making decisions in the context of flooding problems, given that it enables the systematic and effective utilization of spatial information (Ouma & Tateishi, 2014). Therefore, integrated AHP and GIS approaches are extensively utilized in studies worldwide (see, for instance, Feloni et al., 2020; Ouma & Tateishi, 2014; Atijosan et al., 2021; Desalegn & Mulu, 2021; Tempa, 2022; Gupta & Dixit, 2022).

Hussain et al. (2021) emphasized the importance of possessing comprehensive knowledge on field conditions, hydrological statistics, detailed socioeconomic statistics, and flood protection structure characteristics to effectively utilize the GIS and AHP methodologies in their research. The authors emphasized the significance of geospatial techniques in producing vulnerability maps with high levels of accuracy and precision. However, they also drew attention to the challenges associated with gathering data for spatial decision-making methods in economically disadvantaged nations (Hussain et al., 2021). Likewise, Chakraborty and Mukhopadhyay's research (2019) proposes that the combined application of AHP and GIS demonstrates an outstanding level of efficacy and serves as a dependable mechanism for evaluating vulnerabilities associated with flooding, particularly in data-scarce regions. Another research by Ali et al. (2019), mixing AHP and GIS methodologies, showed that topographic parameters had a considerably less significant impact on flood risk than distance from river, LULC, and soil features. In contrast to previous research, a recent investigation aimed to evaluate the vulnerability of the Accra Metropolis to flooding by examining its temporal variances. The study employed the AHP-GIS composite urban flood vulnerability assessment technique to identify areas that are prone to flooding for the years 2007, 2010, 2015, and 2020 (Nkonu et al., 2023). The study findings indicate an increase in vulnerable to flooding regions from 2007 to 2020, with the primary causative factors being alterations in land use (Nkonu et al., 2023).

The amalgamation of AHP-GIS research with various field studies maintains potential for producing spatial outcomes that aid in pinpointing susceptible communities and evaluating their adaptability. A research endeavor carried out in Vietnam effectively delineated regions susceptible to flooding and exhibited a robust association between the identified vulnerable communities along with the field survey data (An et al., 2021).

All in all, the combined use of AHP and GIS methods can be regarded as complementing one another and capable of offering an in-depth and geographically precise evaluation of flood vulnerability.

2.4. Previous Studies on Flood Vulnerability Assessment in Istanbul

Between 1975 and 2015, Turkey had 1209 floods, resulting in the deaths of 720 people and the flooding of 900,000 hectares (Ekmekçioğlu et al., 2021). Istanbul is the province with the highest population density, with 2 thousand 976 people per square kilometer (TURKSTAT, 2022). The city has experienced many flood disasters throughout history. Factors such as unplanned urban development, rapid population growth, insufficient infrastructure, etc. have also caused the inhabitants of the city to suffer from flood disasters from the past to the present. However, in the literature research conducted within the scope of this study, it was seen that although flood vulnerability assessments have been handled by many researchers around the world, studies conducted specific to Istanbul are rare.

For instance, Ozcan et al. (2010) analyzed the Ayamama River in their study using a combination of image processing, remote sensing, and GIS. They determined the vulnerability of the areas according to their distance from the stream. In this study, MCDA and AHP methods were used to weigh the criteria, and vulnerability was determined according to geology, land use, slope, direction, and Digital Terrain Model (DTM) indicators. Although this study is valuable in terms of studying a stream such as Ayamama, which has witnessed many tragic flood events throughout history, it was found to be narrow in scope since it only studied a single stream basin. Similarly, in another study conducted specifically on four streams on the European side of Istanbul, a GIS-based MCDA approach was used to determine flood susceptibility based on flow, elevation, slope, aspect, drainage density, and sub-basin size. It has been suggested that the outcomes are 97% identical to those obtained using the Rational Method (Yalcin & Erdogan, 2012). It should be noted that this study only considers susceptibility from a physical standpoint and does not include social processes in its framework.

The research of Ekmekçioğlu et al. (2020), one of the most recent in the field, presented a district-based flood risk assessment framework that quantifies 13 distinct parameters using a fuzzy analytical hierarchy process (FAHP). When the contribution of each indicator is evaluated, land use, population density, and sensitive structures are determined to be the most essential sensitivity criteria, whereas the return time of a storm event, impermeability, and the condition of the stormwater pipe network are presented as the most crucial hazard criteria for the evaluation of flood risk in Istanbul districts (Ekmekçioğlu et al., 2020).

Another study by Aydın and Kahraman (2022) aimed to assess flood vulnerability in 81 provinces of Turkey using social, spatial, and physical indicators. The indicators they examined include precipitation rates, the total coverage of urbanized areas, the number of parks, population and its density, income, health services, infrastructure, the number of elderlies, disabled, female, and child populations, and the socioeconomic development level of cities. Accordingly, Istanbul was determined to be one of the provinces with the highest vulnerability rate in the determined categories (Aydın & Kahraman, 2022). Although the research is a significant effort since it covers the whole country and has a wide range of indicators, it remains a rather macro approach as it does not include indicators related to variable urbanization and settlement in each province, different behavior of river basins during precipitation, social institutions, and coping.

Even though it was conducted in the early 2000s and does not concentrate on a specific type of natural disaster, a study on Pendik's social vulnerability was found crucial to this thesis (Haki, 2003). The 1990 population data served as the source for the social vulnerability index created by the author, which was derived from indicators of occupational status, education level, household size, age, gender, and property ownership and applied to all neighborhoods of Pendik. The research determined that the southeast neighborhoods of Pendik are highly vulnerable (Haki, 2003). However, it has limitations as it fails to focus on a specific type of disaster, which makes it hard to identify which neighborhood is more vulnerable to which disaster category. It is noteworthy to recall here that certain authors emphasize the fact that the term vulnerability can only be employed in a meaningful manner in reference to a specific vulnerability (Brooks, 2003, as cited in Füssel, 2007).

In addition to the quantitative studies evaluating vulnerability, there are also a few studies disclosing its causative factors within the scope of Istanbul. In an investigation that assessed Istanbul based on its spatial, economic, demographic, social, environmental, and institutional structures, for instance, it was found that Istanbul is extremely vulnerable to the effects of climate change as well as disasters across all indicators (Kaya, 2018). Furthermore, it is argued that the construction pressure inside its basins exacerbates the flooding threat (Kaya, 2018).

When the literature on flood vulnerability in Istanbul is examined, two main shortcomings draw attention. First, since there is a rapid and intense urbanization trend in Istanbul, the dynamics are constantly changing, so up-to-date research is needed when looking at the years of research in the existing literature. Secondly, and most importantly, since vulnerability cannot be measured only physically, social factors should also be included in the calculation, and, if possible, a rich set of criteria should be set out. For this reason, this thesis aims to stay at the intersection of these two deficiencies and to stay at a current, holistic, and inclusive point in the existing literature. The findings of this study can be used by water resource authorities, disaster management institutions, and government organizations to mitigate flood risk, as well as allocating a fair budget to local municipalities for flood risk mitigation measures. (Ekmekçioğlu et al., 2020).

Overall, previous studies on flood vulnerability assessment in Istanbul have used a variety of indicators and approaches. The studies have highlighted the importance of considering social, economic, and physical factors in assessing flood vulnerability in urban areas. Moreover, the studies have identified specific areas in Istanbul that are particularly vulnerable to flooding and provided insights into potential strategies for reducing flood risk in the city. However, there is still a need for further research to address the gaps in the literature and develop more comprehensive and accurate flood vulnerability assessments for Istanbul. As Kaya (2018) argues, in a late-capitalizing country like Turkey, where development discourse always precedes environmental concerns, it is crucial to take urgent, concrete measures for a solution, and focusing on vulnerability studies is one of the most important ways to achieve this.

3. METHODOLOGY

This thesis's major objective is to generate flood-vulnerability maps for one of Istanbul's most densely populated watersheds. The sections that follow provide additional details about the methods utilized in this thesis. Figure 3.1 illustrates the fundamental methodological workflow of this thesis.

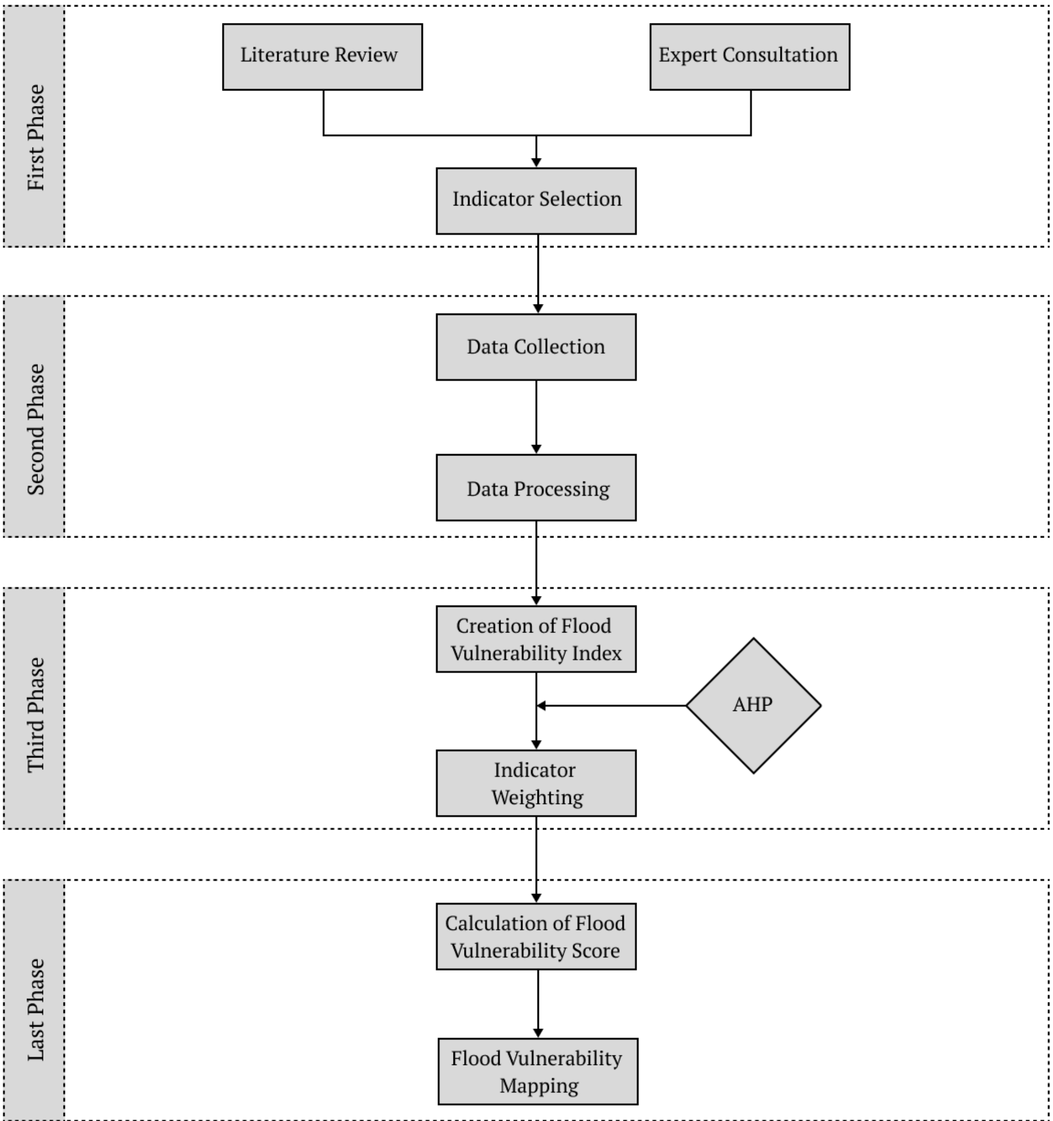


Figure 3.1. The flowchart of the methodology.

3.1. Study Area

Istanbul is a metropolitan area located at the intersection of the Europe and Asia continents, linking the Black Sea to the Mediterranean Sea (see Figure 3.2).

Figure 3.2. Location of Istanbul city.

The city has a rich history and a highly diverse cultural heritage. Istanbul is one of the most populous cities in the world, with a population of more than 15 million people and an area of approximately 5.461,00 km^2 (TURKSTAT, 2022; Istanbul Governorship, 2022). Istanbul is in the Marmara region of Turkey. The city enjoys a warm and temperate climate, and the amount of precipitation during the winter season is greater than that observed during the summer season. According to Köppen and Geiger's classification system, Istanbul is categorized as Csa (mild climate) (Altun, 2022).

Istanbul is often characterized by a complex and heterogeneous urban structure with diverse land uses, varying topography, and multiple water bodies. Istanbul has a total of 67 streams, which together span a distance of 473.5 kilometers (ISKI, 2014). Even the names of many streets and districts in Istanbul point to the presence of streams there in the past, i.e., Dereboyu, Ihlamurdere, Büyükdere, etc. However, since the 1950s, intense internal migration has opened river basins to intense urbanization, similar to other natural areas. Today, many historical streams are now closed either by roads, streets, or buildings.

Factors such as rapid and unplanned urbanization characteristics, a dense population, and insufficient infrastructure cause Istanbul to be considered vulnerable to floods. The inadequate carrying capacity of the artificial drainage systems in Istanbul is considered a significant contributor to flash flood events. This is attributed to the alteration of riverbeds from their natural directions and channel sections, resulting in a lower capacity compared to natural waterways (Turoğlu, 2011). Furthermore, Istanbul has encountered a surge in the frequency of flash floods over the past few decades, leading to substantial damage to both human life and property. Istanbul was hit by several significant flood events within the 21st century (Kömüşçü et al., 2011).

Pendik is a district located on the eastern coast of Istanbul, Turkey. It has a rich historical background and has undergone significant transformations over the years. According to Haki (2003), Pendik was initially a small fishing village with around two thousand inhabitants in the early 1920s. During that period, the district was perceived as a refuge for wealthy citizens of Istanbul seeking a break from urban life (Eskin et al., 2012). It served as a spot for vacation and weekend residences. The district underwent a substantial demographic shift subsequent to the population exchange agreement between Turkey and Greece in 1923. Additionally, from 1955 to 1990, the district experienced a noteworthy surge in population due to significant immigration from Anatolia (Haki, 2003). The establishment of the Pendik Shipyard and Heavy Industry Facilities in the 1980s had a significant impact on the regional economy, as well as the demographic composition and urban structure of Pendik (Eskin et al., 2012). This demographic diversity adds to the cultural richness of Pendik and reflects the broader social fabric of Istanbul.

According to Ustaoğlu and Aydınoğlu (2020), Pendik is a district in Istanbul covering an approximate area of 180 km^2 and comprising 36 neighborhood areas. It is bounded by the Kartal-Sultanbeyli district to the west and the Tuzla district to the east, while Şile forms its northern boundary. The northern part of Pendik exhibits a variety of non-urban land uses, including agricultural areas spanning 770 ha, scattered natural vegetation covering 550 ha, and significant primary forests spanning 5300 ha. On the other hand, the southern part of Pendik is characterized by commercial and industrial sites, high-density to medium/low-density residential developments (Ustaoğlu & Aydınoğlu, 2020). The strategic location of Pendik is a noteworthy characteristic. Located along the shoreline of the Marmara Sea, this region enjoys convenient proximity to key transportation nodes, including the Sabiha Gökçen International Airport, a prominent aviation hub in Istanbul, and a network of interconnected highways. The advantageous geographical position of Pendik has played a significant role in its expansion and establishment as a noteworthy center for commerce and transportation in Istanbul. Furthermore, the development of new roads, highways, and public transportation systems, including the Istanbul Metro and the Marmaray commuter train, connected Pendik to the center of Istanbul and aided the flow of people and commodities.

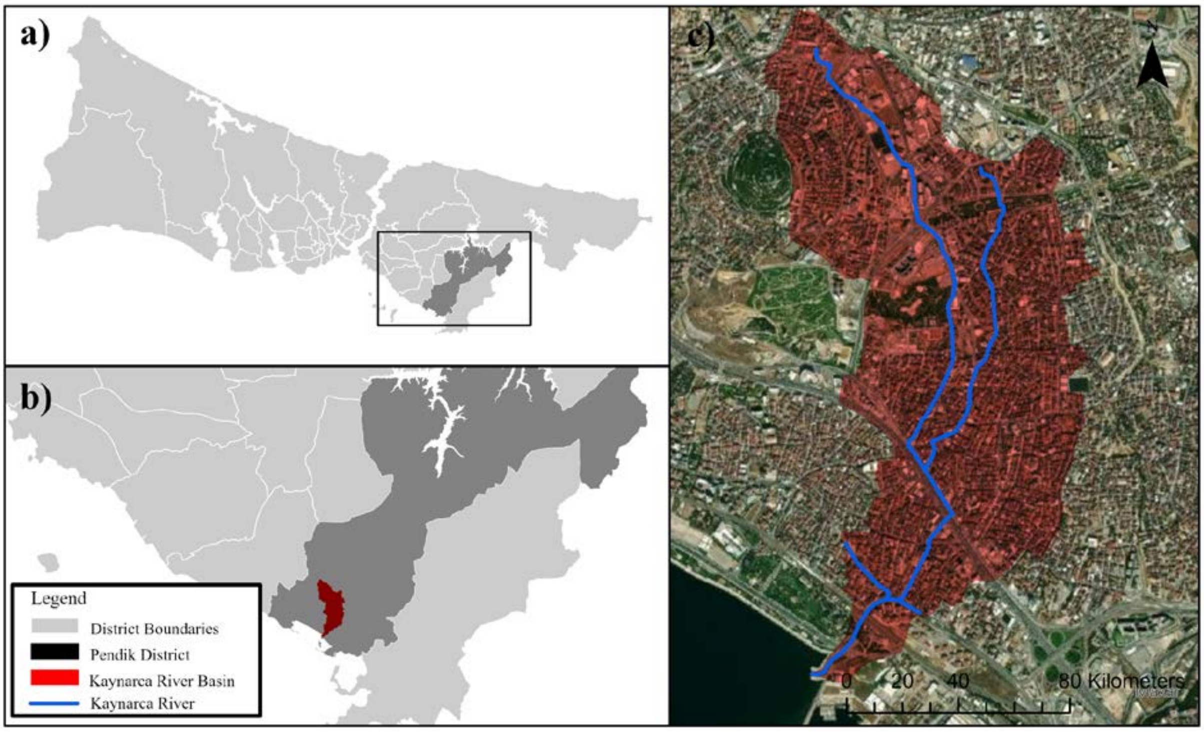


Figure 3.3. a) Pendik district b) Kaynarca Basin c) Kaynarca Stream and the basin area.

The district of Pendik exhibits similarities regarding its urbanization characteristics compared to the broader metropolitan area. A notable similarity between Pendik and Istanbul is their shared historical background and consequential transformations that have taken place throughout the years. Both regions have undergone changes in their demographic composition, economic growth, and urban configuration. Moreover, the demographic heterogeneity of Pendik, which has arisen due to substantial migration from Anatolia, is indicative of the wider societal composition of Istanbul. The presence of diverse socioeconomic conditions, housing types, and infrastructure characteristics can aid in comprehending the social factors that impact flood vulnerability. Overall, Pendik reflects the urbanization characteristics and trends of Istanbul, making it an ideal example for understanding city-wide dynamics. Through the examination of Pendik as a microcosm of Istanbul, scholars may gain significant knowledge regarding the social, economic, and environmental mechanisms of the city, thus facilitating an in-depth understanding of the urbanization practices and leading efficient urban planning and management approaches for Istanbul as a whole.

The aforementioned characteristics have rendered the Pendik area the primary focus of investigation, with particular emphasis on the Kaynarca River and its basin located in Pendik. The total coverage of the basin is 364.56 ha (see Figure 3.3). The research area includes six different neighborhoods. Table 3.1 summarizes the information on neighborhoods within the study area and Figure 3.4 illustrates the locations of neighborhood within the basin. Although there are commercial activities and public services such as hospitals and schools, the land use characteristic of the watershed is mainly residential.

Table 3.1. Geographical and demographic information on neighborhoods within basin.

