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Green Infrastructure and Flood Resilience in Fatih, Istanbul

Yvette van der Velde

4734092 (TU Delft)

s1500511 (Leiden University)

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1st Supervisor: Dr. Aksel Ersoy

2nd Supervisor: Dr. Laura Scherer

Universiteit Leiden

TU Delft

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Abbreviations

AFAD	Disaster and Emergency Management Presidency
AHP	Analytical Hierarchy Process
AKOM	Disaster coordination Directorate of Istanbul
DSI	General Directorate of State Hydraulic Works
ES	Ecosystem Services
GI	Green Infrastructure
GNP	Gross National Product
IBB	Istanbul Metropole Municipality
ISKI	Istanbul Water and Sewerage Administration
OECD	Organisation for Economic Co-operation and Development
OSM	Open Street Map
SES	Socioeconomic Status
SRC	Stormwater Runoff Coefficient
TSI	Turkish Statistical Institute

Summary

This thesis focuses on the challenges Istanbul faces due to extensive urbanisation and global warming. The metropole has become vulnerable to climate change, especially to the increasing threat of floods. As a result of urbanisation and poor city planning, the green spaces have decreased considerably in Istanbul, which reduced stormwater retention considerably. This is concerning, as green infrastructure provide ecosystem services that can serve as flood control. The thesis describes the context of Istanbul's flood governance, including international, national and metropolitan flood policies and Istanbul's flood resilience actor-network. In Istanbul's flood risk management plans, the role that green infrastructure can play in flood control has been neglected. To meet this gap, this study aims to analyse how green infrastructure could enhance Istanbul's flood resilience. Fatih is one of the oldest districts in Istanbul and is taken as a case study due to its high vulnerability to flash floods.

The study presents a case study on Fatih with a spatial approach to monitor flood resilience and ecosystem services through green infrastructures that can foster resilience. A Geographic Information System in combination with a multi-criteria evaluation is used as a tool to identify priority areas for green infrastructure investments. Finally, the effect of three green infrastructure investments is analysed.

The research finds that the indicators proposed by Li et al. (2016) are appropriate to use to analyse the priority areas for green infrastructure investment. These indicators reflect a system approach as they include technical, environmental as well as social variables. This is important for the city of Istanbul, as they provide a holistic framework with these indicators.

Furthermore, using the flood map provided by ISKI, the flood sensitive areas in Fatih have been identified, and especially the infrastructures surrounding the main boulevard are subject to flooding. Molla Gürani resulted to be the neighbourhood being most flood vulnerable, and therefore the main priority is for green infrastructure development. For this neighbourhood, increased green infrastructure is modelled. The results show a significant reduction in flood vulnerability, which concludes the part green infrastructure have in flood control.

The thesis concludes that there is no one-size-fits-all response to enhance flood resilience. Especially since flood resilience is not only based on flood mitigation but rather coping and transforming from floods. Green area investments prove useful to enhance resilience, as these investments provide benefits that can transform the resilience of urban flood management into a more adaptive state due to the nature of the ecosystem services. This research proposes a few recommendations for decision-makers in Istanbul to take into consideration.

1. Introduction

The expansion of urban areas is a global trend. People are increasingly migrating to cities. As a consequence, urban landscapes are enlarging. Green areas make way for grey infrastructure to accommodate the rising demand for housing. This can pose flood challenges as dense urban areas make cities vulnerable to floods if there is no adequate storm water drainage system (Hudeková, 2011). The effects of climate change will only exacerbate these vulnerabilities, as extreme weather events are expected to increase. Especially in dense urban areas where there is no green infrastructure (GI), such floods are likely as there is little to no natural stormwater retention. Hence there is a need for more sustainable stormwater management and an increase in urban infrastructure. In cities experiencing more frequent flash floods, policies tend to be more directed towards enhancing flood resilience through the use of GI (Lennon, Scott, & O'Neill, 2014; Pappalardo, La Rosa, Campisano, & La Greca, 2017). Istanbul is an example of a city in which the urban area has rapidly increased over the last few decades and where the share of GI has decreased significantly. It is experiencing increasing flash floods and the need for sustainable flood management is pronounced. Istanbul has various good policies and institutions in place (i.e. 2.2.1.). However, the implementation and the absence of ecosystem services (ES) and GI remain a challenge. Furthermore, researchers have recognised the valuable role GI can play in meeting Istanbul's flood challenges (Balaban, 2016; Onur & Tezer, 2015). In addition, research has found that GI can enhance the city's flood resilience.

In this thesis, a case study approach is taken to analyse the land use in Istanbul and its GI capacity to provide flood resilience. This study is part of the scientific discipline Industrial Ecology, as it takes a systemic approach to tackle flood adaptation issues, using GI. The systemic approach of the method integrates environmental, technical and social indicators to identify priority areas for GI investments, in order to integrate sustainable development in flood governance. This thesis aims to make recommendations for policymakers to enhance local flood resilience using GI investments. The focus is to determine the priority areas in the case study where GI investments should be prioritised. In this chapter current research on urban climate challenges is presented, as well as the role of GI and ES along with the discussion of urban flood resilience.

1.1. Urban Environments and Climate Vulnerability

Because urban environments differ physically in a vastly different way from their natural surroundings, average temperatures, air, and soil quality differ as well (Hudeková, 2011). Therefore, it is expected that climate change in cities will only aggravate these differences. According to Hudeková (2011), these issues include increases in temperature, reductions in air humidity and, decreases in precipitation with longer periods of drought leading to a decline in soil quality. However, storm precipitation will increase, which in conjunction with lower soil quality, increases the probability of local flooding and landslides. Additionally, more extreme weather events such as windstorms and tornados are increasingly likely to occur, as well as changes in natural ecosystems. Furthermore, to what extent cities are vulnerable to these climate change effects depends heavily on how cities have developed historically and how they are currently developing. Construction plans lead to less permeable surfaces which can hamper the natural infiltration of water. Pappalardo et al. (2017) point out that the consequences of urban flooding are usually adverse human health, caused by contaminated food or water, injury, as well as emotional distress.

1.2. Green Infrastructure and Ecosystem Services

GI is defined as the interconnected network of green spaces and open areas. It includes natural systems into the built environment such as cities (Farrugia, Hudson, & McCulloch, 2013). Examples of GI are parks, green roofs, trees, and watercourses, or a combination of these. According to the Centre for Clean Air Policy, the development of GI help achieve sustainability and resilience goals, which subsequently foster climate change adaptation (Foster, Lowe, & Winkelman, 2011). Research has shown that GI can host services of ecosystems, which are beneficial to society (Farrugia et al., 2013; Onur & Tezer, 2015). The benefits of these ES include the management of stormwater runoff, as well as flood prevention, water capture, and water conservation (Foster et al., 2011). Furthermore, ES can protect against sea-level rise and can reduce the amount of urban heat island effects (Foster et al., 2011). Additionally, GI can foster the mitigation of climate change impacts on the water cycle by capturing precipitation and distributing this water to lower layers of the soil and groundwater through root systems. GI make the soil more porous and thereby increase the infiltration capacity of soil and the downward flow of water by gravity (Zimmermann, Bracalenti, Piacentini, & Inostroza, 2016). Some of the precipitation that falls into the basin is initially held by the plants on the basin surface, which is called retention. Some of the water held by plant transpiration and surface disposition evaporates back into the atmosphere. The remaining water infiltrates into the soil and ultimately reaches a river. The peak of the water flow is thereby reduced as it moves through the GI (Hudeková, 2011; Tuskan, Müh, & Karisan, 2011). Furthermore, it can reduce erosion caused by extreme storm precipitation and landslide, exacerbated due to climate extremes. The main focus of this research is the benefit of ES on flood risk management. However, other benefits include improved air quality, wildlife habitat, recreational space, and improved human health (Carter, Handley, Butlin, & Gill, 2018).

Hence, GI goes beyond storm-water management and has become an integral part of resilient city planning. The role of GI in flood risk management is therefore progressively acknowledged by city planners and research groups (Carter, 2018;

Pappalardo et al., 2017). It is urgent to define strategies to cope with the issue of stormwater runoff in flood management and point out the positive effects GIs have as part of the strategy. As a result of increased vegetation cover, water interception increases, as well as increasing storage and infiltration capacity (Zimmermann et al., 2016). This substantially improves the urban drainage system, especially when the infrastructure is very difficult and expensive to modify.

1.3. Urban Flood Resilience

Hegger et al. (2016) define resilience as being a "property of a system", including stability and the ability to change. Such a definition is used in the academic field of flood risk management, where the concept of resilience is applied as being resilient to floods as the ultimate goal in the new trend towards flood risk management (Hegger et al., 2016). On a further note, resilience of an urban environment should represent that of a natural system, where the system should not be disturbed by any discrepancies of natural and/or human impacts (Dong, Guo, & Zeng, 2017). Furthermore, it is noted that resilience is the capacity of such a system to react to turmoil and shocks without changes (Ahern, 2011; Foster et al., 2011).

The previous understanding of resilience is defined as the ability of the system to go back to its single equilibrium (Holling, 1973). Nowadays, the understanding is that the system adapts and transforms to multiple possibilities of an equilibrium, which shifts the study of resilience to a more dynamic form of system resilience (Davoudi et al., 2012; Gunderson, 2000). Hence the focus is on the system's capacity to change and transform from shocks and stresses, into an improved state.

ES support this transformative resilience through its provisioning, regulating, and cultural services (Pappalardo et al., 2017). The paper by Lennon et al. (2014) focuses on GI as an approach to realise evolutionary resilience for enhanced urban drainage. It positions urban design as integral in facilitating the evolutionary resilience of flood risk management through GI. They argue that most of the literature on flooding used to mainly focus on defence mechanisms to reduce the threat of floods, mainly in the form of grey infrastructure and engineering interventions to constrain rivers and channel heavy precipitation. In recent years, academia seems to realise the paradigm shift to move beyond the notion of 'keep the water out' into a more holistic, resilient approach, by adopting both mitigating and adaptive flood risk measures. Lennon et al. (2014) view GI measures as a transformative approach in one of the pillars of flood resilience. They argue that GI works with nature in relation to flooding because it is multifunctional, responsive, and flexible. In other words, these aspects have the ability to transform the resilience of urban flood management into a more adaptive state due to the nature of the provisioned ES.

2. Literature Review

In this section, indicators that have previously been used in research to analyse GI in relation to flood control are reviewed. Furthermore, the urban situation of Istanbul is described including the flood challenges it faces as a result of this situation. Furthermore, Istanbul's flood governance is discussed to review its historic and current efforts regarding flood risk management. In addition, flood risk management policies of three different governmental levels are stated as well as Istanbul's flood resilience actor-network. These matters will result in the knowledge gap and research questions.