Neighborhood Name	Neighborhood Area (km^2)	Total Population
Çamçeşme	1,16	31.654
Dumlupınar	1,42	26.883
Esenler	1,05	33.603
Fevzi Çakmak	1,84	37.892
Kaynarca	3,22	47.531
Velibaba	3,37	41.375

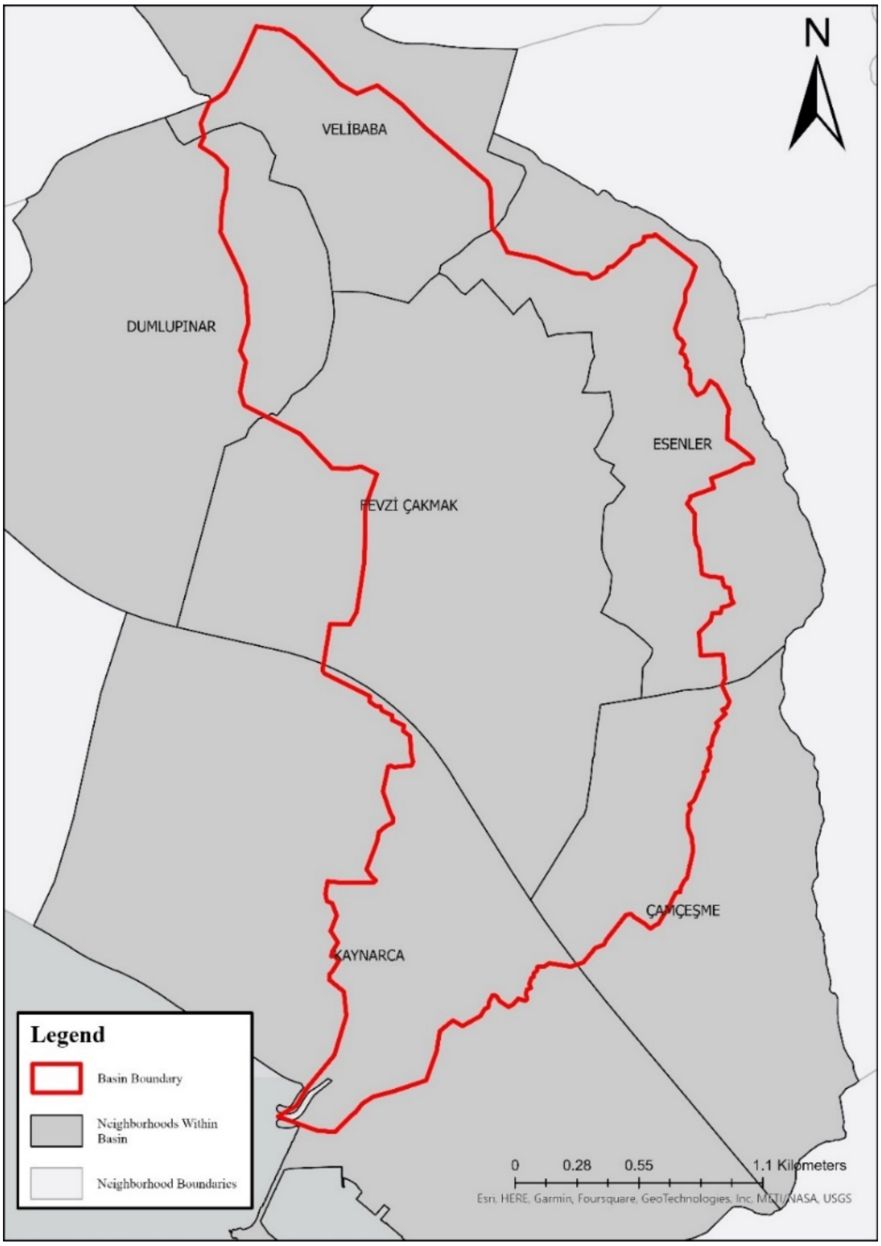


Figure 3.4. The locations of neighborhoods within Kaynarca Basin.

Similar to numerous rapidly developing areas in Istanbul, Pendik is currently experiencing continuous urbanization and demographic expansion. The expansion of urban development has led to a greater concentration of infrastructure, buildings, and critical facilities in areas that are vulnerable to flood events. This has the potential to exacerbate the vulnerability of these areas to floods. The present study endeavors to examine the urban development patterns of Pendik and their correlation with flood vulnerability, with the objective of identifying the determinants that contribute to the vulnerability of rapidly urbanizing regions. Comprehending this correlation holds paramount importance in shaping urban planning and development strategies that may mitigate the probable hazards linked with urban growth and guarantee the enduring resilience of comparable regions in different contexts.

3.2. Flood Vulnerability Indicators and Criteria Selection

Flood vulnerability is a concept that emerges due to several social and physical phenomena within an area. In vulnerability assessment studies adopting the indicator-based method, the very first procedure is to identify indicators while also limiting their numbers to a reasonable level (Sullivan, 2002; Sullivan & Meigh, 2005; Balica et al., 2010). Therefore, the development of a relevant index for assessing flood vulnerability is considered a crucial component of the research since it directly impacts the efficiency and validity of the findings.

An integrated strategy was employed in the present thesis to derive the indicators for flood vulnerability assessment. The methodology included in-depth research on relevant literature, collaboration with experts in environmental science and urban planning, and research on available data to produce an indicator list.

Initially, a literature investigation was carried out to identify the physical, environmental, and social factors linked to flood vulnerability. The literature review part was carried out utilizing national and international theses databases as well as online platforms such as Web of Science, Scopus, and Google Scholar. The website of the National Thesis Center was used for theses published in Turkey, and the websites of each institution were utilized to access international dissertations.

Scientists and professionals working on urban water management, floods, and natural disasters were then engaged to share perspectives on the indicator selection process. This procedure encompassed researchers, academics, practitioners, and local government officials. The experts were consulted through face-to-face or virtual meetings and via emails. Participants were asked to comment on the key flood vulnerability components in the study area.

Based on the outputs of the literature review and expert consultation phases, a rich set of indicators was identified for the assessment. The selected criteria included both physical and environmental factors, such as topography, land use, and soil type; precipitation trends; and social drivers, such as population density, poverty, occupational status, and educational attainment.

In addition to the literature research and expert input, the collection of factors for flood vulnerability assessment entailed searching for available data pertaining to the selected criteria. Online databases, government agencies, and scholarly research were utilized to identify data sources. The availability and quality of data were examined to guarantee that the preselected criteria could be measured precisely and efficiently. In examples where data were inaccessible or of low quality, substitute criteria were taken into account, or the criterion was eliminated from the list. Eventually, due to the abundance of data in the study area, the number of criteria was reduced to nine. Table 3.2 provides an overview of the selected indicators for this study, the studies in which they have been employed, and their causal relationship to vulnerability.

Table 3.2. An overview of selected indicators.

Indicator	**Indicator Abbreviation**	**Relationship with Flood Vulnerability**	**References**
Proportion of elderly or very young population	POPAGE	The vulnerability to flooding increases as the proportion of elderly or very young individuals in a population rises. (+, +).	Ngo, 2001; Aldrich & Benson, 2007; Meyer, 2017
Literacy rate of the population	POPEDU	The vulnerability to flooding decreases as the literacy rate rises (-,+).	Fernandez et al. (2016), Ghosh & Kar (2018) Salazar-Briones et al. 2020; Chakraborty & Mukhopadhyay, 2018; Chen et al., 2013
Quality of building material used in construction	BMAT	The vulnerability to flooding increases as the quality of construction materials decreases (+,-).	Hussain et al., 2021
Construction Year of Buildings	BYEAR	The vulnerability to flooding increases as the age of building increases (+,+)	Wing et al., 2020; Fatemi et al., 2020
Number of floors in buildings	BFLOOR	The vulnerability to flooding increases as the number of floors in building decreases (+,-)	Usman et al., 2021
Population Density	POPDEN	The vulnerability to flooding increases as the density of population increases (+,+)	Sanyal & Lu, 2006, Sinha et al., 2008, Balica et al., 2009, Mollah, 2016
Proximity to Floodplain	PRFLOOD	The vulnerability to flooding increases as the distance to the floodplain decreases (+,-).	Mavhura, 2019
Proximity to Health Services	PRHEALTH	The vulnerability to flooding increases as the distance to health services increases (+,+).	Chakraborty & Mukhopadhyay, 2018
Socio-Economic Status of the population	POPSES	The vulnerability to flooding increases as socioeconomic status decreases (+,-).	Mitra et al., 2022

All in all, an applicable flood vulnerability index was developed following the steps above, and the criteria chosen were found to be appropriate for the study area to offer a detailed knowledge of the variables underlying flood vulnerability.

3.3. Data Acquisition

The thesis is mainly based on quantitative patterns; hence, the data have been collected using secondary sources. The procedure for acquiring data for the flood vulnerability assessment consists of the gathering and analysis of various sources of information pertaining to the selected indicators.

National as well as regional statistical databases, demographic information, and publicly accessible or scientific-use-only GIS datasets are used to collect the data required for the aforementioned indicators. The subsequent sections therefore provide a broad overview of the datasets used in this study, including their sources, scales, and limitations.

3.3.1. Distribution of Population by Age Groups

The number of elderly inhabitants is a crucial indicator for assessing flood vulnerability, as elders are frequently perceived as more vulnerable to the unfavorable consequences of flooding due to their physical and financial conditions.

TURKSTAT provided information on the population by age group. TURKSTAT is the coordinating body in charge of gathering, organizing, evaluating, and publishing official numbers in Turkey.

The data was compiled at the neighborhood level and used to point out the number of elderly people residing in each neighborhood. In the TURKSTAT statistics, the population figures for various age categories can be determined. Therefore, it is possible to determine the proportions of age-specific categories to obtain a deeper picture of the age structure in a particular area. The data was obtained in a tabular format, with population counts corresponding to various age categories. The data consists of sixteen main age categories, namely, the number of people with an age of 0-4, 5-9, 10-14, 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-69, 70-74, and 75 or above by gender.

One of the limitations of the study is that the TURKSTAT data is outdated and only applies to the year 2021. Another disadvantage is that the data only offers information on the number of elderly people based solely on neighborhoods instead of their actual distance to the floodplain or locations they choose to reside in. This has prompted a shift from point-based analysis to a wider area.

The percentage of the neighborhood's elderly population was determined by subtracting the number of residents 65 and over and dividing it by the total population. Figure 3.5 and Figure 3.6 depict the distribution and concentration of the 65+ aged and 0-15 aged population in the study area respectively.

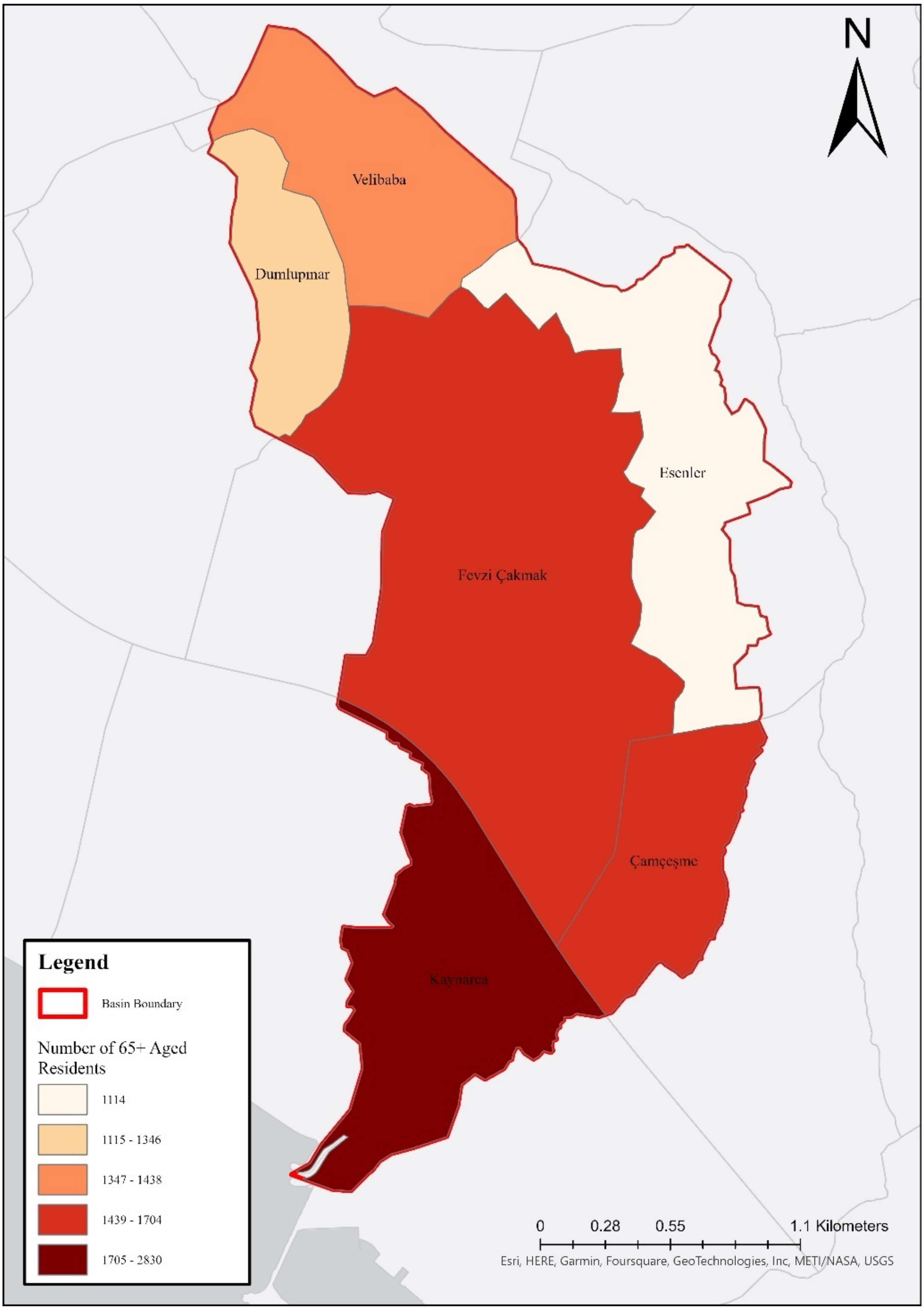


Figure 3.5. The distribution of the 65+ aged population in the study area.

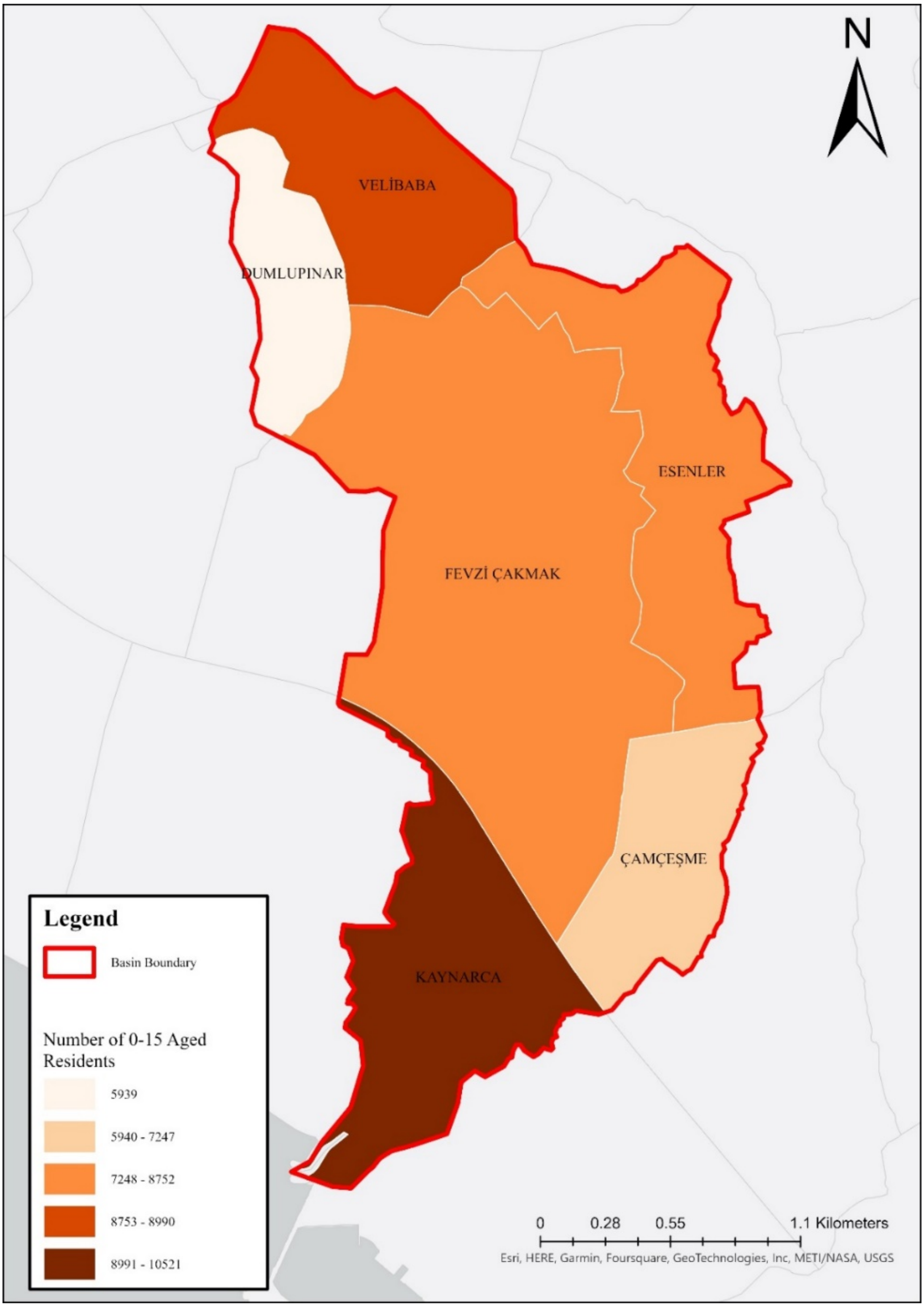


Figure 3.6. The distribution of the 0-15 aged population in the study area.

3.3.2. Distribution of Population by Educational Attainment

A neighborhood's literacy level is an essential indicator of its vulnerability to flooding because education shapes the capability of residents to access information on flood warnings and to take preventative measures. TURKSTAT provided data on the literacy levels and educational attainment of each neighborhood. The data was obtained in a tabular format, with population counts associated with different education levels. The data has nine different categories, namely, unknown, illiterate, literate but did not complete primary school, primary school graduate, lower secondary school graduate, upper secondary school or equivalent graduate, undergraduate graduate, graduate degree (masters) holder, and doctorate degree holder (see Table 3.4). Figure 3.6 and Figure 3.7 illustrate the distribution and concentration of the number of MSc or PhD graduate residents and illiterate population in the study area respectively.

Table 3.3. Population distribution by educational attainment in basin neighborhoods

Neighborhoods	Unknown	Illiterate	Literate but did not Attain Education	Primary School	Mid School	High School	University Graduate	MSc Graduate	PhD Graduate
Çamçeşme	180	681	2534	11996	4048	5666	3049	170	21
Dumlupınar	128	609	1987	9986	3090	4635	2347	134	0
Esenler	217	559	2866	11977	3695	5043	2868	227	21
Fevzi Çakmak	184	763	2936	13579	4662	6789	3803	290	24
Kaynarca	359	797	3550	14919	5815	10118	7306	594	78
Velibaba	223	706	2874	13290	4343	6671	3964	280	23

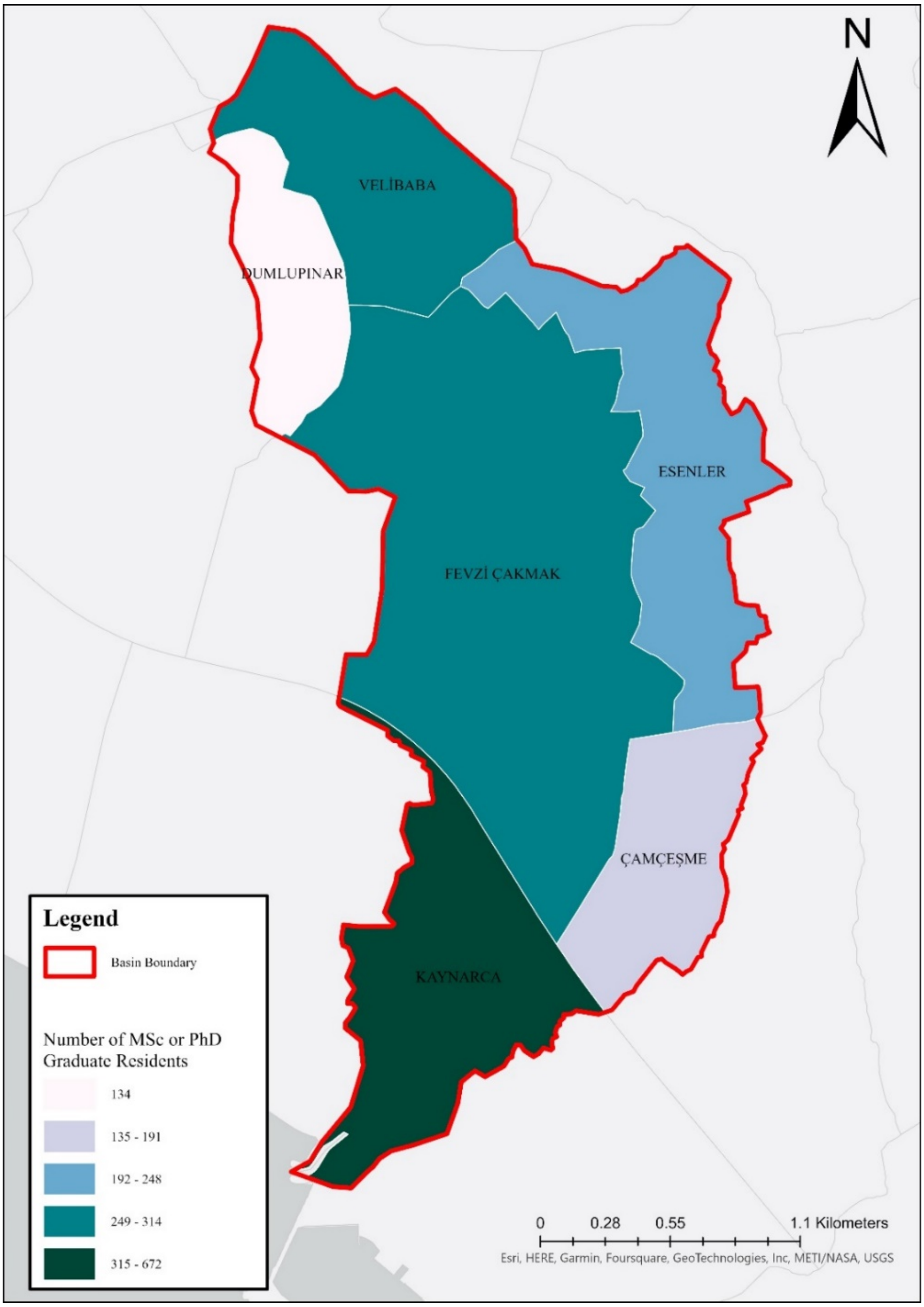


Figure 3.7. The distribution of the number of MSc or PhD graduate residents within basin.