2.1. Indicators

Various studies point out that there are multiple values of urban ES in improving resilience in cities in relation to flood prevention and management, focusing on the runoff regulation service. According to them, the indicators usually assessing this runoff regulation service are soil infiltration capacity and percentage of sealed surface. They also refer to this as biophysical indicators for economic valuations, which focuses on avoided costs by ES for increasing property damages as a result of floods or dependence on water purification technologies (Pappalardo et al., 2017). In order to apply ES in practice and decision-making, quantifying, modelling and mapping ES become a very fundamental step. Appropriate indicators are needed to quantify the processes by which water flows are regulated in the urban catchment. This requires catchment-scale hydrologic and hydraulic models, as essential tools for calculating indicators that quantify different water-related ES. The response of catchments to precipitation is affected by different ecosystems and land use elements included in GI (Pappalardo et al., 2017). The simulation of this response becomes fundamental in order to identify the most effective adaptation strategies. Furthermore, distribution, quantity and quality of GI have an important influence on the vulnerability of cities regarding flooding. It is important to assess these, as well as the distribution of impermeable surfaces in the public environment (Hudeková, 2011).

Hence, to model Istanbul's flood resilience, appropriate indicators have to be found that can be quantified into GIS, and positively impacted by GI. Another example of this is the study of Farrugia et al. (2013), where they used habitat mapping and a multi-criteria framework to identify the green space score for flood control. They used a normalisation method to quantify the flood control of the green spaces per administrative border (Farrugia et al., 2013). A normalisation method is used to adjust values of any element to different scales, in order to create a common scale that enables better comparison (Guichard, Moisan, & Morel, 2005).

Another important factor in analysing flood resilience of ES in GI are land cover types. Gill et al., (2007) have researched adapting cities for climate change and focused on the role of the GI in this. Their methodology is regarding the performance of several urban morphology types regarding several environmental functions. This means that they assessed the performance of farmland, woodland, residential areas, transport infrastructures etc. on the maximum surface technology and flood control. In the latter, they focus on what the surface runoff coefficient of these urban morphology types is in order to analyse its flood control. They argue that soils that can infiltrate water fast, such as sand, have a lower runoff coefficient as opposed to soils that infiltrate water slower, for instance, clay (Gill, Handley, Ennos, & Pauleit, 2007). The paper takes the urban morphology types and measure their flood storage and infiltration capacity to analyse climate adaptation.

The study by Li, Uyttenhove, and Van Eetvelde (2020) did something similar as pointed out for indicator assessment in the previous papers and focused on the planning of GI to mitigate urban surface water flood risk. As one of the goals of this study, their methodology focuses on identifying priority areas. In their methodology, they make use of a flood sensitive map of the study area, to identify the flood sensitive infrastructures. The indicators focus on three different categories relating to mitigating urban surface flood risk using GI for their GIS assessment (Table 1). The indicators have different measurements and are weighted to aggregate the priority areas (Li, Uyttenhove, & Van Eetvelde, 2020).

Table 1: *Methodology paper Li et al., 2020.*

Category	Indicator	Measurement	Normalisation
Hazard mitigation	Storm-water runoff mitigation	Rational method	weight: 0.45
Vulnerable flooding receptors protection	Social flood vulnerable group	Identify the spatial location of the social flood vulnerable location	weight: 0.25
	Flood sensitive area road infrastructure protection	Identify the potential flood-prone road infrastructure	weight: 0.17
	Flood sensitive area buildings protection	Identify the potential flood-prone buildings	Weight 0.09
Exposure reduction	Environmental justice	Identify the areas that lacking existing green spaces	Weight 0.04

Carter (2018), studied the role of the GI of urban climate change adaptation in the context of urban cooling and flood risk management. He recognises the importance of scenario planning to support decision-makers in responding to climate change adaptation, as urban areas are subject to various changes in future land use patterns. Therefore, the paper considers how land-use change over the coming decades, focusing on GI that may influence the capacity of urban areas to adapt to climate change hazards such as floods and heatwaves. Hence, it focuses on the adaptive capacity of urban areas, which relate to their resilience to climate change, influenced by urban land cover characteristics. The author makes a good point that the adaptive capacity of the city to climate change is influenced by various environmental, institutional and social drivers (Carter, 2018).

Additionally, it is of importance to assess the amount of water that can be managed within the system area, including the infiltration, storage and drainage of the water (Pappalardo et al., 2017). The authors focus on the potential of GI in urban runoff control. They mention that the ES GI provide resilient options to face flood risk management. Furthermore, the authors state, that the quality and quantity of the urban water system is mainly influenced by urbanisation, as it alters soil into less impermeable surfaces. In order to analyse the watershed of the system area, the authors used the ArcGIS Spatial Analyst Hydrology tool, as well as drawing an urban storm-water sewer system provided by the municipality of the study area. They modelled two scenarios using the US EPA Storm Water Management Model, which simulates the urban catchment response to specific precipitation.

Zimmermann et al. (2016), evaluated the relative impacts of GI on flooding, using an indicator based on the runoff coefficient, as it allows quantifying the impacts on the runoff due to the increase of GI that is presented. Additionally, the study proposes to focus the indicator on the risk of flooding. Using this, they created four scenarios to be evaluated, the baseline scenario and three hypothetical future scenarios, considering different outcomes concerning the amount of GI. However, this method to evaluate the impacts of GI on flooding is specifically proposed, since the study area lacked spatial data.

The research by Carter et al. (2018) demonstrated that GI provides valuable flood risk management services. The research explored three related issues using two case studies. The first issue was describing and mapping flood risk management functions provided by GI. Secondly, it identified spatial relationships between GI and administrative borders. Thirdly, the implications of changes in landscapes on future runoff levels are assessed, using future projections (Carter et al., 2018). Even though the authors researched on the landscape scale, they stress that aiming for flood resilience concerning climate change adaptation, it needs to be tackled from multi-sectoral and scalar approaches and call for the use of a system perspective. By doing so, other benefits of the ES provided by GI should be researched, and networks of responsible actors related to the issues should be encouraged to cooperate in making GI landscape planning a priority in urban climate change adaptation (Carter et al., 2018).

Stürck, Poortinga, and Verburg (2014) presented a paper on ecosystem service modelling, with a spatial approach to supply and demand. With this approach, they analysed flood regulation services on a European scale and addresses the spatial distribution of the demand for ES. The spatial indicator used for flood regulation demand is the land use sensitive flood damage estimates, and the supply as natural vegetation (Stürck, Poortinga, & Verburg, 2014). This research mainly focuses on the context of river basins, and while it focuses on ES in relation to floods, the research does not aim for flood resilience.

To summarise, this review indicates that clear indicators are necessary to adopt, which allows for a spatial approach to the research. The indicators that are often used for such an approach are flood sensitive demographic, stormwater runoff, flood sensitive areas and land cover types. The relationship between land covers, flood sensitive social groups and flood sensitive infrastructure can result in priority areas and help GI planning and design (Li et al., 2020). Therefore, the indicators proposed by Li et al. (2020) are appropriate to use to analyse the priority areas for GI investment. Additionally, these indicators reflect a system approach as they include technical, environmental as well as social variables. This is important for the city of Istanbul, as they provide a holistic framework with these indicators.

2.2. Istanbul

Istanbul's population has increased almost fifteen times as much since the start of 1925, while its urban area has expanded widely as well (Figure 1)(Erdem & Kaya, 2017; Unalan, 2011). This extreme urbanisation happened due to excessive migration to Istanbul to find employment in the abundance of factories that were newly constructed. Currently, the city has a population of 15.5 million and is one of the biggest metropolises in the world. Its population density is 2,500 people per square kilometres, contrasting Turkey's average of 81 people per square kilometres. This massive urban growth came at a cost, as many of Istanbul's natural areas have been displaced to make way for the large demand for housing and the constructions of highways. Green spaces, such as parks, and forests, which would benefit flood control, cooling of temperature, home of biodiversity, etc., had to make way for mainly grey infrastructure (Konijnendijk, Nilsson, Randrup, & Schipperijn, 2005).

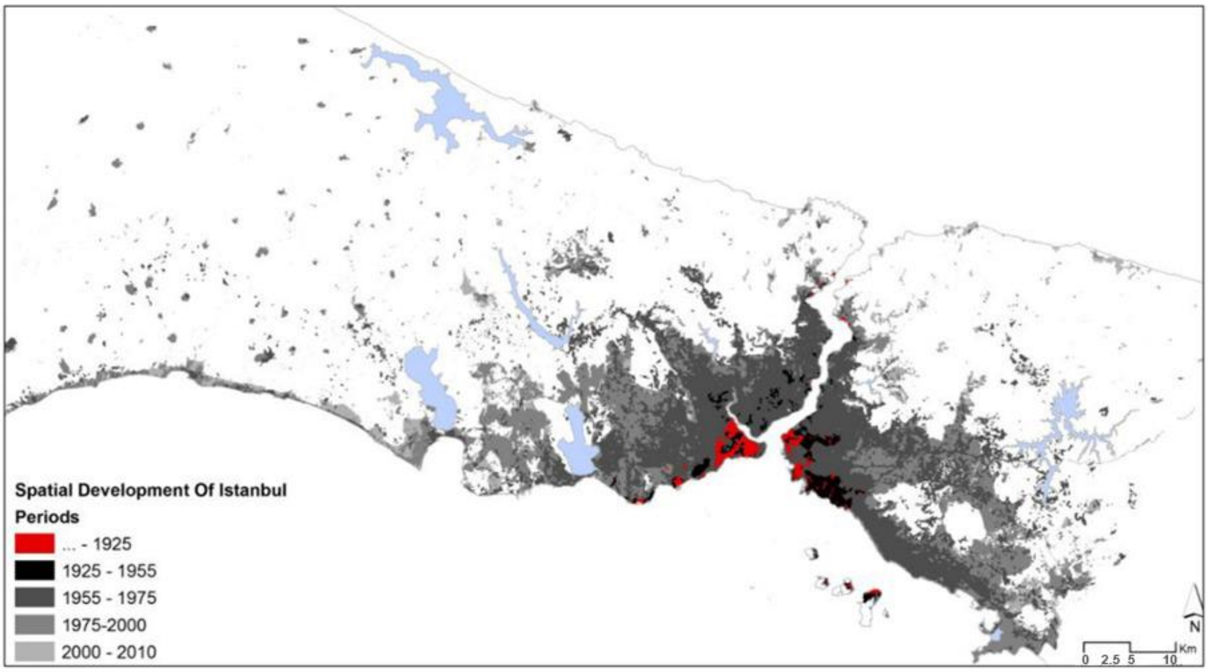

***Figure 1**: Spatial Development of Istanbul (Erdem & Kaya, 2017, p. 35)*

Accompanied by this massive urbanisation and global warming, the metropole has become vulnerable to climate change, especially the increasing threat of floods. To reiterate, average temperatures will increase which is accompanied by extreme weather events, changes in precipitation levels, and an increase in natural hazards including floods (Onur & Tezer, 2015; van Leeuwen & Sjerps, 2016). These challenges will impact the livelihood of Istanbul's inhabitants and interfere with Istanbul's sustainable development goals in the long term. Hence, there is an urgent need for Istanbul to tackle these challenges, by including the use of ES.