Limitations on age data also apply to educational attainment data. The most recent data available for educational data is for the year 2020. As a result of the resolution of the data, it is equally difficult to determine where residents with particular educational levels are concentrated.

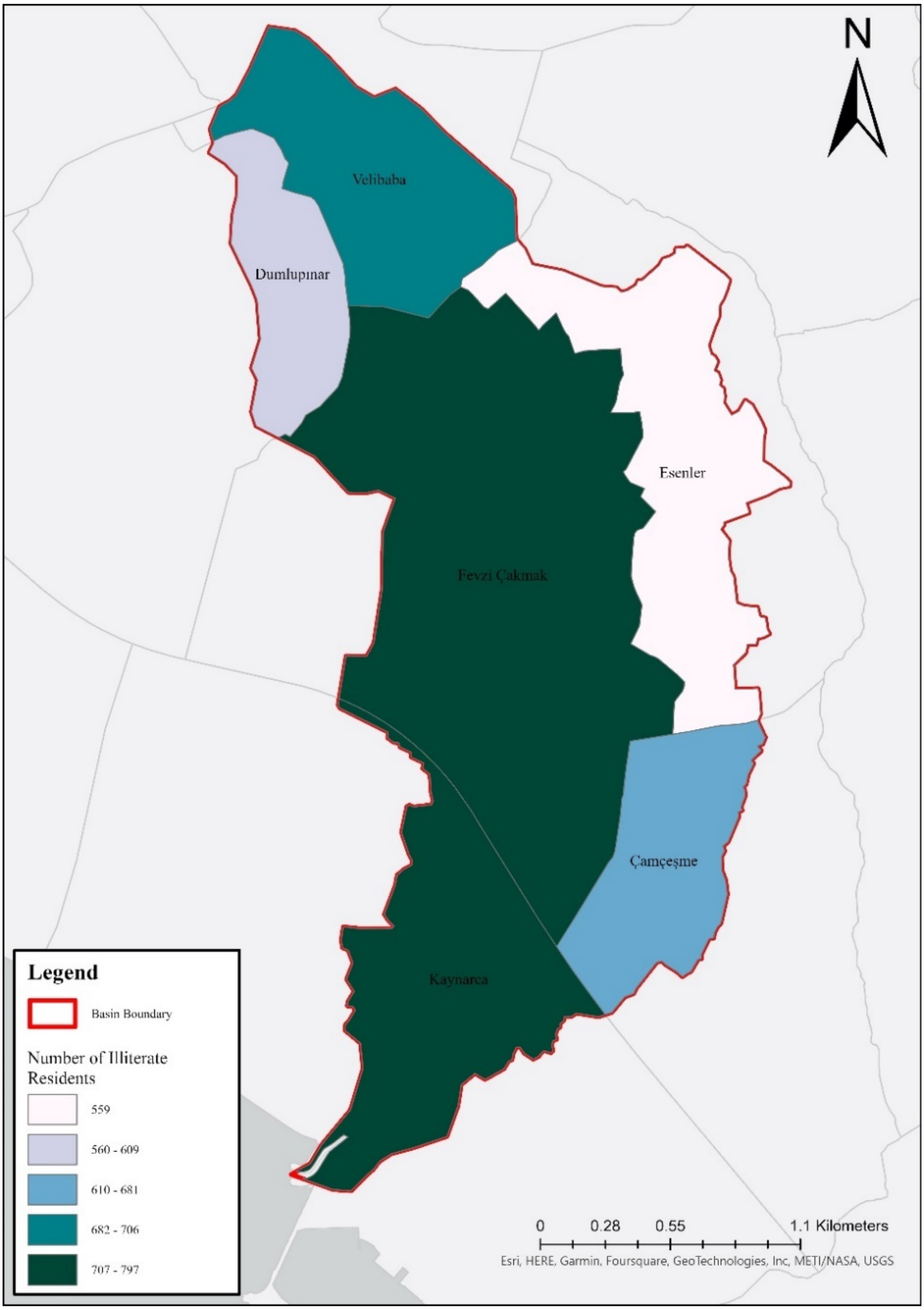


Figure 3.8. The distribution of the number of illiterate residents within basin.

3.3.3. Building Based Data

The building-based dataset in Istanbul contains information on the construction year, building material, number of floors, and population living in the buildings. This dataset is essential for understanding the physical vulnerability of the built environment and the potential impact of floods on buildings and their inhabitants.

The building-based data used in this study was obtained from the thesis of Ergun Konukçu (2016), titled Effects of Building Collapse Direction and Bridge Functionality on Road Networks Following an Earthquake. In order to accurately estimate earthquake damage, the objective of that research was to gather a database of dependable building information for Istanbul, including building age, construction type, number of stories, and occupancy classes. Due to the lack of knowledge about the absolute number of buildings and their ages in Istanbul, detailed building data acquisition was necessary. The data was gathered using a combination of vector data sets and raster data from various sources (Ergun Konukçu, 2016).

The building data for each building in Istanbul was identified by digitizing selected aerial photos, orthophoto mosaics, and satellite images of Istanbul. The digitization process was carried out manually using GIS software, which involves tracing the outlines of buildings on the images and assigning attributes such as building age, occupancy classes, and construction types. The preferred images included aerial photos from 1966 to 1982, orthophoto mosaics from 1996 to 2013, and satellite images from 2004 to 2007 (Ergun Konukçu, 2016).

Once the digitization procedure had been completed, the resulting building data set included the accurate number and location of Istanbul's buildings, as well as their age, occupancy class, and construction type. The accuracy of the data was further validated through two separate studies of Istanbul over different periods of time. This building data set is essential for hazard damage analysis in Istanbul and can be used for any loss assessment studies related to natural hazards (Ergun Konukçu, 2016). Since the most comprehensive and highest-resolution building data available for this study are the outputs of the above-mentioned thesis, it was decided to use their findings as one of the main inputs of this research (Figure 3.8).

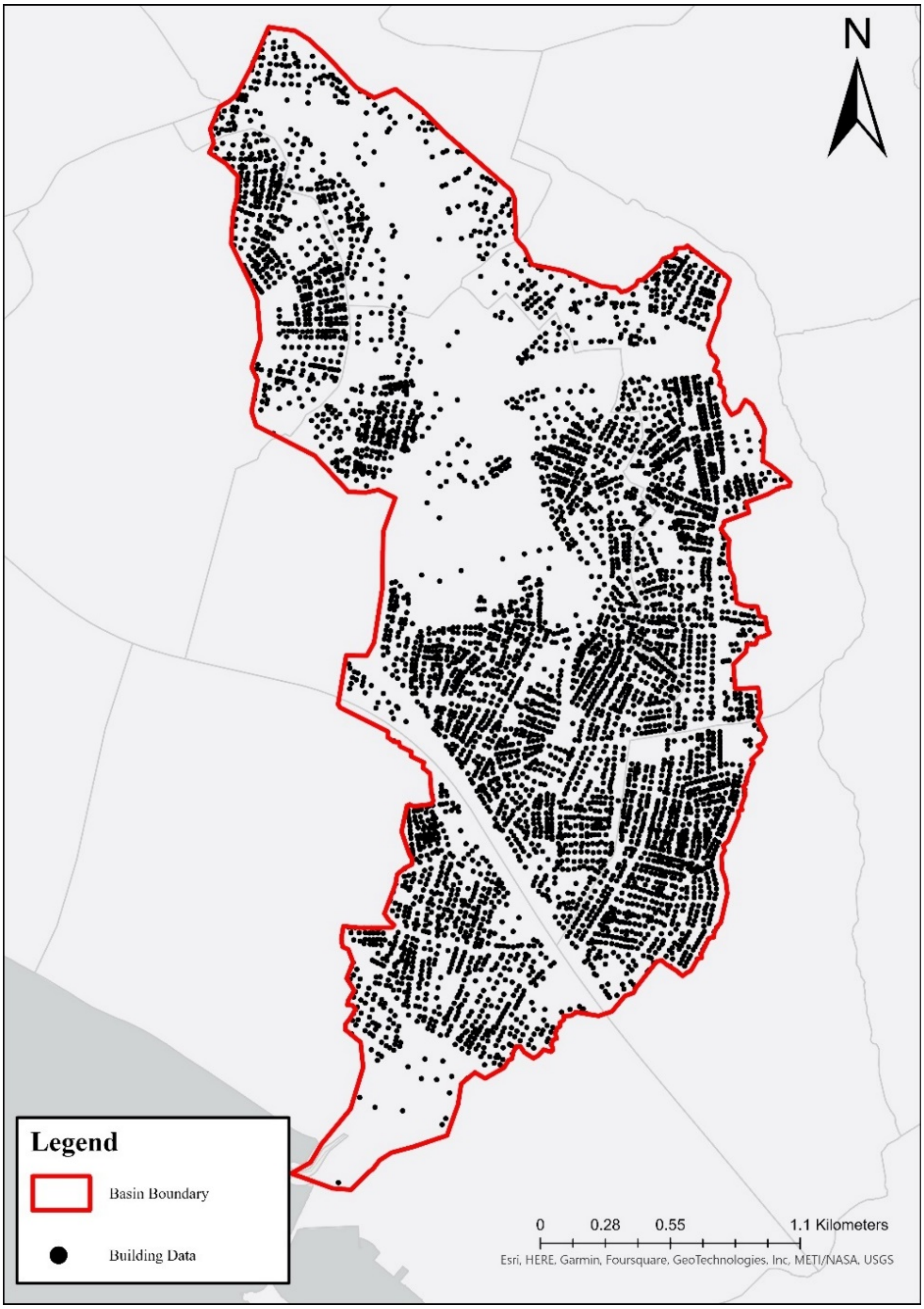


Figure 3.9. The building data of the study area.

An important indicator of a building's vulnerability is the year it was built, which is provided by the construction age data. Based on the numerous Istanbul building codes in effect at the time of their construction, this dataset divides the statistics on the age of buildings into three distinct time periods: before 1980, between 1980 and 2000, and after 2000. Figure 3.9 depicts the distribution of the construction years of the buildings located in the study area.

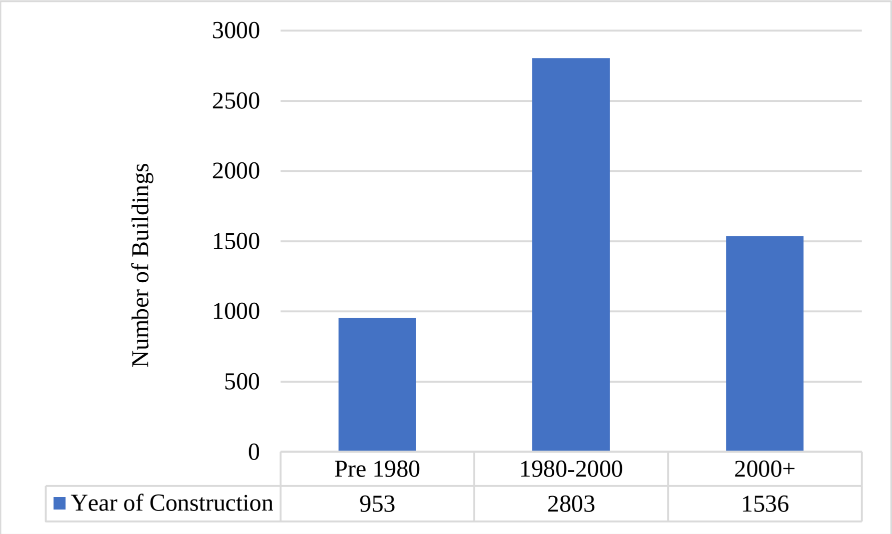


Figure 3.10. The distribution of construction year of the buildings within the study area.

The major materials used in the construction of any building are represented by the construction material data. The construction material data in this dataset is divided into six categories: concrete, masonry, steel, prefabricated, steel construction, and tunnel form. The presented dataset indicates that RCC structures with masonry infill walls account for the majority of Istanbul's construction typology (Ergun Konukcu, 2016). Figure 3.10 shows a map of the distribution of the several construction materials used in the buildings located in the study area.

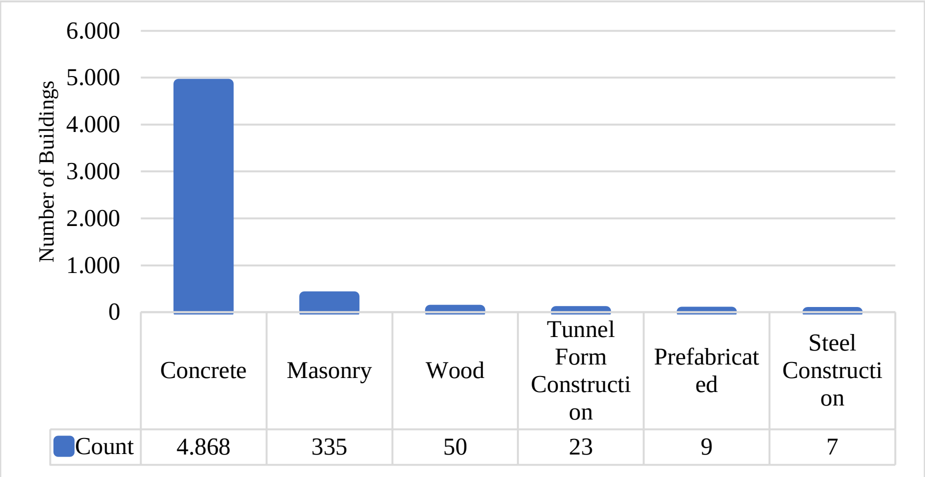


Figure 3.11. The distribution of the type of building material used within the study area.

The number of floors information specifies how many floors or levels each building possesses. The number of floors in this dataset is not divided into distinct groups; however, it can be correlated to typical architectural typologies such as low-rise, mid-rise, and high-rise structures. Figure 3.11 shows the distribution of the number of floors in buildings in the study area.

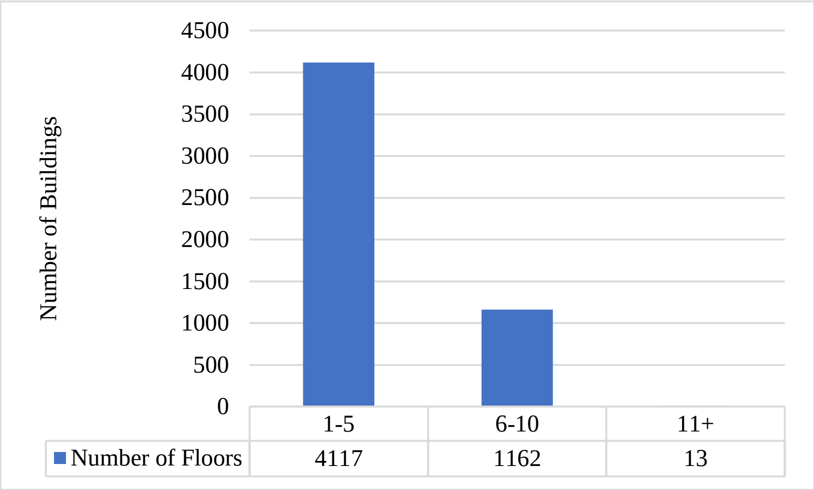


Figure 3.12. The distribution of the number of floors in buildings within the study area.

3.3.4. Floodplain Data of the Basin

The utilization of floodplain data is a crucial element in the assessment of flood vulnerability, as it enables the identification of regions that are prone to inundation. Delineating the spatial extent of flood-prone zones facilitates an in-depth understanding of the areas that are vulnerable to flooding. Moreover, floodplain data facilitates the recognition of crucial regions and infrastructure that could be unevenly impacted by inundation. Through the integration of floodplain data with information pertaining to critical facilities, transportation networks, residential areas, and economic assets, it is feasible to evaluate the potential ramifications and susceptibilities linked to diverse flood scenarios.

The floodplain data provides an assessment of the potential hazard of inundation in a given area, with varying levels of likelihood attributed to distinct geographical zones. The Federal Emergency Management Agency (FEMA, 2020) has established guidelines for characterizing regions based on their risk of flooding. According to these guidelines, a region with a 0.2% annual risk of flooding is based on data derived from a 500-year period, while an area with a 1% chance of flooding annually is described by statistics based on a 100-year period. The floodplain data provided by ISKI was an essential component of the methodology utilized to evaluate vulnerability to flooding within the examined region. This data has been obtained from flood risk maps that were created by ISKI in 2016. These maps have been formulated by amalgamating data from multiple sources and employing different computations, thereby ensuring their dependability and precision (ISKI, 2016).

The analysis carried out by ISKI involved the modeling of the primary basin area and its sub-basins, as well as the identification of the flow segments that constitute these basins. The calculations were performed using a range of inputs and these inputs facilitated a comprehensive comprehension of the region's attributes and proved to be pivotal in ascertaining flood flow computations and plausible flood risk zones (ISKI, 2016). Model inputs used by ISKI Flood Risk Mapping studies:

- 2008 satellite photos,
- 1/1000 scale photogrammetric plans (2006),
- Zoning Plans
- Cadastral Plans
- Approved Application Projects
- GIS Projects
- Transportation and Junction Plans
- Meteorological data
- Ongoing projects
- End of Business Projects
- Land Use Plans

The analysis utilized precipitation data from the Kartal station, which is regarded as the meteorological station closest to the study area. The dataset encompassed a duration of 64 years, commencing from 1942 and culminating in 2007, and served as the foundation for evaluating flood magnitudes at pivotal sites. Table 3.4 presents the findings of the analysis, which showcase the highest water levels observed at four discrete sites during various flood events, including the 100-year and 500-year floods, as well as the 100-year flood determined by the Rational Method (ISKI, 2016).

Table 3.4. Measurements of water levels at critical locations determined by ISKI (2016).

Flood Period	First Location	Second Location	Third Location	Fourth Location
100-year	3.157	1.628	0.000	0.675
500-year	3.244	2.146	0.500	1.713
100-year (Rational Method)	3.636	2.670	1.171	1.986

Units are expressed in meters.

Figure 3.12 depicts the data pertaining to the floodplain of a 500-year flood, which serves as the principal input for the present study. The graphical illustration presented herein offers a clear portrayal of the regions that are at risk of inundation and facilitates comprehension of the geographical dispersion of flood threats.

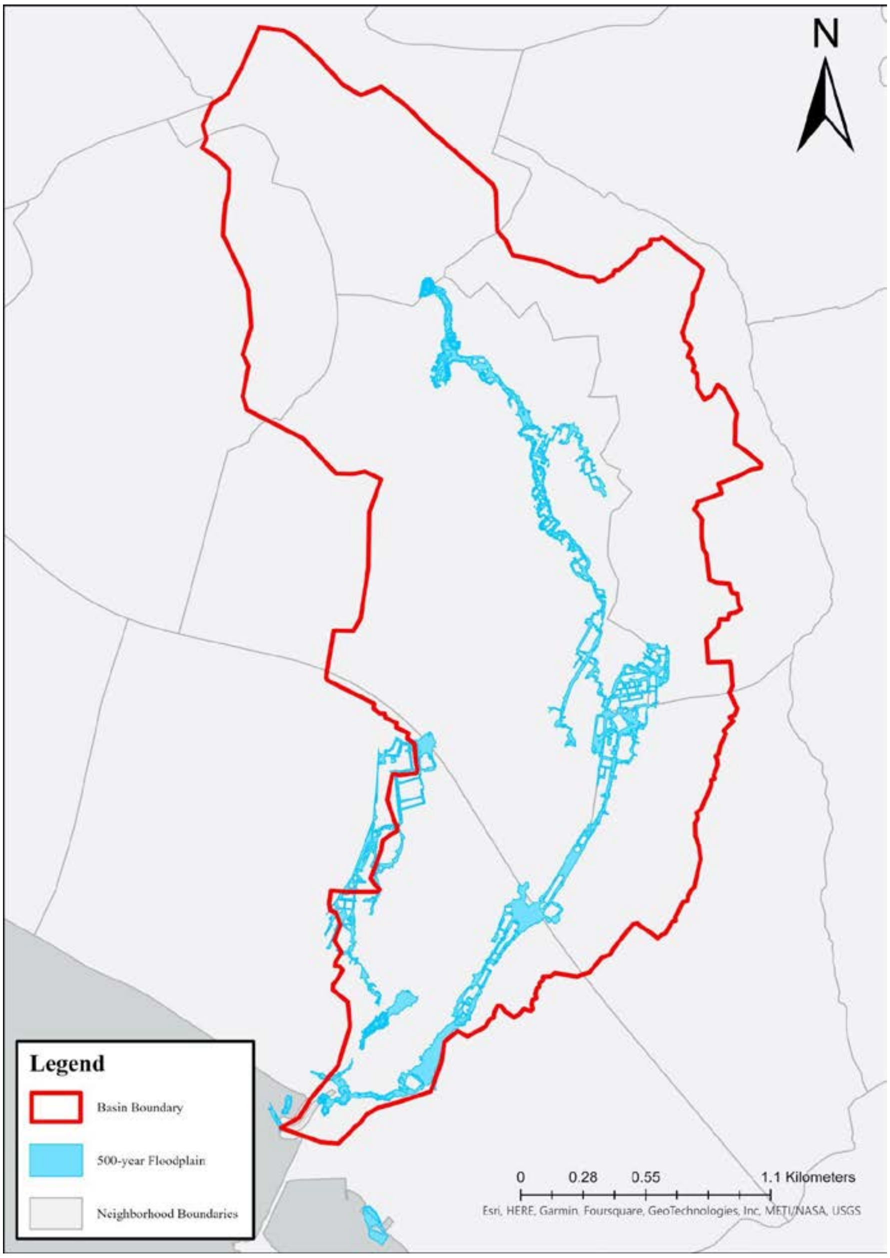


Figure 3.13. 500-year floodplain data of the study area (ISKI, 2014).

3.3.5. Healthcare Facilities Data

In order to assess the accessibility of flood-prone areas to healthcare facilities, a dataset comprising the locations of healthcare services in the study area was obtained from the IMM's open data portal. The dataset provides detailed information on Istanbul's health facilities and organizations, i.e., veterinary clinics, hospitals, polyclinics, etc. (see Table 3.5). The data provides access to the address, phone number, website, number of beds, ambulance, and latitude and longitude coordinates. Figure 3.13 depicts the locations of the healthcare facilities across the watershed.

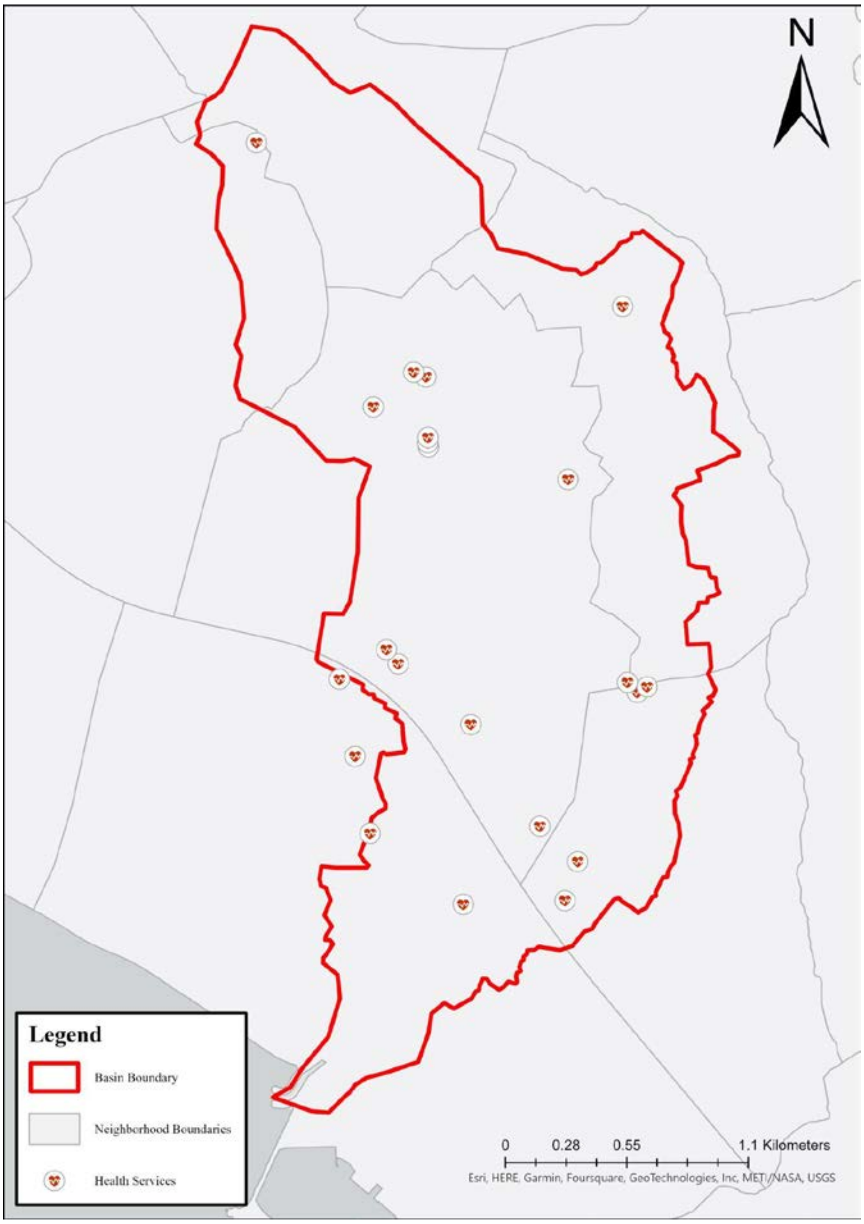


Figure 3.14. The locations of healthcare facilities intersect with the study area.

Table 3.5. Healthcare Services Information within basin.

Name of the Institution	Category	Emergency Service	Number of Beds	Ambulance
Pendik Family Health Service No. 7	Family Health Center	No	0	No data
Oral and Dental Health Center	Oral and Dental Health Center	No data	5	No
Pendik Family Health Center No. 6	Family Health Center	Yes	0	No data
Kaynarca Family Health Center	Family Health Center	No	0	No data
Fevzi Cakmak Family Health Center	Family Health Center	No	0	No data
Private Kaynarca Oral and Dental Health Polyclinic	Private Oral and Dental Health Centers	No data	No data	No data
Dentist Ayla Uygun - Murat Koçak	Surgery	No data	No data	No data
Camcesme Family Health Center	Family Health Center	No	0	No data
Private Cihan Medical Center	Medical Center (Private)	Yes	No data	No
Private Derman Health Cabinet	Health Cabinet (Special)	No data	No data	No data
Private Hero Dialysis Center	Dialysis Center (Private)	No data	No data	No
Private Century Pendik Hospital	Private Hospital	Yes	82	Yes
Malazgirt Family Health Center	Family Health Center	No	0	No data
Marmara University Pendik Training and Research Hospital	Training and Research Hospital	Yes	647	No
Marmara University Pendik EAH Hemodialysis and Peritoneal Dialysis Center	Dialysis Center	Yes	15	Yes
Pendik Emergency Aid Station No. 6-9	Emergency Station	No	3	Yes
Nazli Medical	Medical	No data	No data	No data
Marmara University Pendik Training and Research Hospital Hematology Oncology Annex Building	Training and Research Hospital	No data	No data	No data
Pendik Care Rehabilitation and Family Counseling Center	Rehabilitation and Family Counseling Center	No data	No data	No data
Çiğdem Family Health Center	Family Health Center	No	0	No data
Pendik Family Health Center No. 9	Family Health Center	No	0	No data

3.3.6. Socio Economic Status Score

Socioeconomic status (SES) is a critical determinant for assessing the financial and social well-being of individuals as well as communities. The absence of economic statistics in Turkey is a complex issue that has been debated by experts and scholars for years. That is why alternative data sets were sought since economic metrics such as labor force participation rate, average income, and unemployment rate of the neighborhoods could not be reached for Istanbul. Thus, it was decided to obtain the neighborhood-based socio-economic status scores, which were calculated within the scope of the "My Neighborhood Istanbul (Mahallem İstanbul)" project supported by the Istanbul Development Agency in 2016.

An index study was carried out as part of the My Neighborhood Istanbul project through the utilization of secondary data sources. The objective of that research was to determine the socio-economic relative performance of 959 different neighborhoods in Istanbul. This index comprised parameters that incorporated several aspects, such as economic capacity indicators, health indicators, demographic characteristics, and transportation data. The findings of the research led to the neighborhoods being divided into eight distinct classes on the basis of the SES variable. These classes are as follows: A+, A, B+, B, C+, C, D, and E. Table 3.6 shows the SES scores of the six neighborhoods within the watershed.

Table 3.6. SES scores of neighborhoods located in the study area.

Neighborhood Name	**SES Score**	**SES Score (Letter)**
Çamçeşme	25	D
Dumlupınar	25	D
Esenler	25	D
Fevzi Çakmak	25	D
Kaynarca	37,5	C
Velibaba	25	D

The neighborhoods with the greatest scores for the SES variable are represented by the letter A+, while the areas that contain the neighborhoods with the lowest scores are represented by the letter E. Figure 3.14 illustrates the SES scores of each neighborhood within basin.

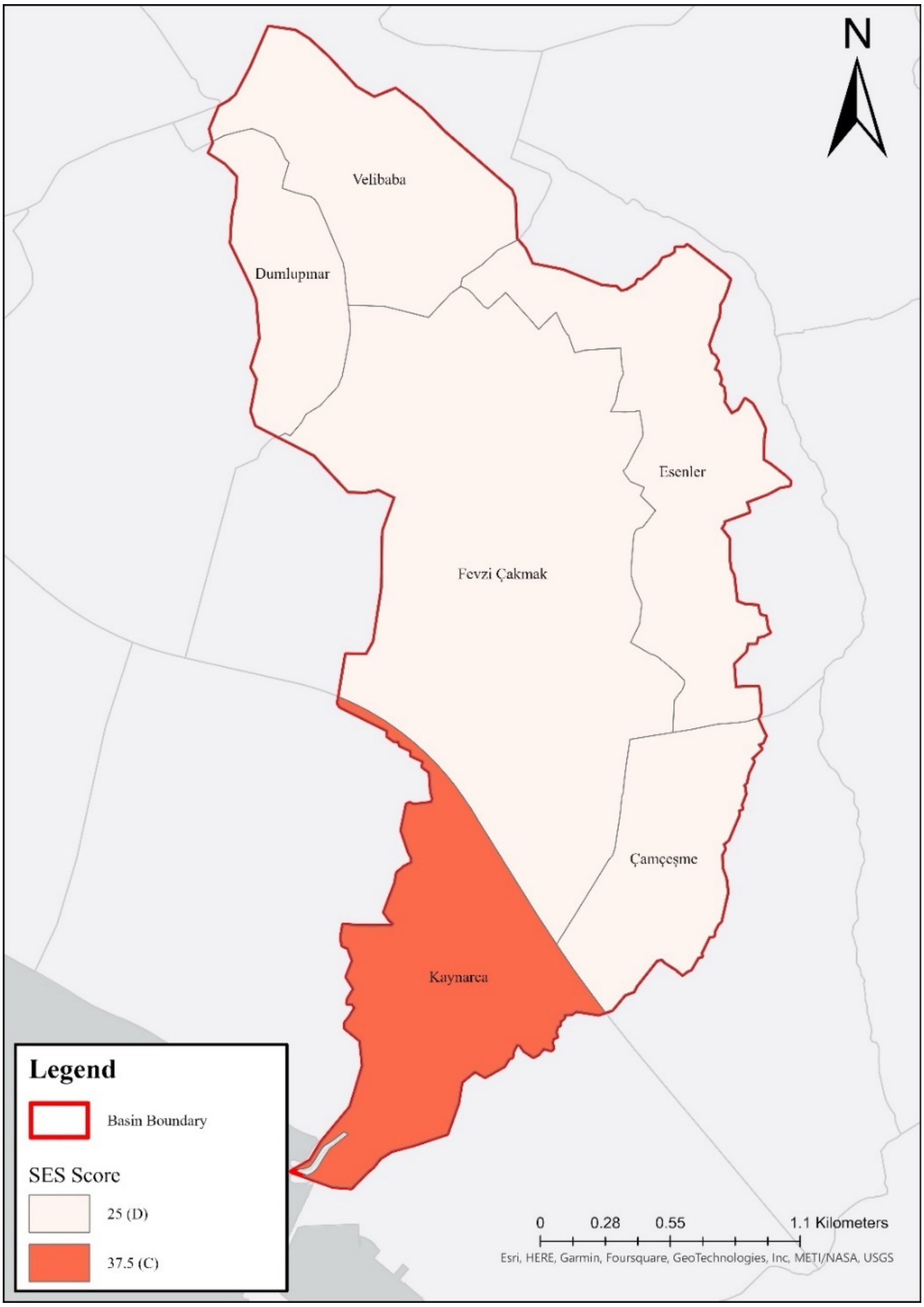


Figure 3.15. SES scores of neighborhoods within study area.

3.4. Analytical Hierarchical Process (AHP)

As mentioned in Section 2.3.1, AHP is one of the MCDA tools that assists in ranking the indicators of flood vulnerability. In this thesis, the AHP method was adopted to weigh the flood vulnerability indicators in order to accomplish an inclusive and collective decision-making process from the perspectives of several parties. This methodology comprises a total of seven phases that encompass the fundamental steps (Vaidya & Kumar, 2006):

1. The identification of the decision problem

2. The decision problem's objectives and outputs are comprehensively outlined, and all relevant actors or stakeholders are considered.

3. The factors that impact or lead to the decision problem in question have been identified.

4. The problem is converted into a hierarchical structure that comprises objectives, criteria, sub-criteria, and alternatives.

5. Each individual criteria are systematically evaluated against its corresponding set of criteria and assigned a numerical value on a calibrated scale. The number of criteria that are compared is represented by n in this approach, and the number of judgments necessary to form a specific matrix for comparison is $n(n - 1)/2$ since the matrix must be reciprocal and the diagonal components must be equal to one.

6. Calculations are performed to determine the maximum Eigenvalue, consistency index (CI), consistency ratio (CR), and normalized values associated with each criterion, alternative, or sub-criteria.

7. If the maximum Eigenvalue, CI, and CR meet the minimum requirements, the decision is made based on the normalized values. However, if these values exceed the ideal threshold, the process is repeated until these values are below the desired limits.

The present study employed the AHP methodology, which was executed through a meticulously developed nine-step procedure to ensure the evaluation process's reliability and validity (see Figure 3.16).

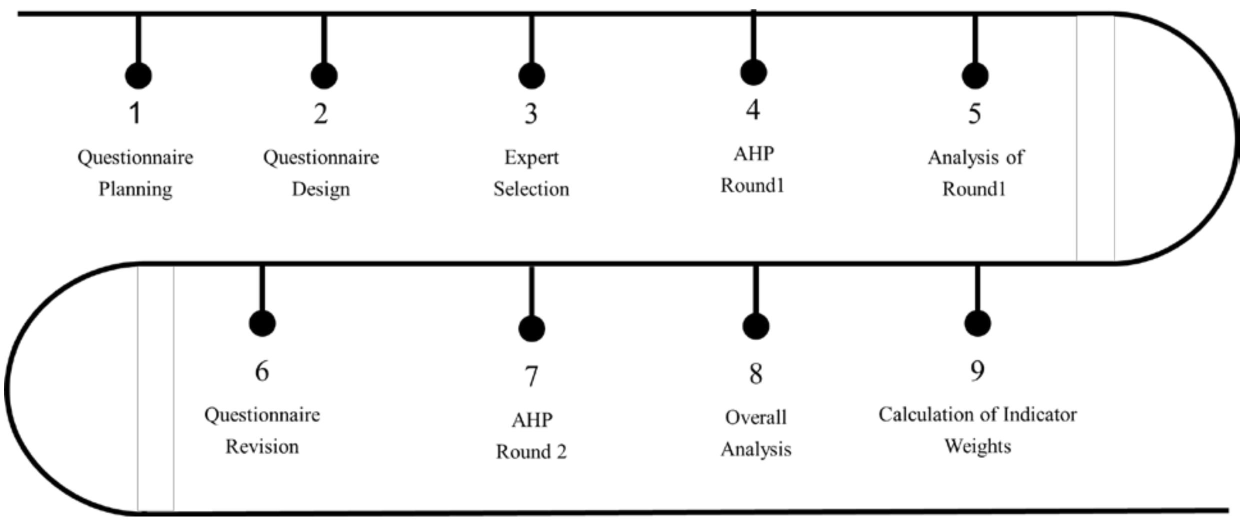


Figure 3.16. Workflow of the AHP methodology

During the preliminary phase of questionnaire development, particular focus was given to the construction and preparation of the AHP survey questionnaire. The process encompassed the establishment of research objectives and precise delineation of the criteria and sub-criteria that were to be assessed. The questionnaire's structure and format were established to ensure an accurate structure for gathering the information needed. Figure 3.17 illustrates the fundamental hierarchical structure of the AHP questionnaire.

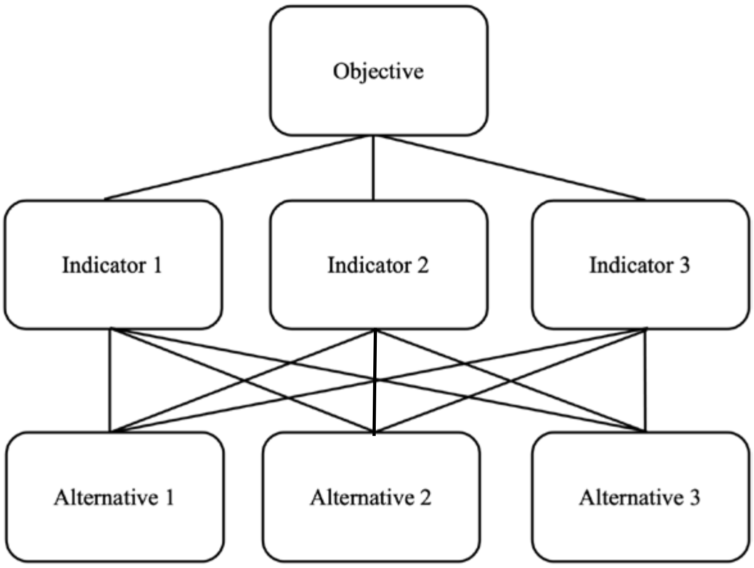


Figure 3.17. The basic framework of AHP modified from Taherdoost (2017).

After the initial planning phase of the questionnaire, the subsequent step involved the development of the questionnaire itself, which was based on the established criteria and sub-criteria (see Appendix A). The process involved arranging the inquiries in a systematic and cohesive design to enable significant and dependable feedback from the experts. The integration of clear guidelines and suitable criteria for assessment was implemented to foster uniformity in the acquisition of data. The AHP process involved a critical stage of expert selection, which entailed the careful identification and enlistment of suitable people with the requisite proficiency in the domain of urban vulnerability evaluation. The experts who were chosen for the role were carefully selected to represent a wide range of professional backgrounds and perspectives, with the aim of ensuring thorough and comprehensive evaluations.

The designed questionnaire was distributed to a limited group of experts for the purpose of piloting, and they were requested to complete it. The initial phase of the process has been designated as AHP Round 1. In this phase, the experts assessed the criteria and sub-criteria, and rendered judgments and pairwise comparisons based on their expertise and knowledge. The analysis of Round 1 data involved the processing and analysis of the responses provided by the experts. The questionnaire revision step, as informed by the Round 1 analysis, entailed a careful review and enhancement of the questionnaire in accordance with the feedback and insights obtained from the experts. The aforementioned measure was taken to ensure that the questionnaire comprehensively encompassed the evaluative aspects and effectively resolved any probable concerns or uncertainties detected during the analysis.

The second round of the AHP entailed the utilization of an updated questionnaire and the subsequent re-administration of said questionnaire to the group of experts. The experts conducted a reassessment of the criteria and sub-criteria, and the final evaluation process was influenced by the judgments and pairwise comparisons made by the participants in this round. The overall analysis incorporated the information obtained from the two iterations of the AHP questionnaire. This stage encompassed the process of consolidating and integrating the judgements of the experts, merging the evaluations made through pairwise comparisons, and computing all-encompassing values for the criteria. The evaluation process yielded a comprehensive analysis of the relative importance of flood vulnerability indicators. The determination of indicator weights constituted the ultimate phase within the Analytic Hierarchy Process. The process entailed the computation of the respective weights allocated to the distinct indicators in each criterion and sub-criterion.

The relative importance of each element of criteria or sub-criteria is determined through a nine-point mechanism ranging from 1 (when two indicators contribute equally to the objective) to 9 (when one indicator is significantly favored over another in accomplishing the objective) developed by Saaty (see Table 3.7). Basically, a score of 1 denotes equivalent significance, while scores of 3 indicate an average preference, and scores of 5, 7, and 9 indicate a clear and robust inclination. Even numbers, such as 2, 4, 6, and 8, are utilized in situations where a middle ground between numbers that are odd is essential (Dandapat & Panda, 2017).