2.3. Istanbul's Flood Governance

Istanbul's coast is surrounded by the Marmara Sea and the Black Sea is situated north of the metropole. However, research indicates that the city has no risk of coastal flooding, as sea-level rise is not an issue in this area. Nonetheless, there are risks of inland floods (OECD, 2016). In the last few decades, Istanbul has been experiencing an increase in flash floods which result in a loss of property and even human casualties. Due to climate change, it is expected that floods will increase even more. In addition, the construction plans in Istanbul played a major part in the flow direction of precipitation and blocking of its runoff. Therefore, the city has become more susceptible to flooding (Turoğlu, 2011).

Achieving urban flood resilience requires solving a combination of interdependent challenges related to the socio-political, engineering and environmental spheres. This includes adapting to future uncertainties associated with climate change and increasing urbanisation (Fenner et al., 2019). How floods in Turkey are generally ought to be managed is that before floods, the focus should be directed towards risk reduction and preparation (Figure 2). This is operationalised through structural measures, land use planning, reservoir operation rules, preparation of intervention plans, and flood forecasting and early warning. During floods, there should be a focus on intervention by providing health services, search, and rescue teams. After the flood, the focus is on recovery, return to normalcy, and flood evaluation. They do so by assessing the causes and results of the event and analysing and learning from the flood (Özcan, 2015a).

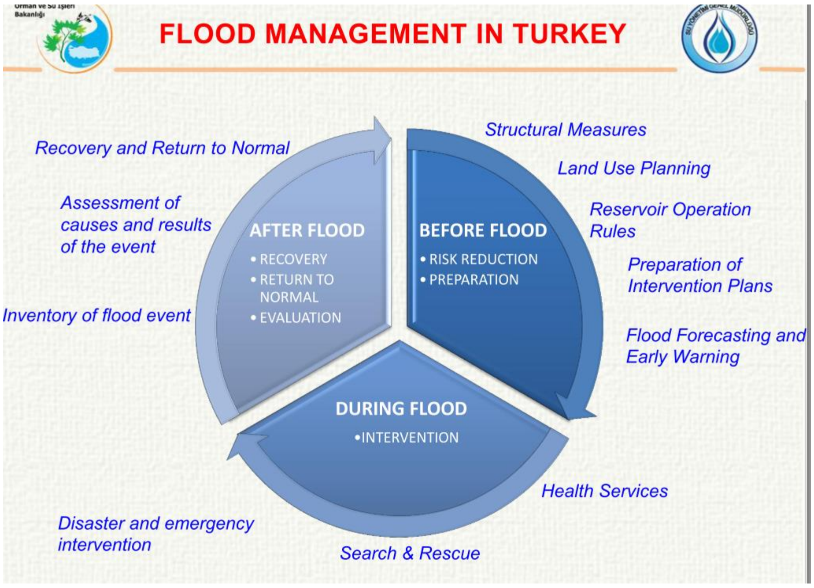

Figure 2: *Flood Management Cycle of the Turkish General Directorate of Water Management (Özcan, 2015a)*

This is currently not adequately happening in Istanbul. Istanbul invests significantly in its water management but makes use of non-preventative measures towards flooding as it mainly focuses on its water availability (Varis et al., 2006). Nonetheless, it has not been enough to foster sustainable integrated water resource management, which includes coping with floods as well (van Leeuwen & Sjerps, 2016). Moreover, flood mitigation efforts are being undermined by new land-use developments that expand the areas at risk (OECD, 2016). Additionally, decision-makers in Istanbul mainly take capital-focused approaches which lead to pressured ES as well as increasing concerns for water safety (Unalan, 2011). In this study on governance and planning in Istanbul, the author calls for Istanbul to adopt sustainability instruments regarding its urban planning to preserve water and to create and foster transparent communication between different parties involved. Furthermore, it is argued that due to Istanbul's condition, flood regulation that includes the development of green spaces is crucial (Onur & Tezer, 2015).

2.3.1. Flood Risk management policies

International Policies:

Any given place differs in size, environment, land use, as well as organisational dynamic and demographic structure, there is no one-size-fits-all approach to managing floods. This is because different characteristics of a place impact its water functions and management (Akhmouch & Clavreul, 2019). In other words, what might seem like the perfect flood policy in the Netherlands such as dikes, will not necessarily be appropriate for Istanbul. Nonetheless, general recommendations for flood governance can be made.

Meng et al. (2020) have developed a framework of five different types of measures that can be implemented in the planning of flood risk management (Table 2). These measures are translated into policies/regulations as well as different interventions in practice. These measures fall under the three pillars of flood resilience as well as assisting in designing strategies to cope, adapt and transform with and from floods.

Table 2: *Five types of flood risk management measures (Meng, Dabrowski, & Stead, 2020)*

Measures	Statements in Planning Policies/Regulations	Affected (Non-) Structural Interventions in Practice
Avoidance/prevention	Floodplain zoning plans; land acquisition and relocation plans	- Watershed management and retreating from waters (avoiding urban development in flood-prone areas) - Function arrangement (economic enterprises, residential areas and recreations) - Population move and building (re)locations
Defence	Multi-purpose/multifunctional engineering measures to deal with coastal and fluvial floods with the consideration of leisure, landscape, and commerce	- Dykes, floodwalls or quay walls (setting back, combined with residential buildings, commercial development, greening, and transportation) - Reservoirs (water storage, supply, natural landscape, and recreation)
Mitigation	Nature-based infrastructure for coastal flooding reduction, rainfalls detention and retention, and river discharge passage	- Creation of green buffers and flood detention areas - Creation and preservation of mangroves, dunes, mashes wetlands, lakes, and green–blue corridors - Waterways and channels de-culverting, greening, and improvement - Sustainable Drainage Systems (SuDS)/Low impact development measures (rain gardens, permeable paving, green roofs)
Preparation	Building codes and building controls; evacuation plans; safe havens arrangement	- Buildings waterproofing (removable stop logs, water-retaining walls, mobile barriers, the lowest flood elevation for footings, structural requirement to withstand water pressure, prohibiting basements, flood-proof facades, standards for buildings anchored to foundations) - Road networks optimization - Safe havens creation
Recovery	Post-recovery plan; critical infrastructure protection	- Building reconstruction - Re(location) and reinforcement of supporting buildings such as power plants, healthcare centers, and police stations