Table 3.7. Saaty's (1977) scale of preferences

Numerical Rates	**Definition**	**Description**
1	Equal Importance	Two factors equally affect the process.
3	Moderate Importance	One factor is moderately dominant over the other factor.
5	Strong Importance	One factor is strongly favored over the other factor.
7	Very Strong Importance	One factor is strongly significant over the other factor.
9	Extreme Importance	Significance of one factor over other factors affirmed on the highest.
2, 4, 6, 8	Intermediate Values	For compromises between the above.

The allocation of the aforementioned ratings ultimately generates a matrix of comparisons, namely, a pairwise comparison matrix. An n-dimensional pairwise comparison matrix [A] for the conditioning factors is prepared at this stage (Yaralıoğlu, 2004). The size of the matrix is dependent on the number of parameters involved. Particularly, a matrix with dimensions of 3x3 corresponds to three parameters, while a matrix with dimensions of 4x4 and so forth. Equation (3.1) is utilized to determine the weighting calculation for nine indicators (Rimba et al., 2017).

$$A = \begin{bmatrix} a_{11} & \cdots & a_{19} \\ \vdots & \ddots & \vdots \\ a_{91} & \cdots & a_{99} \end{bmatrix}, a_{xx} = 1, a_{yx} = \frac{1}{a_{xy}}, a_{xy} \neq 0 \tag{3.1}$$

where A is the weight of the parameter, a_{xy} (xy = 11, 12, . . . 98, 99). Subsequently, normalization of the A matrix is performed, resulting in the attainment of the A' matrix as shown in Equation (3.2). To accomplish this, the A matrix's elements are divided by the sum of their respective column elements (Boulomytis et al., 2019).

$$A' = \begin{bmatrix} a_{11}' & \cdots & a_{19}' \\ \vdots & \ddots & \vdots \\ a_{91}' & \cdots & a_{99}' \end{bmatrix} = \begin{bmatrix} {a_{11}}/{\sum_{i=1}^{9} a_{i1}} & \cdots & {a_{19}}/{\sum_{i=1}^{9} a_{i9}} \\ \vdots & \ddots & \vdots \\ {a_{91}}/{\sum_{i=1}^{9} a_{i1}} & \cdots & {a_{99}}/{\sum_{i=1}^{9} a_{i9}} \end{bmatrix} \quad (3.2)$$

To calculate the weights of each criterion, the pairwise comparison matrix is analyzed using the Eigenvector method. The eigenvector is a weight vector that denotes the relative significance of each criterion. Following this, a mathematical algorithm is employed to normalize and ascertain the corresponding importance of each matrix. The relative weights can be obtained through Equation (3.3), wherein the maximum eigenvalue (λ_{max}) corresponds to the right eigenvector (w) (Rimba et al., 2017).

$$A_w = \lambda_{max} w \quad (3.3)$$

It is essential that the results obtained from the AHP exhibit consistency across all the pairwise comparisons that are evaluated using the Consistency Index (CI) and Consistency Ratio (CR) metrics (Saaty, 1977). The CI methodology adheres to the mathematical expression represented by Equation (3.4), wherein the variable 'n' denotes the quantity of parameters involved and λmax is the maximum eigenvalue of the matrix.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3.4)$$

The ultimate computation involves the consistency ratio, which represents the ratio between the CI and the random index (RI). RI relates to the consistency of the pairwise matrix that has been randomly generated and was illustrated in Table 3.8. The values presented in the table are dependent upon the diverse parameters implicated in the AHP. Following that, the computation of CR is facilitated through the utilization of Equation 3.5.

Table 3.8. Random Index values based on various criteria numbers.

Number of Criteria (n)	1	2	3	4	5	6	7	8	9	10
RI Value	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

$$CR = \frac{CI}{RI} \tag{3.5}$$

Ultimately, the comprehensive evaluation of each alternative is derived by computing the result of the weight assigned to each criterion and the corresponding score of the alternative on that criterion, followed by the summation of the results obtained. The above-mentioned task is accomplished through utilization of the Equation 3.6:

$$Flood\ Vulnerability\ Score = \sum_{i=1}^{n} W_i \times R_i \tag{3.6}$$

Where n is the number of parameters, W_i is each factor's weight, and R_i is the rating of the factors (Hammami et al., 2019).

3.4.1. Questionnaire Planning and Design

While using the questionnaire to collect expert opinions, two conditions were found as essential for the validity of pairwise comparisons. First, each expert received a comprehensive overview of the survey's instructions. Secondly, the questionnaire was designed with the intention that each expert could provide only one integer score (1–9) to each of the survey's nine factors.

Thirdly, the questionnaire was designed to be simple to comprehend and complete. This was accomplished by avoiding technical terminology and utilizing straightforward, brief language. Once necessary, examples of the sub-breakdowns of the indicators were also provided.

Ultimately, the questionnaire was developed so that experts could respond independently. This was accomplished by suggesting that the experts complete the survey independently and without consulting one another. The anonymity of the experts was also maintained in order to ensure they would not be influenced by other experts.

The investigation was conducted in two phases. First, the initial questionnaire was sent to a particular group of respondents in order to collect their feedback and criticisms. In the second round, the corrected survey was sent to all experts. The overall questionnaire used to gather expert opinions for assessing the relative importance of indicators is included in Appendix A.

3.4.2. Expert Profiles

The developed AHP survey was provided to a total of eight experts. The experts were selected due to their profound expertise, knowledge, and experience in the fields of flood risk management, urban planning, architecture, and climate change. The respondents were chosen based on their availability, eagerness to contribute, and field experience. The experts involved had been working in their respective fields for at least three years. Experts were systematically selected from the following four categories of organizations:

- Local government,
- Commercial consulting companies,
- Nonprofit or non-governmental organizations,
- Academic or research institutions.

Participants were contacted through email and briefed about the research's objectives and methodology. After that, they were given instructions for filling out the AHP questionnaire and were requested to submit it by a certain deadline. Table 3.9 summarizes the expert's background and the time required to complete the questionnaires by each expert.

Table 3.9. Information on selected experts.

Expert No	**Occupation**	**Field**
1	Academic	University
2	Architect	Consultant
3	Urban Planner	Local Government
4	Urban Planner	Local Government
5	Urban Planner	NGO
6	Urban Planner	NGO
7	Environmental Engineer	Local Government
8	Sociologist	Local Government

The purpose of selecting experts with varied backgrounds and professional experiences is to encompass a comprehensive spectrum of perspectives in the evaluation of urban vulnerability. The incorporation of academic, architectural, planning, engineering, and sociological viewpoints guarantees a multidisciplinary methodology that can effectively tackle the intricate and interrelated characteristics of urban vulnerabilities.

A scholar with expertise in the relevant field was selected from the university to furnish a theoretical basis and capitalize on their considerable research acumen in the domain of evaluating urban vulnerability. The expert's academic expertise and cognizance aid in the advancement and authentication of assessment methodology. Similarly, an architect with consultancy experience was included to offer expertise in building design and resilience. The expert’s comprehension of the vulnerability of buildings and metropolitan constructions facilitates the detection of areas of vulnerability in the urban system and the creation of design fixes that improve resilience. On the other hand, the inclusion of two urban planners from local government agencies provided practical insights into the assessment of urban vulnerability. The individual's proficiency in the field of urban planning provides them with a thorough comprehension of the complexities and obstacles present in urban settings, thus enabling them to offer significant insights into vulnerabilities at the community level. Moreover, the civil society community was represented by two urban planners affiliated with non-governmental organizations (NGOs), who offered their unique perspectives. These experts bring practical expertise in addressing urban vulnerabilities and environmental injustices, offering valuable insights into community engagement, resilience-enhancing initiatives, and the social dimensions of vulnerability assessment. A professional in the field of environmental engineering, employed by the municipal government, was selected to provide specialized knowledge and skills in evaluating the environmental factors associated with urban vulnerability. The expert's observations regarding hydrological and environmental systems offer a comprehensive comprehension of the vulnerabilities presented by natural disasters. Lastly, a sociologist from the local government was involved to provide expertise in social vulnerability assessment. The individual's expertise in the areas of social dynamics, community resilience, and the effects of vulnerabilities on various societal groups contributes to a more comprehensive comprehension of urban vulnerability through a sociological lens.

As an outcome of expert participation in the AHP questionnaire, the research provided innovative thoughts and different perspectives on the weighting of selected indicators. The several fields of expertise and fields of interest that they brought to the table ensured a detailed and comprehensive evaluation of the different drivers of flood vulnerability.

3.5. Data Analysis and Processing

In this research, the stages of data processing and analysis were rigorously performed in order to ensure the validity of the results that were obtained. For the purpose of being able to carry out a more precise assessment of the area of study, the initial step involved the clipping of the acquired data sets based on the basin area, given that a significant proportion of the data sets encompassed the whole city.

Secondly, the research adopted a grid-based analysis procedure to evaluate the vulnerability of flooding. The grid-based analysis technique, which involves dividing a study area into a uniform grid or pixels, is a widely used spatial analysis approach. The described technique has demonstrated performance in determining and analyzing patterns and connections among various geographically dispersed events, including but not exclusive to natural disasters. The consistency in the size and configuration of every grid or pixel within a specific area result in a consistent and equitable distribution of information across the study area, presenting a significant benefit in maintaining the consistency of data. In addition, the implementation of grid-based analysis enables the integration of diverse sources of data and contexts, such as remote sensing information, socioeconomic factors, and flood-related data, into an integrated framework. The basin area was divided into 2500 square meter grids (50 m x 50 m), resulting in 2746 grids as depicted in Figure 3.17. The Generate Tessellation tool of ArcGIS Pro was utilized during the process. Each of the grids received a unique identification number that enables monitoring and analysis of records at the grid level. The considerable amount of detail provided possesses the ability to represent hidden drivers of vulnerability that might have been neglected in a broader assessment. Thus, the aforementioned methodology was found suitable for the research context, considering its respective benefits.

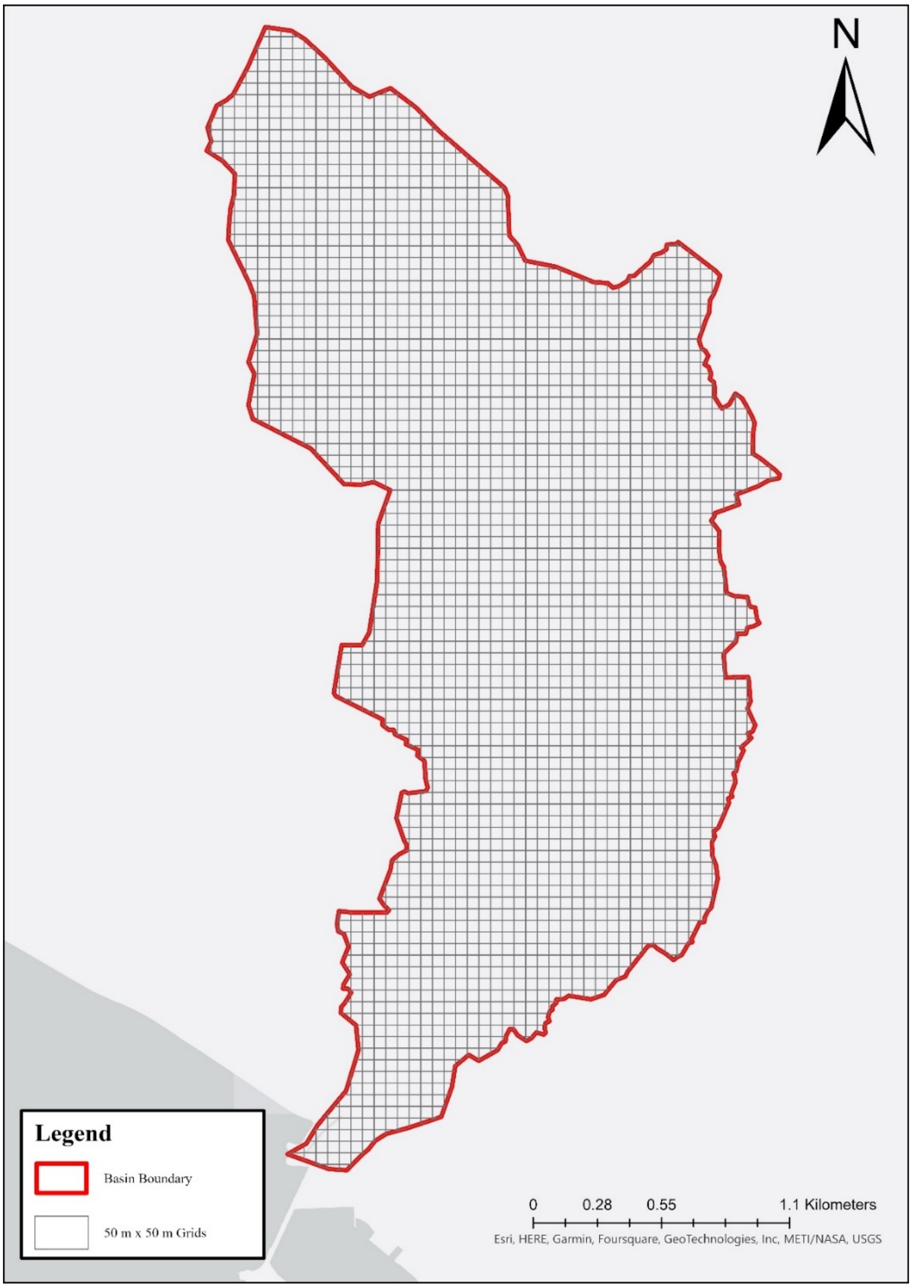


Figure 3.18. The grids obtained by dividing the basin into 50m x 50m areas.

The implementation of a grid-based approach in analyzing the study area has highlighted the need for proper processing of neighborhood-based data, i.e., educational attainment, population by age groups, and socio-economic status data. The socio-economic status data was not relevant to the number of residents and instead provided a broad overview regarding the neighborhoods, thereby differing from the aforementioned scenario. However, the downsizing of neighborhood-based data to grids became necessary due to the fact that demographic datasets are primarily available at the neighborhood scale, but the entire geographical area of the neighborhoods is not located inside the basin area. Given that demographic data pertaining to age and education exhibit a correlation with population size and the degree to which these groups are distributed across each grid is an essential consideration in determining flood vulnerability, it was essential to downscale this information into a grid format.

Hence, the study utilized a methodology based on population to enable the conversion of data from a larger scale to a more detailed grid-level resolution. As a result, the total population of each grid was calculated based on the number of individuals residing in each building, as provided by the building data presented by Ergun Konukcu (2016). To calculate an estimate of the distribution of education and age variables across each grid in the research, the population value of the respective variable in the pertinent neighborhoods was divided by the overall neighborhood population. This process enabled the determination of the representation rate of the indicators within their respective neighborhoods. Afterwards, the ratio that was identified was multiplied by the total population residing within the grid, thereby enabling the determination of the degree to which the chosen indicator displayed itself within each grid.

This procedure facilitated the computation of the quantity of inhabitants who demonstrated the particular indicator being investigated within each and every grid. To illustrate with an instance, the population of individuals aged 65 and above in the Kaynarca neighborhood was scaled in proportion to the overall population of the neighborhood. Following that, the value obtained by this calculation underwent multiplication by the overall populace within each grid. Finally, the demographic dispersion of individuals who are 65 years old and above across each grid that corresponds to the Kaynarca neighborhood was ascertained. This calculation methodology was utilized to evaluate further indicators pertaining to age and educational attainment.

The data associated with buildings was subjected to a similar process, and an analysis was conducted on the characteristics of the buildings within each grid. The building-based data were utilized to enhance comprehension of the structural vulnerabilities of the buildings inside each grid.

Additionally, the number of buildings within specified floor number intervals and their respective construction years were also identified. The variable pertaining to the year of construction for the buildings has also undergone a comparable process. Similarly, the population density of each grid was ascertained by dividing the population data based on buildings by the overall area that constitutes the grid. The calculation involved determining the population density per unit area by dividing the total population by the area of a grid, which was uniformed at 2500 square meters. The visual illustration presented in Figure 3.19 depicts the distribution of population density throughout grids in the study area.

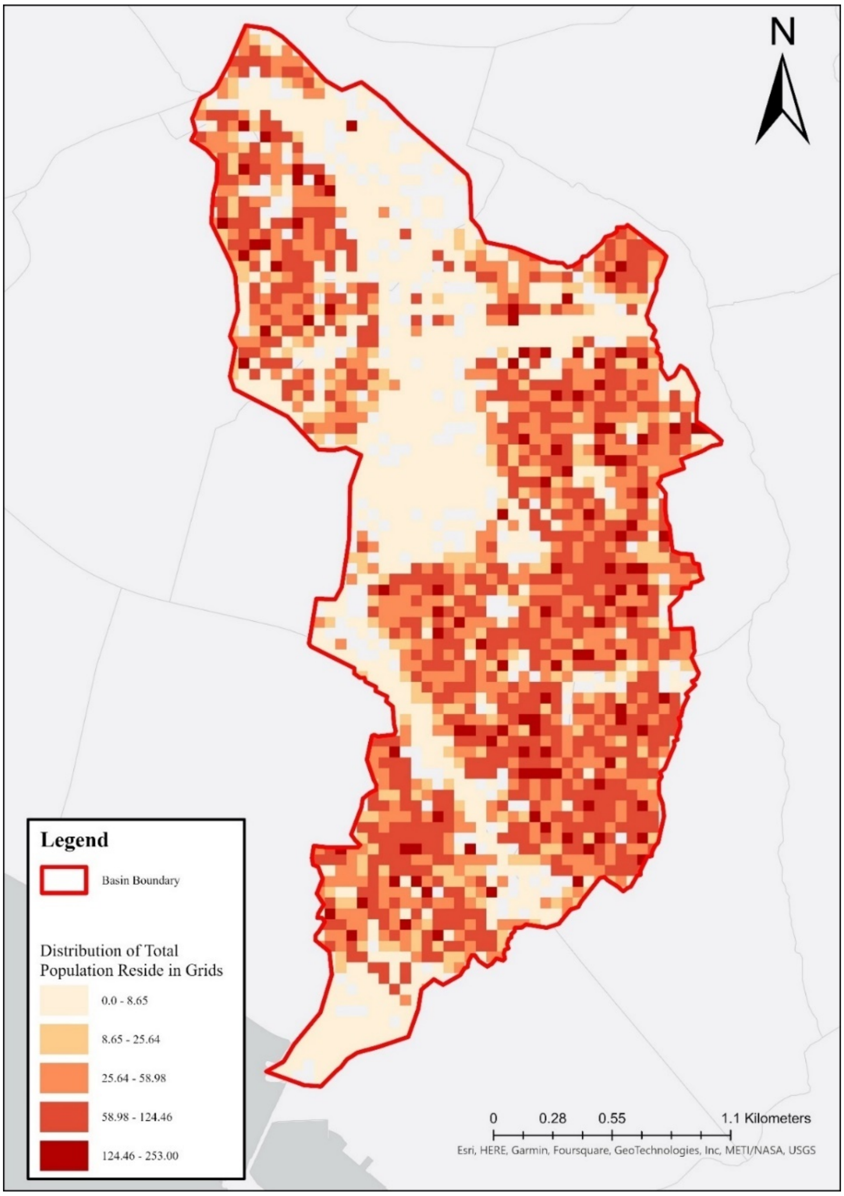


Figure 3.19. The distribution of population density throughout grids in the study area.

To conduct a thorough evaluation of physical vulnerability, it was considered essential to consider the proximity to both the flooded area and healthcare facilities. Consequently, a buffer analysis was performed to ascertain the spatial correlation between each grid and the healthcare establishments, in addition to the floodplain. The study utilized multiple ring buffer technique at different intervals, namely 250 meters, 500 meters, and 1000 meters (see Figure 3.20).

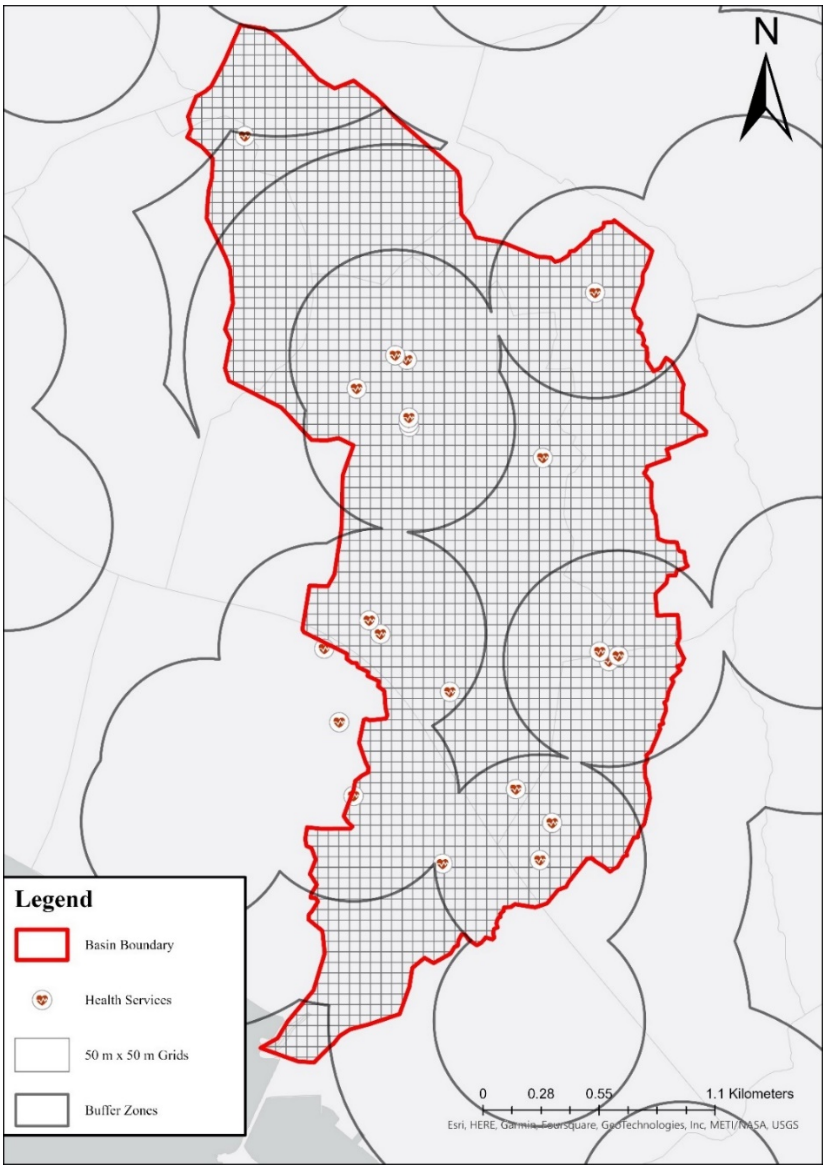


Figure 3.20. Multiple ring buffer analysis around healthcare facilities.

Following a step-by-step process of individually processing each dataset and converting them into a format that can be analyzed on a grid-based system, the standardization phase was initiated. The research required standardization of the data to facilitate comparison and combining procedures due to the distinct ranges, units, and scales of the data sets employed. Normalization is a widely employed methodology that involves converting variables to a uniform scale, thereby rendering them suitable for comparative analysis. The current research employed the min-max normalization technique to normalize distinct datasets obtained from disparate sources. One of the primary benefits of employing min-max normalization was its capacity to maintain the relative differences between the original distribution and the values of the variables during the procedure of scaling from 0 to 1. Additionally, this normalization technique is capable of being effortlessly implemented by the majority of GIS software. The normalization formula to employ is also determined by the functional relationship between the data variables and the vulnerability, or whether those variables impact positively or adversely on the vulnerability (Percival & Teeuw, 2019; Wang et al., 2022). The Equation 3.7 is used for those that favorably affect flood vulnerability, whereas the Equation 3.8 is used for factors that negatively influence it (Erena & Worku, 2019).

$$x' = \frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{3.7}$$

$$x' = 1 - \frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{3.8}$$

where x' is the standardized value; x_i is the value of the indicator; x_{max} is the maximum value of the indicator; and x_{min} is the minimum value of the indicator.

4. RESULTS AND ANALYSIS

4.1. Ranking of Flood Vulnerability Indicators

The methodology employed to determine the ranking of each factor involved pairwise comparison, as demonstrated in Equation (3.2) and Table 4.1 displays the results of the analysis. Subsequently, the converted matrix underwent the normalization process, as presented in Table 4.2. Equation (3.3) provides a more comprehensive explanation of computation methodology. The normalized principal eigenvector, also known as the priority (as presented in Table 4.2), is employed to assign weights to the criteria (Rimba et al., 2017). This table displays the division of each element in the 9×9 decision matrix by the total sum of priority rankings, as described by Saaty (1980), for the selected indicators. The process of normalization involves rescaling the ten parameters to a range of 0 to 1.

Table 4.1. Ranking of flood vulnerability indicators.

	BYEAR	BFLOOR	BMAT	POPDEN	POPEDU	POPAGE	PRFLOOD	POPSES	PRHEALTH
BYEAR	1	$3\frac{2}{5}$	$\frac{3}{5}$	$1\frac{7}{9}$	$6\frac{4}{5}$	3	$\frac{3}{8}$	$2\frac{2}{5}$	$1\frac{8}{9}$
BFLOOR	$\frac{2}{7}$	1	$\frac{3}{8}$	$1\frac{4}{7}$	$6\frac{1}{4}$	$4\frac{4}{7}$	$\frac{1}{5}$	$3\frac{1}{6}$	$1\frac{2}{3}$
BMAT	$1\frac{2}{3}$	$2\frac{2}{3}$	1	$2\frac{4}{7}$	$4\frac{5}{7}$	4	$\frac{4}{7}$	$3\frac{3}{4}$	$3\frac{1}{8}$
POPDEN	$\frac{5}{9}$	$\frac{5}{8}$	$\frac{2}{5}$	1	$3\frac{7}{8}$	4	$\frac{2}{7}$	3	$1\frac{1}{6}$
POPEDU	$\frac{1}{7}$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{4}$	1	$1\frac{1}{4}$	$\frac{1}{8}$	$\frac{2}{3}$	$\frac{4}{9}$
POPAGE	$\frac{1}{3}$	$\frac{2}{9}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{4}{5}$	1	$\frac{1}{7}$	$\frac{5}{6}$	$\frac{2}{7}$
PRFLOOD	$2\frac{2}{3}$	5	$1\frac{3}{4}$	$3\frac{5}{9}$	$7\frac{5}{6}$	$7\frac{2}{5}$	1	$7\frac{5}{6}$	5
POPSES	$\frac{3}{7}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{3}$	$1\frac{4}{9}$	$1\frac{1}{5}$	$\frac{1}{8}$	1	$\frac{4}{9}$
PRHEALTH	$\frac{1}{2}$	$\frac{3}{5}$	$\frac{1}{3}$	$\frac{6}{7}$	$2\frac{1}{4}$	$3\frac{2}{5}$	$\frac{1}{5}$	$2\frac{2}{7}$	1

Table 4.2. Normalized weighted comparison table.

	BYEAR	BFLOOR	BMAT	POPDEN	POPEDU	POPAGE	PRFLOOD	POPSES	PRHEALTH
BYEAR	0.13	0.24	0.12	0.15	0.19	0.10	0.12	0.10	0.13
BFLOOR	0.04	0.07	0.07	0.13	0.18	0.15	0.07	0.13	0.11
BMAT	0.22	0.19	0.19	0.21	0.13	0.13	0.19	0.15	0.21
POPDEN	0.07	0.05	0.08	0.08	0.11	0.14	0.09	0.12	0.08
POPEDU	0.02	0.01	0.04	0.02	0.03	0.04	0.04	0.03	0.03
POPAGE	0.04	0.02	0.05	0.02	0.02	0.03	0.04	0.03	0.02
PRFLOOD	0.35	0.35	0.34	0.29	0.22	0.25	0.33	0.31	0.33
POPSES	0.05	0.02	0.05	0.03	0.04	0.04	0.04	0.04	0.03
PRHEALTH	0.07	0.04	0.06	0.07	0.06	0.11	0.07	0.09	0.07
Priority	0.1475072	0.1030466	0.1836188	0.0873985	0.0279675	0.0304341	0.3118668	0.0380523	0.0701083

According to the pairwise comparison results, physical factors hold more importance than social factors. Given Saaty's recommended maximum acceptable consistency rate of 10%, the research's calculated consistency rate of 3.5% allows for the direct utilization of the aforementioned weights in the evaluation process.

A summary of targeted factors, their weights, and rankings are listed in Table 4.3. We applied the information in this table to generate the distribution of areas vulnerable to flooding. The ranking of each reclassified factor is based on the literature review. The order of normalized weight was proximity to flood plain (31.2%), building material parameter (18.4%), construction year of buildings (14.8%), number of stories (10.3%), population density (8.7%), proximity to health services (7%), SES (3.8%), age (3%), and educational attainment (2.8%).

Table 4.3. Final Indicator weights using the AHP method.

Criteria	Final Weight
Proximity to Flood Plain	0.312
Building Material	0.184
Construction Year	0.148
Number of Floors of Building	0.103
Population Density	0.087
SES	0.038
Age Groups of Population	0.030
Educational Attainment	0.028
Proximity to health services	0.007

Following the determination of weight for each factor the vulnerability of each grid was computed using a weight linear combination, as demonstrated in Equation (3.6).

4.2. Flood Vulnerability Mapping of Kaynarca Basin

The flood vulnerability factors in the Kaynarca watershed were analyzed using a Geographic Information System environment and multi-criteria decision-making techniques in accordance with the results of the AHP. Based on the outcomes of this research, the Kaynarca watershed experienced a total inundation area of 0.28 km^2 for the 500-year return periods.

The methodology employed to generate the flood vulnerability map involved overlaying vulnerability factors using a weighted linear combination, as detailed in Equation (3.6). Following the establishment of the weights for the factors, a multi-criteria assessment is performed by utilizing the specific weights assigned to each variable and the variables themselves. The generation of the overall flood vulnerability map involved a systematic procedure of assigning scores to the various subsections of nine distinct parameters, in tandem with their final weights that were derived from the Analytic Hierarchy Process (AHP). The flood vulnerability scores of subsections for each criterion are shown in Table 4.4. These scores have been determined by considering the relevant literature. It is important to acknowledge that the sub weight approach is exclusively employed for certain criteria. The utilization of sub-weights in criteria can be briefly described as a method in which each sub-criterion possesses unique attributes and establishes distinct causal connections with vulnerability. For instance, the comparative vulnerability of a wooden structure versus a reinforced concrete structure and their respective responses to flooding necessitate consideration of an intermediary weight. On the other hand, the study incorporated multiple variables that exhibit a linear correlation with flood vulnerability, including population density, SES score, number of floors, proximity to flood area, and proximity to health services. These criteria were subjected to direct normalization and were subsequently multiplied by the weights derived from the AHP. The resulting values were then integrated into the overall score.

Table 4.4. Ratings and weights assigned to several classes of flood vulnerability indicators.

Criteria	Class	Rating	AHP Weight
Proximity to Flood Plain	0-50 m	Normalization	0.312
	50-100 m		
	100 m +		
Building Material	Concrete	0.33	0.184
	Wooden, Prefabricated, and Masonry	0.45	
	Steel Construction	0.22	
Construction Year	Pre 1980	0.45	0.148
	1980-2000	0.33	
	2000+	0.22	
Number of Floors of Building	1-5	Normalization	0.103
	6-10		
	10+		
Population Density	0-100	Normalization	0.087
	100-200		
	200 +		
SES	25	Normalization	0.038
	37.5		
	50		
Age Groups of Population	0-15	0.45	0.03
	65+	0.55	
Educational Attainment	No Schooling/Illiterate	0.45	0.028
	Primary, lower secondary, or upper secondary education	0.33	
	Bachelor’s, Master’s or Doctoral level	0.22	
Proximity to health services	0-500 m	Normalization	0.007
	500 m-1000 m		
	1000 m+		

The result of this procedure is the production of a flood vulnerability chart for Kaynarca Basin, as demonstrated in Figure 4.1. The process of categorization was executed by implementing the geometric interval technique, which encompasses a hierarchical framework comprising five levels of vulnerability classification, namely, extremely high, high, moderate, low, and very low. Table 4.5

indicates that the areas of 1.08 km^2, 1.20 km^2, 1.14 km^2, 1.70 km^2, and 1.25 km^2 were associated with flood vulnerability levels classified as very low, low, moderate, high, and very high, respectively.

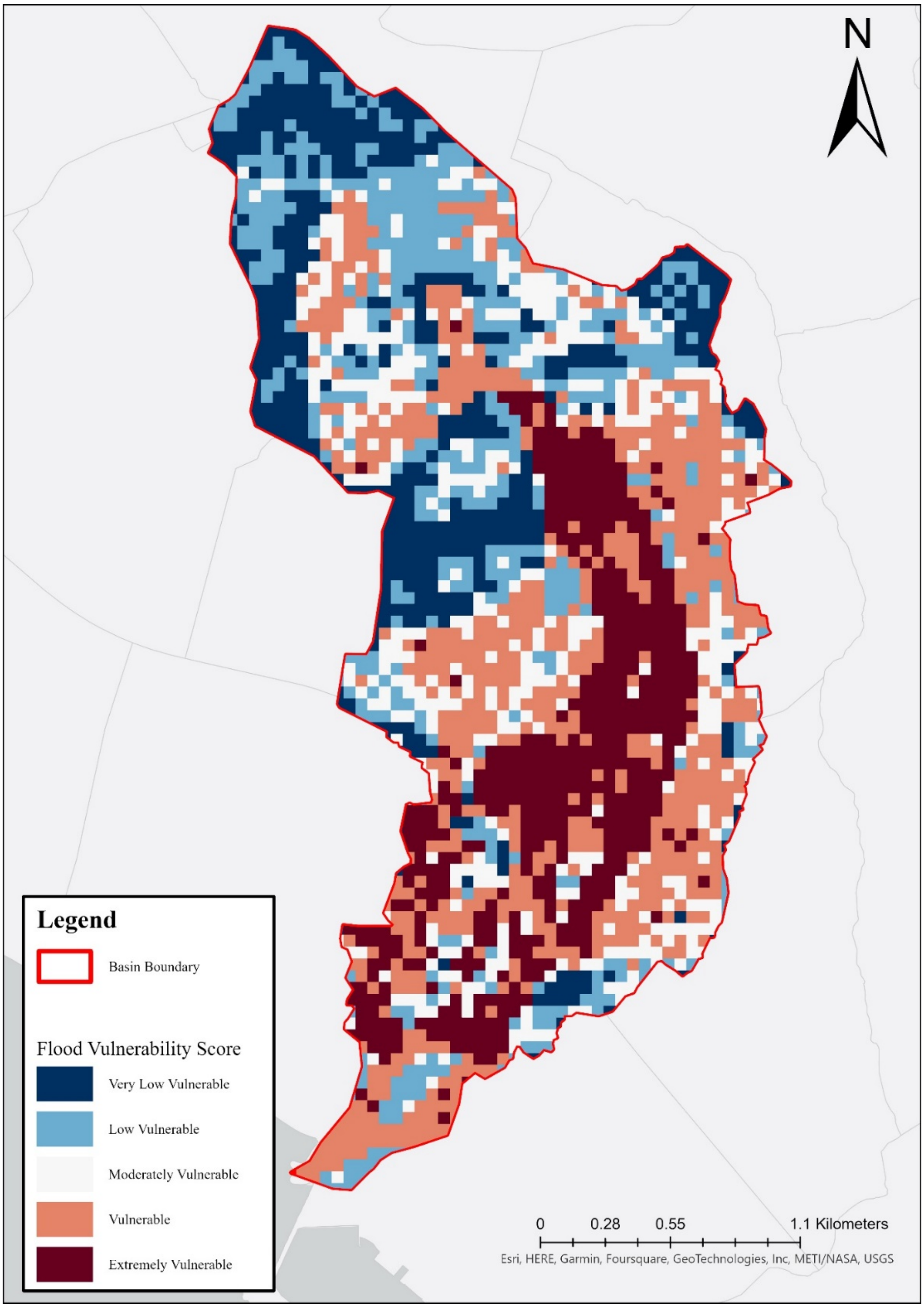


Figure 4.1. Overall Vulnerability Map of the Kaynarca Basin

Table 4.5. Kaynarca Basin flood vulnerability level, area coverage, and percentage.

Flood Vulnerability Level	**Area (km^2)**	**Percent of Area Coverage**
Very Low	1.08	19.37%
Low	1.2	19.44%
Moderate	1.14	17.22%
High	1.7	25.60%
Extremely High	1.25	18.35%

According to the vulnerability map, the downstream parts and the surroundings of active channel are at a high to extremely high level of flood vulnerability. Despite the relatively low percentage of coverage, the high flood vulnerability zones encompass vibrant characteristics that include significant residential properties, transportation infrastructure, and business activity. Indications of low to very low vulnerability to flooding were identified in the central and upstream parts of the watershed. The lower vulnerability of these parts can be attributed, to some extent, to the comparatively small number of buildings and population concentration, as elaborated subsequently in the discussion part of this thesis.

5. DISCUSSION

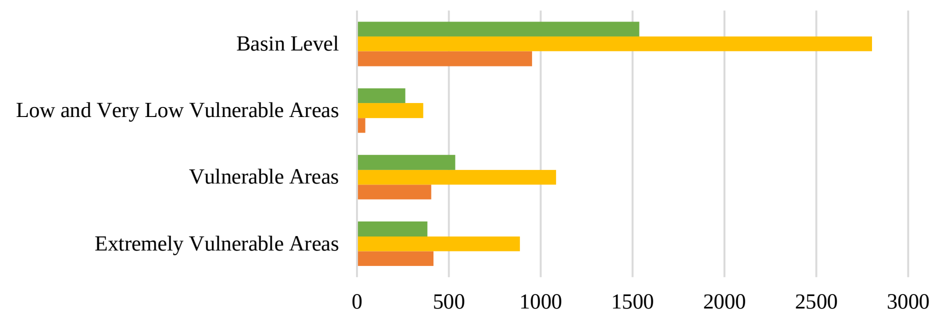
The results of the study clearly show that the degree of flood vulnerability in the region is not evenly distributed. Specifically, a proportion of 19.37% of the area was categorized as exhibiting very low vulnerability, while 18.35% of the area was classified as displaying extremely high vulnerability. 62.28% of the area was categorized as exhibiting low to high vulnerability. The findings of the AHP survey suggest that the vulnerability to flooding of the examined area is predominantly impacted by its proximity to floodplains, the quality of building materials, the year of construction, and the number of floors in a structure. An in-depth examination of the primary determinants of both vulnerable and non-vulnerable regions has the capacity to yield valuable insights for enhancing and formulating policies in these areas. This section thus analyzes the variation in distribution and the occurrence of each of the parameters across areas with varying levels of vulnerability.

5.1. Interpretation of Results and Findings

The findings indicate that the period of the construction of a structure plays a pivotal role in ascertaining its vulnerability to flooding. The vulnerability of older buildings to floods is attributed to their lack of incorporation of flood-resistant materials and techniques during construction. Newer constructions exhibit more effective flood resistance, resulting in a decreased vulnerability to flood-related injury, as opposed to older structures. This finding points out the significance of revising building codes and regulations to guarantee that newly constructed buildings are built utilizing flood-resistant materials and methodologies.

Furthermore, the year of construction of the structures holds significant significance, particularly in the context of Istanbul. The primary factor contributing to this phenomenon is the evolution of building codes and construction methodologies throughout history. Following the 1999 earthquake, the government implemented stricter regulations and monitoring related to building construction and materials throughout the country. Henceforth, within the disaster literature of Turkey, structures built after, and post-2000 period are considered to possess greater resilience against disasters in comparison to previous periods. The primary factor contributing to this disparity is attributed to the internal migration that occurred during the 1950s, which led to the growth of numerous unauthorized constructions throughout various areas of the city. Therefore, Istanbul has witnessed the commencement of a novel building endeavor that has been undertaken without proper consideration of regulations, zoning legislation, and engineering assistance. Furthermore, unplanned areas within unauthorized dwellings are frequently situated in hazardous locations, including water basins, alluvial soil, and landfills (Türkoğlu & Kundak, 2011). All in all, the primary concern in Istanbul relates not solely to the vulnerability of a structure to flooding because of its age, but rather to the fact that the construction methods employed during those times were significantly inadequate in comparison to contemporary standards. It is essential for one to recognize that older structures, constructed with meticulous attention to requisite conditions and specifications, may possess greater resilience to disasters in comparison with current buildings.

Results from the research demonstrate that approximately 45% of the structures constructed prior to 1980 are in areas of high vulnerability, thereby confirming that a substantial proportion of the initial settlements in the basin were established in considerably susceptible regions. It is also noteworthy that the structures predating the 1980s are found near the active channel. On the other hand, it is important to recall that only 25% of the buildings constructed during the period of 2000 and thereafter are situated in areas that have been classified as highly vulnerable to damage. This is another indication that the structural resilience of buildings in vulnerable regions could be comparatively inadequate, based on the claims on building codes and construction techniques (Figure 5.1).



	Extremely Vulnerable Areas	Vulnerable Areas	Low and Very Low Vulnerable Areas	Basin Level
Post 2000	383	535	262	1536
1980-2000	886	1083	360	2803
Pre 1980	416	403	45	953

Figure 5.1. Distribution of building construction years by vulnerability classes.

Similarly, the height or quantity of levels of a building can provide significant insights into the built environment of Istanbul. While the majority of buildings in Istanbul consist of one to five stories, there is a prevailing viewpoint that structures with six or more floors exhibit greater resilience to disasters due to their association with buildings that have undergone recent and innovative engineering advancements. Based on the current data, it can be inferred that a significant proportion of the structures in the basin and the vulnerable zones are low-rise buildings, thereby rendering them more vulnerable to flood damage (Figure 5.2).