The Organisation for Economic Co-operation and Development (OECD) recommends five different flood action points for its member states. The organisation is established to provide policy guidance that fosters improved resilience for governments. The OECD consists of many member countries, including Turkey (OECD, n.d.). All levels of governments can adopt these points to govern floods (OECD, 2019). These action points include:

1. Enhance national resilience and responsiveness through establishing and promoting a holistic approach to country-level flood governance.
2. Anticipate on all-encompassing impacts of floods through flood analyses, risk assessments, and financial frameworks.
3. Educate and raise awareness of flood risks to all involved stakeholders, from households to international actors, and promote investments in risk
4. Coordinate resources across the government and its network to enhance decision-making, communication, and emergency responses. This will increase the adaptive capacity in flood crisis management.
5. Be transparent and accountable in the decision-making of flood governance, and incorporate good governance practices and learn from experience and science.

National Policies:

The flood policies that Turkey is said to currently undertake on the national scale are:

- Flood coverage in insurance programs. Although, in flood-prone areas, some insurance companies may not include flood coverage or determine extra conditions (OECD, 2016).
- Investments in flood risks maps (OECD, 2016).
- The naturalisation of river channels (Balaban, 2016).
- Allocating more space along the riverside for rivers to flood safely (Balaban, 2016).
- Investing in sustainable urban drainage systems (Balaban, 2016).
- Developing adaptive flood prevention measures such as green roofs (Balaban, 2016).
- Cooperation between sectors and different levels of the government, mainly on the national and regional level (Peer Review Turkey, 2015).
- Participate in EU conferences on flood resilience, and implement the EU Flood Directive (Peer Review Turkey, 2015).
- Establish stakeholder groups including representatives from various bodies from the national and local level, involving citizens as well. The objective is to share knowledge and discuss flood prevention and mitigation actions (Peer Review Turkey, 2015).
- Follows international standards and EU regulations on flood prevention and flood risks (Peer Review Turkey, 2015).

Istanbul Policies:

Flood management policies on the local scale fall mainly under the responsibility of Istanbul's water and sewerage administration (ISKI) (ISKI, 2021). In their strategic plan 2021-2025, several flood management measures and actions are proposed (ISKI, 2021). However, specificities on who, what, when, and where these propositions should take place are not discussed.

According to Article 697.1, flood management plans are allocated (ISKI, 2021). Regional flood plans will be prepared and integrated into provincial disaster plans. Additionally, an early warning system will be developed for floods warnings. In addition, ISKI will update current flood risks in all basin maps. Article 4.4.1.15 is about the balance of water supply and demand (ISKI, 2021). Herein, it is mentioned that delay reservoirs and storage systems should be constructed to control flash floods in urban areas. It reiterates that flood management plans should be completed and implemented.

The strategic plan mentions that ISKI wants to regulate and protect water structures in a more integrated manner through soil conservation, afforestation, and pasture improvements and constructing permeable pavements in urban areas. In streams where the flood risk is not high, it is proposed to encourage preventing canalisation and restoring these streams with vegetal elements to increase water quality.

In order to provide flood control and to protect the groundwater level, ISKI proposes to increase new types of interventions and mentions urban permeable pavement, artificial ponds, and seepage areas (ISKI, 2021). But there are currently no concrete plans to put these measures into action. In 2015, the Istanbul Municipality Metropole (IBB) and ISKI have signed the 'Istanbul Water Agreement Goals'. With these goals, the institutions promise to make appropriate measures to manage water in accordance with urbanisation and global challenges (ISKI, 2015). The goals including flood-related challenges are to reduce the damages caused by water-related disasters from "x%" of the gross national product (GNP) to less than 5%. What the current damages are of the GNP is not mentioned and how they will reduce this. Additionally, they signed to develop concrete plans for flood control, drainage rehabilitation, disaster response and preparedness for sea-level rise. Finally, the goal is to redesign infrastructures to withstand extreme weather events (ISKI, 2015).

2.3.2. Flood Resilience Network

To determine Istanbul's flood management network, relevant actors are reviewed. According to (Brand et al., 2019), the water management network, the urban land development network, and the urban sanitation network are actor networks generally involved in urban flood resilience (Figure 3). This figure illustrates the relationship of these different networks that influence urban flood resilience. The interactions these actors have, produce different measures for the three pillars of flood resilience, namely robustness, adaptiveness and transformation. Important actors not included in this illustration are mainly unorganised groups, households, businesses and community associations (Brand et al., 2019). This framework helps to explain Istanbul's flood management actor-network.