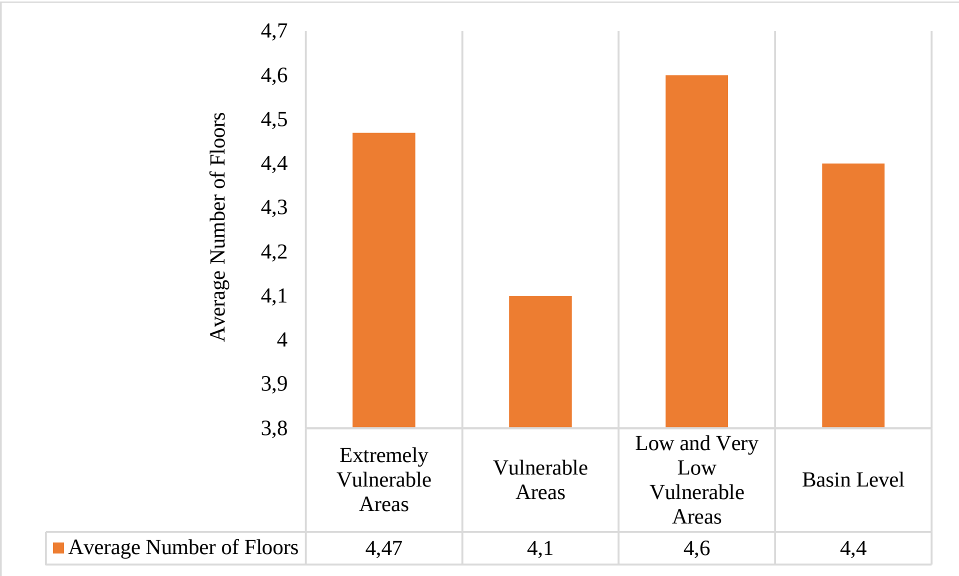
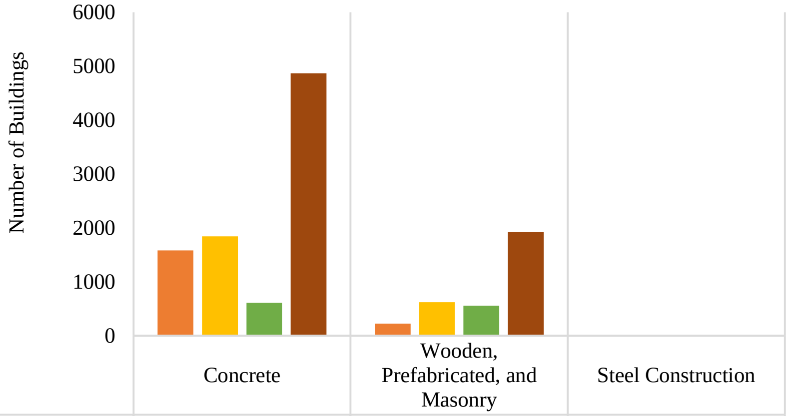


Figure 5.2. Distribution of number of floors of buildings by vulnerability classifications.

The outputs reveal that the flood vulnerability of a structure is also considerably affected by the quality of the construction materials used. Structures built using substandard materials are at a higher risk of being impacted by floodwaters, resulting in their destruction or impairment. The buildings in the area employ three primary classifications of construction materials, namely: antiquated and fragile materials including wood, prefabricated and masonry, reinforced concrete structures, and technological alternatives such as steel construction and tunnel formwork. Tunnel form and steel construction buildings are not prevalent in the most vulnerable parts of the basin due to their limited usage in the local construction industry. Approximately 45% of structures constructed using masonry, wood, and prefabricated materials are in areas that are vulnerable to deterioration or damage (Figure 5.3). Reinforced concrete structures are frequently utilized in vulnerable regions as well as throughout the basin as a prevalent construction method. The findings emphasize the importance of enforcing building codes and regulations to ensure that structures are constructed using quality components that have the ability to endure flooding.



	Concrete	Wooden, Prefabricated, and Masonry	Steel Construction
Extremely Vulnerable Areas	1587	227	0
Vulnerable Areas	1845	625	2
Low and Very Low Vulnerable Areas	612	557	0
Basin Level	4868	1922	7

Figure 5.3. Distribution of construction materials of buildings by vulnerability classes.

The flood vulnerability score is significantly influenced by the proximity to the floodplain. The susceptibility of a region to flooding is directly correlated with its proximity to a floodplain. This is due to the fact that regions situated in close proximity to floodplains are more vulnerable to experiencing sudden and intense precipitation events, which can lead to flash floods and significant damage to both physical structures and public infrastructure. The research produced results that substantiated this claim, as the AHP questionnaire revealed that the distance from the flood zone was the most significant determinant. Upon examination of satellite imagery of the area, it is evident that the buildings and individuals situated in close proximity to the active channel are at a heightened risk. This is due to the fact that construction in the area has been carried out without the incorporation of a buffer distance.

Likewise, there exists a positive correlation between an individual's socio-economic status and their vulnerability to flood hazards. The study employs a socio-economic score that is derived from measurable standards, including but not limited to, high population density, excessive dependency on dependent individuals, and income level. The findings of the study indicate that nearly 80% of the areas that are vulnerable to harm coincide with the communities that exhibit the most unfavorable socio-economic conditions. The basin's mean socioeconomic status (SES) score is approximately 29, whereas the Pendik district's composite score is 32. This renders the basin more vulnerable, even within its own district. Based on the grading scale where A is the highest achievable score, it is apparent that the basin has been evaluated and received a score ranging from D to C, with a closer proximity to D.

The level of literacy and formal education is a crucial factor in disaster preparedness and post-disaster coordination. As such, there exists a direct correlation between flood vulnerability and educational attainment. Upon assessing the educational attainment of the population residing in the basin, the study determined that nearly 70% of individuals lacking formal education or basic literacy were concentrated in regions categorized as vulnerable or extremely vulnerable (Figure 5.4).

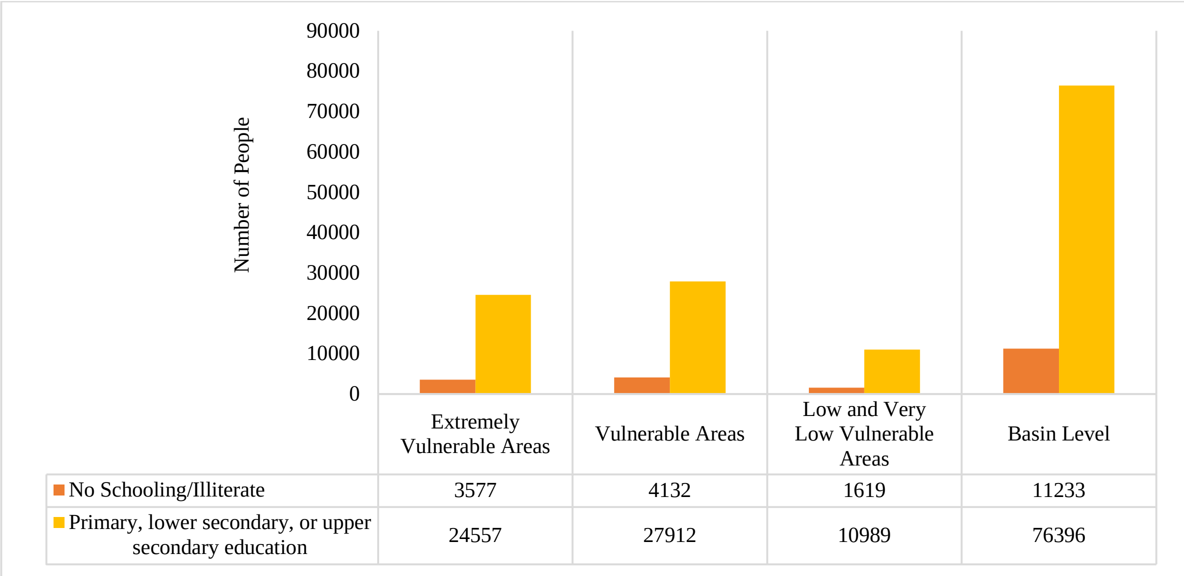


Figure 5.4. Distribution of educational attainment of residents by vulnerability classes.

Conversely, a contrasting trend emerges upon scrutinizing the advanced education level, wherein the areas deemed to be most vulnerable exhibit a greater prevalence of higher education attainment in comparison to the basin. The AHP results also discovered that literacy level among individuals did not have a notable effect on their vulnerability to flooding. The statement suggests that the present endeavors aimed at exploration, education, and awareness may not yield the intended outcomes in mitigating the vulnerability to flooding in the examined region. It is essential to acknowledge that educational and awareness campaigns remain a crucial element in mitigating vulnerability to flooding across various contexts.

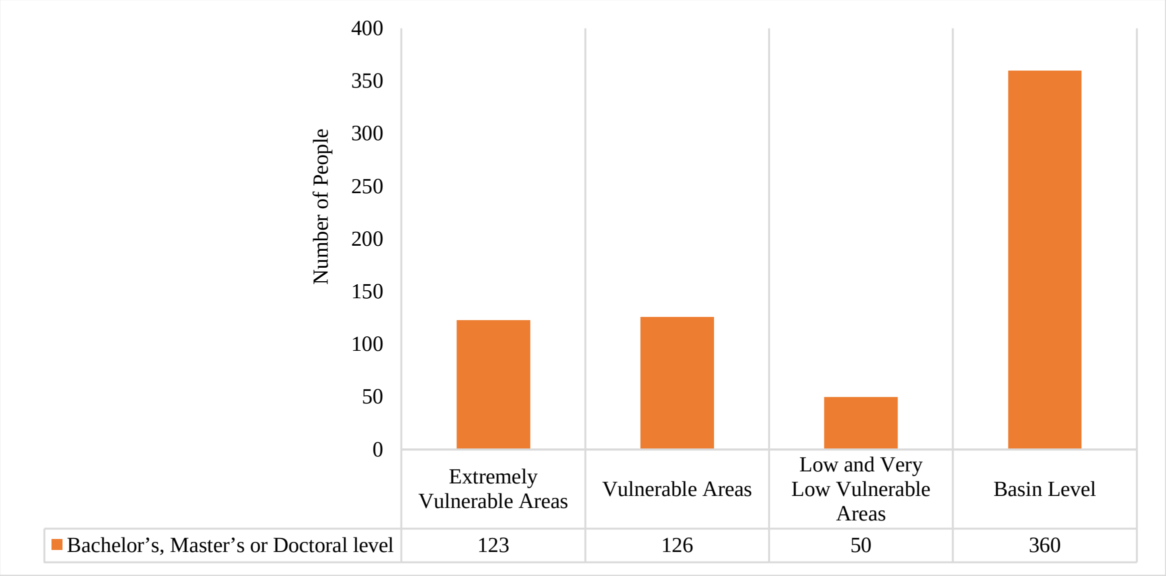
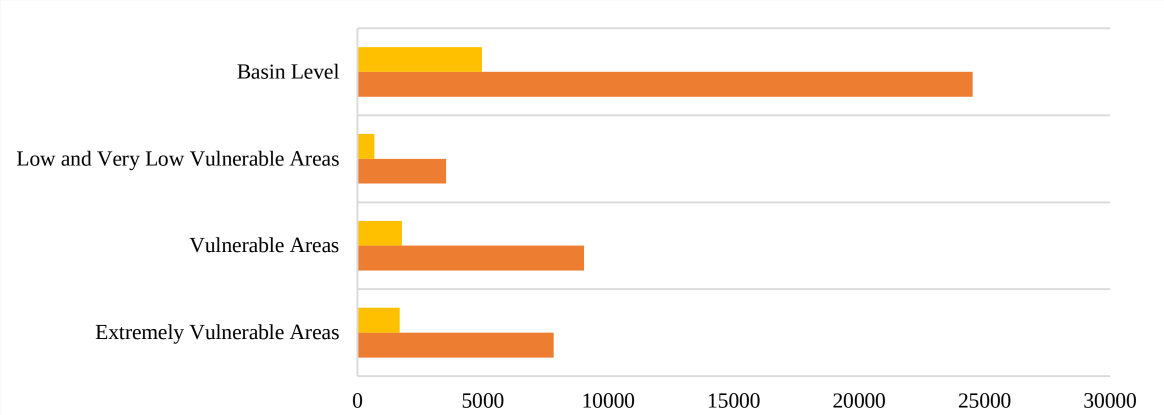


Figure 5.5. Distribution of population with an advanced degree by vulnerability classes.

The proportion of the population aged 65 years and older is another factor that affects flood vulnerability. Older adults may be more vulnerable to flooding than younger people due to their physical limitations and health conditions. For example, older adults may have difficulty evacuating their homes during a flood and may be more susceptible to water-borne illnesses and other health problems associated with flooding. The present research examines age-related information, specifically in two primary groupings, with a particular emphasis on individuals falling within the age range of 0-15 years as well as people aged 65 years and above. According to the analysis, the elderly population (aged 65 and above) residing in the vulnerable and extremely vulnerable areas constitutes 70% of the overall elderly population in the basin. Similarly, the age bracket of 0-15 years, encompassing infants, children, and adolescents, accounts for approximately 68% of the overall population aged 0-15 residing in the basin (Figure 5.6).

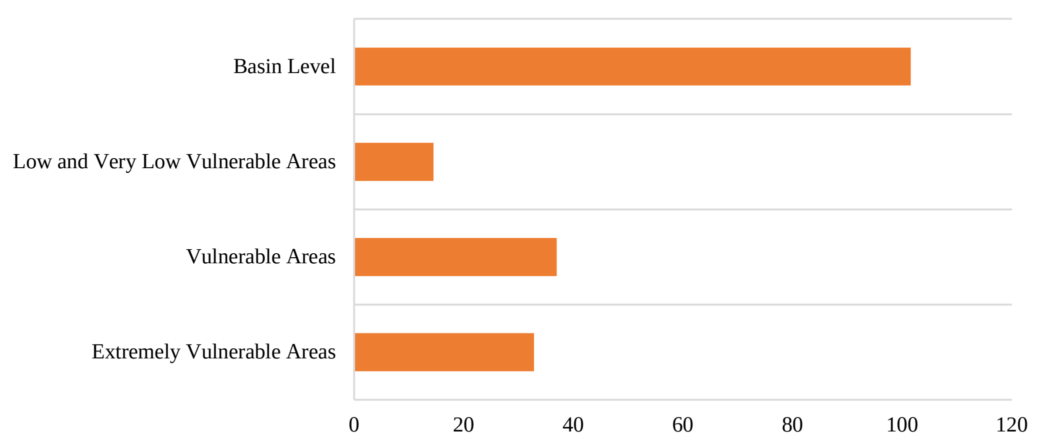


	Extremely Vulnerable Areas	Vulnerable Areas	Low and Very Low Vulnerable Areas	Basin Level
65+	1680	1769	673	4966
0-15	7817	9025	3529	24520

Figure 5.6. Distribution of population by age groups by vulnerability classes.

On the other hand, the impact of the proximity to health services indicator on flood vulnerability was found to be negligible, which is a noteworthy observation. The indicator's low score indicates that the impact of health service availability on flood vulnerability in the study area is not statistically significant. One possible hypothesis for this phenomenon could be attributed to the abundance of significant healthcare establishments located in Istanbul, which may facilitate patient transportation. Furthermore, the finding that regions situated beyond 1 km from the health facilities within the basin account for only 4.3% of the total area implies that the basin benefits from an advantageous position with respect to the accessibility of healthcare services. Nonetheless, it is essential to acknowledge that healthcare continues to hold significance in regions that are vulnerable to flooding, and further examination is warranted to scrutinize the correlation between healthcare and flood risk in different scenarios.

The impact of flood vulnerability is significantly influenced by population density. Areas with higher population densities are more vulnerable to floods due to a greater quantity of people and properties that are exposed to potential flood hazards. The findings indicate that a considerable portion of the watershed, amounting to approximately 68%, was populated by a total of 69.8 thousand individuals, while the rate in regions with low and very low vulnerability is only 14% (Figure 5.7).



	Extremely Vulnerable Areas	Vulnerable Areas	Low and Very Low Vulnerable Areas	Basin Level
Total Population	32,863	36,986	14,523	101,566

Figure 5.7. Distribution of total population by vulnerability classes.

Moreover, it is worth mentioning that the ratio of existing structures situated in regions of ecological importance constitutes 70% of the overall structures positioned in the basin (Figure 5.8). The observation implies that the surfaces located in these areas demonstrate a reduced permeability, which obstructs the penetration of water into the ground and intensifies the severity of the disaster. Conversely, areas characterized by vulnerability to low to extremely low levels were discovered to be associated with parks, hospitals, and unoccupied areas. This finding indicates that the vulnerability to floods may be heightened by an increase in population and urban development, emphasizing the importance of appropriate land use management.

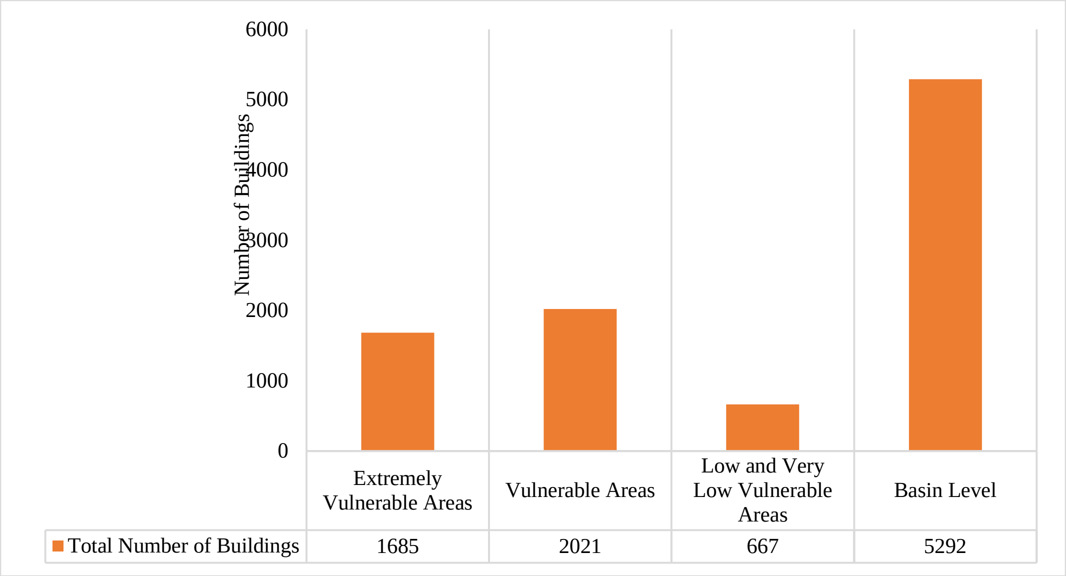


Figure 5.8. Distribution of total number of buildings by vulnerability classes.

In summary, the research findings suggest that areas with elevated flood vulnerability scores are characterized by a combination of factors, such as high population density, proximity to floodplains, use of inadequate building materials, outdated infrastructure, and low socio-economic status. Areas with moderate or low vulnerability to flooding are characterized by factors such as low population density, significant distance from flood-prone areas, use of superior construction materials, recent construction, and higher socio-economic status, as opposed to areas with high vulnerability.

5.2. Comparison with Previous Studies

Upon conducting a comparative analysis with prior research, various noteworthy similarities and dissimilarities have been identified, thereby elucidating the uniformity and situational specificity of vulnerability trends. Acknowledging the variations and contextual nuances that arise when comparing results with prior studies is of utmost importance. The vulnerability patterns specific to the selected study area are highlighted by the indicators in this research. However, it is important to note that other studies conducted in different geographical contexts may place emphasis on different indicators based on their unique socio-economic, environmental, and urbanization characteristics.

The present study enhances the existing knowledge base by integrating the AHP-GIS methodology for evaluating urban flood vulnerability. Prior research has employed diverse quantitative and qualitative techniques, but the integration of the AHP-GIS approach facilitates a thorough and geographically specific assessment of susceptibility trends. The methodology described enables the amalgamation of various metrics, assigning varying degrees of significance to each, and assists in directing the attention of decision makers towards specific sub-criteria in a more accessible manner (Ouma & Tateishi, 2014; Lin et al., 2019). Furthermore, according to certain authors, the utilized methodology offers a comprehensive understanding of multidimensional indicators, including geographical, hydrological, and social factors that contribute to vulnerability. This approach also serves to improve the accuracy and dependability of the findings (Lin et al., 2019). Another point is the scales of the geographical regions where flood vulnerability assessments are applied. While prior research has conducted assessments at the national (Stephenson & D'ayala, 2014), regional (Feloni et al., 2020), district (Lee et al., 2023) or watershed levels (Desalegn & Mulu, 2021), certain studies suggest that conducting assessments at smaller scales can yield more accurate and nuanced outcomes (Wu, 2021). The present study chose to employ the basin level as the assessment scale and computed a more precise output by evaluating all data on a grid basis, rather than through interpolation, for this purpose.

The production of flood vulnerability maps, a primary outcome of this study, is considered significant for policymakers as it facilitates the visualization of vulnerability gradients within a designated geographic region. The challenge of collecting data for flood vulnerability mapping in developing nations has been emphasized, owing to the lack of comprehensive data, restricted resources, and funding. Additionally, it has been noted that census data is typically outdated, ranging from five to ten years (Membele et al., 2022). Scholars have identified the issue of data resolution, reliability, and timeliness as a significant factor that diminishes the usability of flood vulnerability maps (Membele et al., 2022). This problem has also been observed in the current study, as it hinders the accurate representation of the socio-economic and demographic characteristics of individuals at the local level.