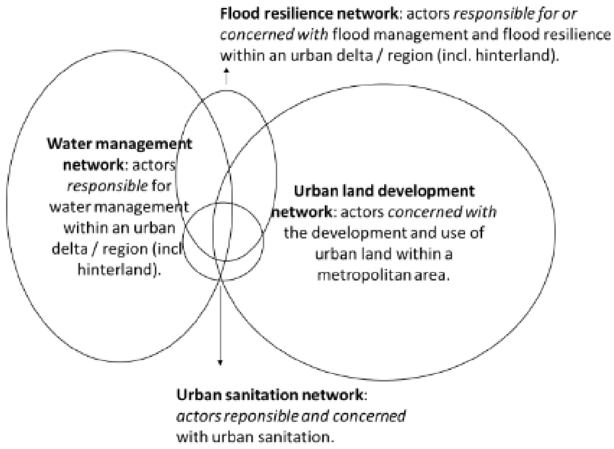

Figure 3: *Overview of actor-networks generally involved in urban flood resilience (Brand et al., 2019, p. 20)*

A water management network consists mainly of public actors that are responsible for water management, and are coordinated by formal and legal frameworks which include the established guidelines for flood management (Brand et al., 2019). An urban land development network is interactions between public and private stakeholders including citizens that are involved with the planning and the management of the urban infrastructure. In addition, these interactions are led by the market mechanism and the legal framework. An urban sanitation network usually includes public and private actors from both the water management network and the urban land development network. Their task is managing sanitation as well as constructing and supporting the infrastructure. While actors are involved on the national level, it is mainly managed on the district level. The flood resilience network consists of actors from each mentioned management network that are involved with flood governance. These range from international organisations, NGOs, the national and local governments, to civilian groups and consulting universities. The interactions between these actors are directed by international and national guidelines for flood risk management (Brand et al., 2019). The table below seeks to list all actors involved in the Istanbul flood resilience network, based on literature and existing policies (Table 3).

Table 3: *Actors involved in Istanbul's Flood Resilience Network including roles*

Level	**Name**	**Role**
International	OECD	Establish and consult guidelines for member states
	EU Flood Directive	Its flood risk map requirements are set as a standard for Turkish flood-risk management (Peer Review Turkey, 2015)
National	Ministry of Forestry and Water Affairs	Covers upper catchment control plan, afforestation, erosion control, flood brooks and degraded forests

		(Özcan, 2015b; Peer Review Turkey, 2015)
	General Directorate of State Hydraulic Works (DSI)	Prepares national flood management strategy and action consultations with relevant ministries (Özcan, 2015b; Peer Review Turkey, 2015).
	Various ministries: environment and urbanisation, public works and settlement, of development.	Mapping and planning of flood management involves these ministries (Özcan, 2015a; Peer Review Turkey, 2015)
	Disaster and Emergency Management Presidency (AFAD)	The legal framework of warning systems and evacuation measures (Ekmekcioğlu, Koc, & Özger, 2021)
	General Directorate of Meteorology	Executing predictions and early warning systems of extreme weather events, which are shared with the relevant institutions (Disaster Risk Management Profile, Istanbul, Turkey, 2005; Peer Review Turkey, 2015).
Istanbul	Istanbul Water and Sewerage Administration (ISKI)	ISKI performs regular flood risk plans and performs risk mitigation measures to manage flood events (Ekmekcioğlu et al., 2021). Additionally, damaged water systems during and post floods are rebuilt by the institution, as well as maintenance and cleaning of the structures.
	IBB	Sustains infrastructure investments and have the right to organise environmental management strategies, which includes increasing green areas. Responsible for environmental protection practises and risk communication to increase community awareness. IBB assigns ISKI to generate flood risk maps and to regulate water management as well as land-use planning concerning water bodies (Ekmekcioğlu et al., 2021).
	households, businesses, community associations	Dealing with the impact of floods
	Disaster coordination Directorate of IBB (AKOM)	Coordination of warning systems and evacuation plans between

		local institutions (Ekmekcioğlu et al., 2021)
Other	Universities	Source of solution. Supplies planning strategies and technical support to (governmental) institutions concerning flood management (Ekmekcioğlu et al., 2021)

Disaster and coordination centres play an important part in this flood resilience network because of their warning, evacuation and rescue activities when disasters happen. They are responsible for the planning and operations of early warning systems and these, in turn, impact the welfare and numbers of flood victims. Appropriate actions of these centres, therefore, reduce vulnerability and increase resilience against floods (Ekmekcioğlu et al., 2021). Prediction and early warning of extreme weather events are executed by the General Directorate of Meteorology and shared with the relevant institutions, including AFAD and AKOM (Disaster Risk Management Profile, Istanbul, Turkey, 2005; Peer Review Turkey, 2015).

2.4. Knowledge Gap and Research Questions

Fatih has been rapidly expanding and increasing in population which led to local ecosystems and natural resources being threatened by this urbanisation. Additionally, due to poor city planning, green areas have significantly decreased over the years and the Istanbul metropole has become highly vulnerable to floods, accompanied by climate change. The priority assigned to tackling flood challenges is high. However, the required measures are currently not actively integrated within planning. In addition, urban ecosystems in combination with flood resilience have not been sufficiently integrated into the flood adaptation strategy of Istanbul, and the role of GI has been neglected in this as well. In order to meet this gap, this study aims to analyse how GI could enhance Fatih's flood resilience.

Based on these findings, the main research question is: How can green infrastructure enhance Fatih's flood resilience? The sub-questions supporting this main research question are:

1. *What are the flood sensitive areas in Fatih?*
2. *What are the priority areas for green infrastructure development in Fatih?*
3. *How is local flood resilience enhanced using green infrastructure investments?*

3. Methods

The study presents a spatial approach to monitor flood resilience and ES through GIs that can foster this resilience. Geographic Information System (GIS), in combination with a multi-criteria evaluation framework that focuses on the different ES related to controlling floods, can represent a suitable support tool in decision-making (Meerow & Newell, 2017). Through such an approach, priority areas for the development of GI can be identified, and the effect of GI investment analysed. The overview of the geoprocessing workflows built-in ArcGIS for this research is visualised in Appendix A.