Moreover, the present study's results regarding the prioritization of indicators align with those of several studies in existing literature. Mavhura's (2019) study examined flood vulnerability and identified proximity to floodplains as a significant factor influencing flood vulnerability. Romanescu et al. (2016) contend that the susceptibility of structures to damage is impacted by a multitude of factors, such as the proximity of structures to the flood zone, the characteristics of the structures, and the selection of materials utilized in construction. The current research validates the previously mentioned findings by establishing the proximity to floodplains and the construction material utilized as noteworthy factors that determine the susceptibility to flooding in the analyzed area. Additionally, in accordance with specific research studies, the primary normalization technique utilized is the minimum maximum method, which scales the values within the range of 0 to 1 (Afsari et al., 2022). While it is worth noting that this study does not incorporate the land use and land cover (LULC) indicator, which has been identified as a significant factor in other studies, the findings indicate that areas with higher levels of urbanization are more susceptible to flooding (Nkonu et al., 2023; Ali et al., 2019).

However, this study also uncovers distinct variations from the findings of prior research. Certain academics emphasize that the density of the population is the primary determinant of susceptibility to flood-related harm. Nonetheless, the study conducted by Afsari et al. (2022) did not uncover a significant association between population density and vulnerability. The disparities that have been observed may be ascribed to potential variations in the geographical region being investigated, the sample size, or the research methodologies utilized across the various studies. Furthermore, unlike certain investigations in the field, this particular study did not conduct a sensitivity analysis as a result of temporal constraints. It is noteworthy that despite the utilization of sensitivity analysis in various studies, the outcomes remained largely unaltered, as reported by Afsari et al. (2022).

Scholarly literature acknowledges the significance of including both physical and social factors in the assessment of urban flood vulnerability. Abdrabo et al. (2023) conducted a study in Alexandria, Egypt that demonstrates the efficacy of utilizing an integrated indicator-based methodology to develop an urban flood vulnerability index. The present research underscores the importance of taking into account various facets of vulnerability, including physical, social, and economic dimensions, to effectively tackle flood vulnerability and the results underscore the necessity of adopting a holistic strategy that amalgamates each of these elements to provide an exhaustive assessment of vulnerability to flooding in metropolitan regions. The present study and the research conducted by Abdrabo et al. (2023) share a common emphasis on the significance of incorporating physical and social elements in evaluating the vulnerability of urban areas to flooding. The utilization of an integrated approach and a unified Flood Vulnerability Index (FVI) facilitates a holistic comprehension of flood vulnerability, thereby empowering decision-makers to make precise and well-grounded judgments based on the varying significance of diverse indicators.

Another aspect highlighted in this research pertains to the overall quantity of criteria employed during the assessment. The literature on flood vulnerability assessment typically employs an approach that does not prioritize the inclusion of a greater number of indicators for the purpose of achieving greater accuracy in results. The importance of reducing the number of criteria for urban flood vulnerability assessment in the AHP can be attributed to various reasons. Initially, an excessive number of criteria may contribute to heightened complexity as well as difficulties in the process of making decisions. The presence of an excessive number of criteria can potentially cause decision makers to experience a sense of being overwhelmed, thereby impeding their ability to precisely evaluate the relative significance of each criterion. Reducing the complexity of the established standards enables a more concentrated and feasible examination. A further benefit of decreasing the quantity of criteria delineated in scholarly articles is the potential reduction in the time and effort required for data collection during the assessment (Abdrabo et al., 2023).

The present study involved a reduction in the number of criteria utilized, with the aim of achieving a more concise set of criteria. Various methodologies towards this matter have been documented in relevant literature. The predominant methodology employed for this purpose is Principal Component Analysis (PCA). For instance, Abdrabo et al. (2023) employed the PCA methodology to decrease the quantity of criteria from 58 to 38 indicators. Utilizing this methodology, a multitude of variables were condensed into a reduced set of uncorrelated variables known as principal components, thereby facilitating the identification of the prominent variables that contribute significantly to the phenomenon of flood vulnerability. The research findings also emphasized that the process of collecting data, albeit in a condensed version of the index, posed a significant obstacle that spanned over a period of six months (Abdrabo et al., 2023).

The decrease in criteria within this research is predominantly influenced by expert input and the availability of data, rather than relying exclusively on statistical methodologies such as PCA. The collection of expert feedback involves requesting input and insights from domain experts who possess specialized knowledge and expertise in urban flood vulnerability. The experts offer subjective assessments and evaluations of the criteria, drawing upon their expertise and comprehension. Thus, the criteria that were specific to the local context were comprehended and those that were deemed unsuitable were eliminated. The research on data availability is aimed at identifying the quality and accessibility of data for each criterion in a comparable way. The study evaluates the viability of obtaining dependable and inclusive data for each criterion. The present study suggests that to ensure the reliability and precision of the vulnerability assessment, it may be necessary to exclude or modify criteria that have limited or inadequate data. At this point, it is also crucial to highlight innovative approaches to find relevant data for the assessment. For instance, Parvin et al. (2022) employed GIS and machine learning algorithms to estimate sensitive areas and the authors highlighted that one of the primary benefits of utilizing machine learning algorithms is the elimination of the need to analyze numerical data on river flow or climatic conditions, which can be challenging and unavailable for certain regions.

All in all, our study contributes to the extant body of knowledge on flood vulnerability in a comprehensive manner, by furnishing a more detailed comprehension of the key indicators that impact vulnerability within the examined region. The research conducted has identified the indicators that exhibit the strongest correlation with flood vulnerability. This information is of great significance to policymakers and urban planners as it enables them to develop interventions that are tailored to specific areas, thereby mitigating the risk of flooding. Additionally, this study underscores the significance of considering a variety of indicators in evaluating urban vulnerability, as opposed to depending on a solitary indicator or factor.

5.3. Limitations and Future Research Directions

This research attempts to explore flood vulnerability assessments in urban areas using the MCDA-GIS integrated approach. Nevertheless, similar to other initiatives in this field, certain obstacles were encountered in this research as well. The main concern relates to the availability of data. For instance, the research was limited to include certain indicators, such as income, employment, and unemployment, due to the lack of access to a publicly or scientifically shareable dataset that provided comprehensive details on Istanbul’s or Turkey’s economic framework.

One of the challenges encountered during the research process was the timeliness of the obtained data. The study was limited in its scope due to the utilization of building data from 2018 and demographic information from 2020 and 2021, which prevented a comprehensive analysis of the current situation and the temporal change in the trends. Maintaining current and accurate data is crucial for policy development and scientific inquiry, particularly in a rapidly changing urban center such as Istanbul that is experiencing significant structural and demographic shifts.

It is also worth mentioning that in Turkey, demographic information is maintained based on addresses, much like building data which is aggregated at the neighborhood level. Although protecting private information is a legitimate concern, acquiring the finest possible data regarding issues that display spatial differentiation, such as vulnerability, is of utmost significance for research conducted in this field. Providing this data, particularly for scientific purposes, enables the generation of crucial inputs for policymaking, including the identification of intervention areas based on location.

The MCDA procedure's subjectivity was a potential limitation that has also been extensively addressed in academic circles. The selection of criteria, their associated weights, and the weighting methodology may have a substantial impact on the conclusions of the assessment. The variability among decision-makers' choices and judgments may be reliant on their degree of knowledge, expertise, and ideals. Despite the attempt of the present research to minimize these challenges by engaging a diverse range of expertise and professionals in the relevant field, it is important to acknowledge that subjectivity remains a crucial aspect of this method. Hence, it is significant to acknowledge that the inclusion of different professionals utilizing the same methodology for the same research may yield different results.

Considering the limitations outlined and the framework of assessment presented in this research, it is also essential to acknowledge potential channels for future research. The integration of multiple hazard assessments is essential in order to conduct a thorough evaluation of urban flood vulnerability. Therefore, it is vital to comprehend the impact of floods on various urban systems, including energy, transportation, and water distribution, and to identify the affected population with respect to these infrastructures not only at the basin scale but also city-wide.

Adding a qualitative dimension to the quantitative vulnerability assessments presented in this research also plays an important role in determining components such as coping capacity and local awareness. Similarly, knowledge on previous flooding experiences and individual measures taken by inhabitants can only be obtained through field studies, surveys, and in-depth interviews. The incorporation of field studies in verifying the quantitative assessment may improve the inclusivity of results in flood vulnerability assessment efforts.

The utilization of novel technological advancements, such as machine learning, in the context of MCDA can potentially enhance the precision of urban flood vulnerability evaluations by reducing subjectivity. By employing machine learning approaches, it is possible to determine the validity of criteria and their corresponding levels of significance based on historical information on damage assessment in areas that have undergone prior flooding incidents.

Finally, the development of decision support tools that are both user-friendly and innovative is essential for enabling informed policymaking. For instance, the development of a map-based desktop application has the potential to significantly contribute to the identification of intervention areas. This tool may allow policymakers to evaluate multiple criteria simultaneously and evaluate the impact of each parameter on vulnerability.

The potential benefit of reiterating the index produced in the present research is substantial and presents noteworthy advantages in evaluating the vulnerability of urban areas to flooding. The index operates as an exhaustive and uniformed instrument that amalgamates various indicators to furnish an in-depth understanding of flood vulnerability. The integration of spatial data through GIS technology facilitates the precise mapping and visual representation of vulnerability patterns. Repeatability of the methodology in other cities or regions that encounter comparable flood risks can be achieved through the customization of indicators, that depend on local circumstances as well as information availability. The level of adaptability provided by the index's structure allows for customization to suit specific circumstances, while taking into consideration distinctive local vulnerabilities and characteristics.

The process of replicating the index provides numerous advantages. Initially, it enables a comparative evaluation among diverse regions, thereby enabling the detection of hotspots or regions with elevated vulnerability. Furthermore, the utilization of the index possesses an opportunity for promoting the establishment of flood vulnerability databases on either a national or regional scale. Through the standardization of indicators and methodology, it becomes feasible to amalgamate data from diverse sources, thereby facilitating a comprehensive evaluation of flood vulnerability over wider geographical regions. This can facilitate data-based decision-making, formulation of policies, and proper allocation of funds. Finally, the establishment of the index presents opportunities for further investigation in the context of assessing vulnerability to urban flooding. Following research endeavors may concentrate on enhancing the index's accuracy, investigating supplementary indicators, ameliorating data collection methodologies, and assimilating advanced modeling approaches to augment the reliability and relevance of flood vulnerability evaluations.

The study's index offers a thorough structure for evaluating urban flood vulnerability. However, it is crucial to recognize that replicating the precise index may not be possible in every case. For instance, the index presented in the study reflects the ranking and weighing of multiple indicators, based on the principles and choices of the involved stakeholders. Consequently, to reapply this index, a comparable participation procedure with local actors would be necessary for establishing the weights of the indicators.

To summarize, despite possible constraints in replicating the index, the study provides important conclusions and benefits for forthcoming research and practical applications in the domain of assessing vulnerability to urban flooding.

6. CONCLUSION

The present study offers a comprehensive framework for assessing flood vulnerability in an urban setting, with a particular emphasis on MCDA utilizing GIS and incorporating various physical and social criteria. Eventually, this research will contribute to a better understanding of flood vulnerability in urban areas. The previous sections of this thesis have expounded upon the significance of flood vulnerability, various interpretations and components of vulnerability, and the application of MCDA and GIS-based analysis to assess the vulnerability to flooding. This section presents a summary of the key findings of the study and highlights their importance in relation to both theoretical and practical implications. Additionally, it offers recommendations for urban flood policy and decision-making based on the conclusions drawn from the research.

6.1. Summary of the Main Findings

The phenomenon of urban flooding and associated vulnerabilities has become a crucial area of research in both developed and developing nations, owing to its escalating occurrence and projected future rise as a consequence of climate change. Addressing the increasing risk necessitates not only the implementation of adaptation and mitigation measures but also the identification of vulnerabilities. The present research proposes an approach that involves examining physical and social indicators in conjunction with mapping vulnerability based on the 500-year floodplain of the Kaynarca Basin in Istanbul, which is characterized by substantial levels of urbanization. The study employed the Analytic Hierarchy Process (AHP) technique to determine the relative significance of each criterion. The criteria were assessed by an independent group of experts, and the approach utilized in this study yielded highly efficacious outcomes in regard to inclusivity and participation. Furthermore, the results were validated by a consistency ratio of 3.5%. The findings derived from the AHP suggest that flood vulnerability is primarily influenced by physical components as opposed to social components. Ultimately, the final vulnerability map classified the basin into five discrete categories, ranging from areas of extremely high vulnerability to areas of very low vulnerability. The classification process yielded that 8.01% of the basin area was identified as extremely vulnerable, whereas 23.08% was classified as the least vulnerable. Specifically, the assessment identified the southern region as the most vulnerable. This was attributed to its close proximity to the river and floodplain, as well as the substandard quality of the area's building stock. Conversely, upon venturing towards the northern regions of the area, it was determined that said area possessed the lowest degree of vulnerability. This was attributed to the comparably lower levels of housing and population density, as well as the considerable distance from the flood-prone zone. The proposed vulnerability index framework and the integration of two distinct methods possess the potential to serve as a data-driven tool for the identification of flood-induced damage and the formulation of adaptation strategies, thereby aiding decision-makers.

6.2. Contribution of Knowledge and Practice

The results obtained from this research hold the potential to enhance scholarly understanding and practical implementation in the field of flood vulnerability assessment. The present research contributes to the comprehension of vulnerability to floods in urban regions through the utilization of a MCDA methodology that incorporates various criteria and viewpoints from stakeholders.

Furthermore, the present research provides an essential contribution to the socio-ecological sustainability area by highlighting the significance of adopting an interdisciplinary methodology to tackle complex environmental challenges. The incorporation of social, economic, and environmental factors within an integrated framework underscores the necessity of a comprehensive approach to flood risk management that acknowledges the interrelationships and trade-offs among different drivers of disasters. This point of view may offer support to encourage urban development and planning to be more sustainable and resilient.

Given the emphasis on Istanbul, a densely populated metropolis that is highly vulnerable to disasters, the present research holds significant importance due to the lack of studies conducted on Istanbul related to flood vulnerability, as previously noted. Furthermore, the study's grid-scale analysis methodology offers vulnerability insights with a high degree of precision, surpassing other research efforts and uncovering the root causes in each grid. The framework presented exhibits ease of application, flexibility, and inclusivity, thereby enabling its utilization for analyzing other movements in Istanbul.

The findings of this thesis have significant implications for comprehending and addressing vulnerabilities, as well as promoting policy development regarding the management of flood risk in urban areas. This study points out the need for implementing a comprehensive and interdisciplinary methodology to assess flood vulnerability. The results can aid in the development of more efficient and sustainable flood risk management schemes in urban areas.

6.3. Recommendations for Urban Flood Policy and Decision-making

The increasing magnitude and frequency of floods in urban areas, attributed to the effects of climate change and growing urbanization, emphasize the significance of urban flood management and planning as crucial areas of policy that demand prioritization by local governments as well as the national government. Addressing the challenge of urban flooding necessitates the adoption of integrated approaches that align with the complex nature of urban environments. For instance, relying solely on traditional gray solutions, such as land use regulations or infrastructure enhancements, has proven to be inadequate in effectively managing flood risks (Galderisi & Treccozzi, 2017). Furthermore, policy-making procedures that do not incorporate public participation and discussion frequently lead to inadequate execution. Therefore, it is essential to establish a comprehensive set of policies rather than relying on a singular best practice to foster the development of flood-resilient cities. The findings of this study present several policy implications that can guide urban flood management and decision-making, while embracing the concept of resilient cities.

The primary and arguably paramount aspect among these is the creation of land use plans that consider potential flood hazards. One example of flood mitigation strategies is the enforcement of regulations that restrict construction activities within floodways, coupled with the creation of buffer zones along rivers and other water bodies. These measures can effectively preserve the natural flood pathways. It is recommended to enhance the permeability of the surface around water bodies through the elimination of existing structures and their replacement with green spaces, recreational areas, or forest regeneration. Furthermore, augmenting the quantity of open green areas within cities possesses the capability to prevent inundations by aiding in the retention and penetration of urban runoff (Schuch et al., 2017). Therefore, it is of great importance for city planners to prioritize water-sensitive land use plans.

An additional subject of concern relates to the necessity of considering novel and ecology-oriented approaches for the conveyance of wastewater and the restoration of rivers in urban areas. The development of green infrastructure is of crucial significance in the effective management of stormwater and mitigation of flood hazards. The implementation of permeable pavements, rain gardens, and urban wetlands has the potential to alleviate the adverse effects of heavy precipitation occurrences (Song, 2022). The incorporation of green roofs into architectural planning has the potential to efficiently diminish peak flow and runoff and mitigate the burden on drainage infrastructure during intense rainfall events (Calheiros & Stefanakis, 2021). Similarly, the prioritization of ecosystem restoration endeavors is vital to augment natural flood mitigation mechanisms and strengthen environmental resilience. The implementation of river channel restoration or naturalization (Wharton & Gilvear, 2007) and reforestation (De et al., 2013) may act as feasible measures for enhancing floodwater absorption and storage in times of heavy precipitation. Moreover, it is essential to acknowledge that these endeavors should be addressed comprehensively across the entire basin, rather than through fragmented execution (Wharton & Gilvear, 2007).

Creating comprehensive floodplain management strategies that effectively evaluate flood hazards, generate precise floodplain maps, and implement appropriate flood protection measures is crucial. Implementing regulations that mandate the flood-proofing or elevation of structures located in flood-prone areas can mitigate the adverse impacts of flood events. Additionally, developing infrastructure standards resilient to climate change requires considering long-term climate projections, conducting vulnerability assessments, and building adaptive capacity. This may involve measures such as constructing elevated roadways and flood-resistant buildings to mitigate the consequences of increased flood hazards.

Integrating real-time monitoring, weather forecasting, and community outreach is also vital for effective flood management and improved early warning systems (Henonin et al., 2013). The use of advanced sensor technologies and communication systems ensures the provision of highly accurate and immediate flood alerts, enabling residents and emergency response teams to take appropriate precautions.

The development of flood preparedness, response, and recovery capabilities can be significantly improved through community engagement and education. The implementation of awareness campaigns, training courses, and grassroots initiatives may successfully improve the awareness and comprehension of flood risks among individuals and promote engaged involvement of the community in flood management. The implementation of training programs and workshops that focus on flood-resistant building techniques, emergency evacuation procedures, and the significance of maintaining clear drainage systems can substantially enhance community resilience.

Finally, the establishment of collaborative efforts across various sectors is of paramount significance in facilitating the creation and execution of comprehensive flood management schemes. The formation of multi-stakeholder coalitions or committees comprising of government departments and agencies, academia, business organizations, and community groups can enhance collaboration, exchange of information, and cooperative planning to tackle ranging stakeholder perspectives and targets (UNISDR, 2015).

The incorporation of the policy recommendations, that rely on the resilient city principle, offers an extensive framework for urban flood policy and decision-making. Through the adoption of these approaches, decision-makers and interested parties can engage in joint efforts to improve urban resilience, mitigate susceptibilities, and promote sustainable urban growth in response to flood-related risks.

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APPENDIX A: AHP QUESTIONNAIRE SAMPLE

	Extreme Importance		Very Strong Importance		Strong Importance		Moderate Importance		Equal Importance		Moderate Importance		Strong Importance		Very Strong Importance		Extreme Importance	
Construction Year of Building																		Number of Floors in Building
Construction Year of Building																		Building Material
Construction Year of Building																		Population Density
Construction Year of Building																		Educational Attainment of Residents
Construction Year of Building																		Age Groups of Residents
Construction Year of Building																		Proximity to Floodplain
Construction Year of Building																		Socio Economic Status of Residents
Construction Year of Building																		Proximity to Health Services
Number of Floors in Building																		Building Material
Number of Floors in Building																		Population Density
Number of Floors in Building																		Educational Attainment of Residents
Number of Floors in Building																		Age Groups of Residents
Number of Floors in Building																		Proximity to Floodplain
Number of Floors in Building																		Socio Economic Status of Residents
Number of Floors in Building																		Proximity to Health Services
Building Material																		Population Density
Building Material																		Educational Attainment of Residents
Building Material																		Age Groups of Residents
Building Material																		Proximity to Floodplain
Building Material																		Socio Economic Status of Residents
Building Material																		Proximity to Health Services
Population Density																		Educational Attainment of Residents
Population Density																		Age Groups of Residents
Population Density																		Proximity to Floodplain
Population Density																		Socio Economic Status of Residents
Population Density																		Proximity to Health Services
Educational Attainment of Residents																		Age Groups of Residents
Educational Attainment of Residents																		Proximity to Floodplain
Educational Attainment of Residents																		Socio Economic Status of Residents
Educational Attainment of Residents																		Proximity to Health Services
Age Groups of Residents																		Proximity to Floodplain
Age Groups of Residents																		Socio Economic Status of Residents
Age Groups of Residents																		Proximity to Health Services
Proximity to Floodplain																		Socio Economic Status of Residents
Proximity to Floodplain																		Proximity to Health Services
Socio Economic Status of Residents																		Proximity to Health Services

Name, Surname	
Title	
Occupation	
Institution	