In this chapter, the method of this research is explained (Figure 4). The answer to sub-question 1 regarding which existing indicators have previously been used in studies relating to flood resilience and ecosystems are reviewed (Appendix B). From this review, the indicators are selected and further presented in this chapter. Following, the steps of the analysis of this research are discussed.

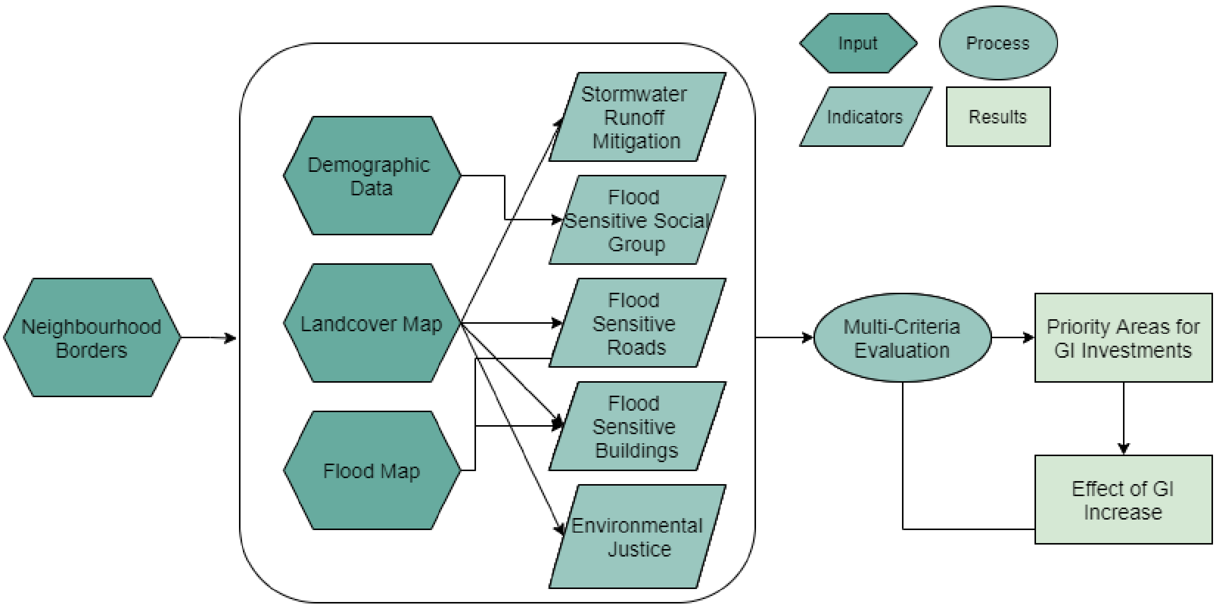

Figure 4: *Research Design*

3.1. Study Area: The Case of Fatih

The case study selected for this research is Fatih, being a district in Istanbul. This district is chosen because research indicates that it is one of the top flood-prone districts of Istanbul. Furthermore, compared to historical flood events of other districts in Istanbul, Fatih experienced significant land-use changes over the past few years that were not covered in past flood events (Ekmekcioğlu et al., 2021). This makes Fatih an interesting case to study for this research.

Fatih is one of the oldest districts in Istanbul. Currently, the total population is about 440,000, and the population density is 27,639 ppl/km2 in an area of 15.62 km2. Historically, the area of Fatih today was well known as Constantinople, home of many religious sites. Since the 1950s, this historical peninsula of Istanbul has transformed rapidly. Immigration to the city highly increased, and Fatih being the centre of Istanbul, the demand for housing grew. Furthermore, city fires in Fatih left some areas in deterioration. The government wanted to solve these issues as well as wanting to transform Istanbul like the European 'modern' cities, and create a big boulevard (Coskun, 2012; Okta, 2017). As a result, they hired a French architect Henri Post to realise this in city planning. He had some ideas about creating more green and open spaces, but the budget of the municipality was too limited. Since his plans mainly focused on constructing and reconstructing roads and public transportation, housing demand increased even more. It left the area to become chaotic, as unplanned concrete apartment buildings were constructed, replacing the old urban city. The urban development of Fatih has not changed much since, other than that the area became more touristic since the 90s, leading to the construction of more hotels. Additionally, some areas of the historic peninsula became open-air museums (Durhan & Özgüven, 2013; Turgut, 2008). Consequently, the rest of Fatih became more crowded and chaotic. However, from 2007 to 2017, the population has decreased by 8.3%, as people migrated elsewhere in the city due to the inadequate conditions (Koramaz, 2018). In some neighbourhoods, the housing is in a poor state, with bad sanitation and uncontrolled and poor living conditions, which mainly houses asylum seekers (Coskun, 2012). Housing renewal plans have commenced to a certain degree. However, priority for the green environment has not been integrated within planning to tackle these issues (Koramaz, 2018).

Regarding existing green spaces, the tip of the peninsula, situated around the Topkapi Palace is the greenest area of Fatih, as it is forbidden to construct on this historic site (Karaca, 2013). Furthermore, additional notable green spaces are located along the coast and at the south of Aksaray and Cerrahpasa (Figure 5). Moreover, there are not many waterways in Fatih. The only type of water found in Fatih are fountains and one historic aqueduct above a busy road, barely visible on the map. Fatih is also bordered by the Marmara Sea, the Bosphorus strait and the Golden Horn (Haliç) river. The influence of the coast on flood resilience is left beyond the scope of this study as research indicates that currently, there is no risk for coastal flooding in Istanbul (OECD, 2016).

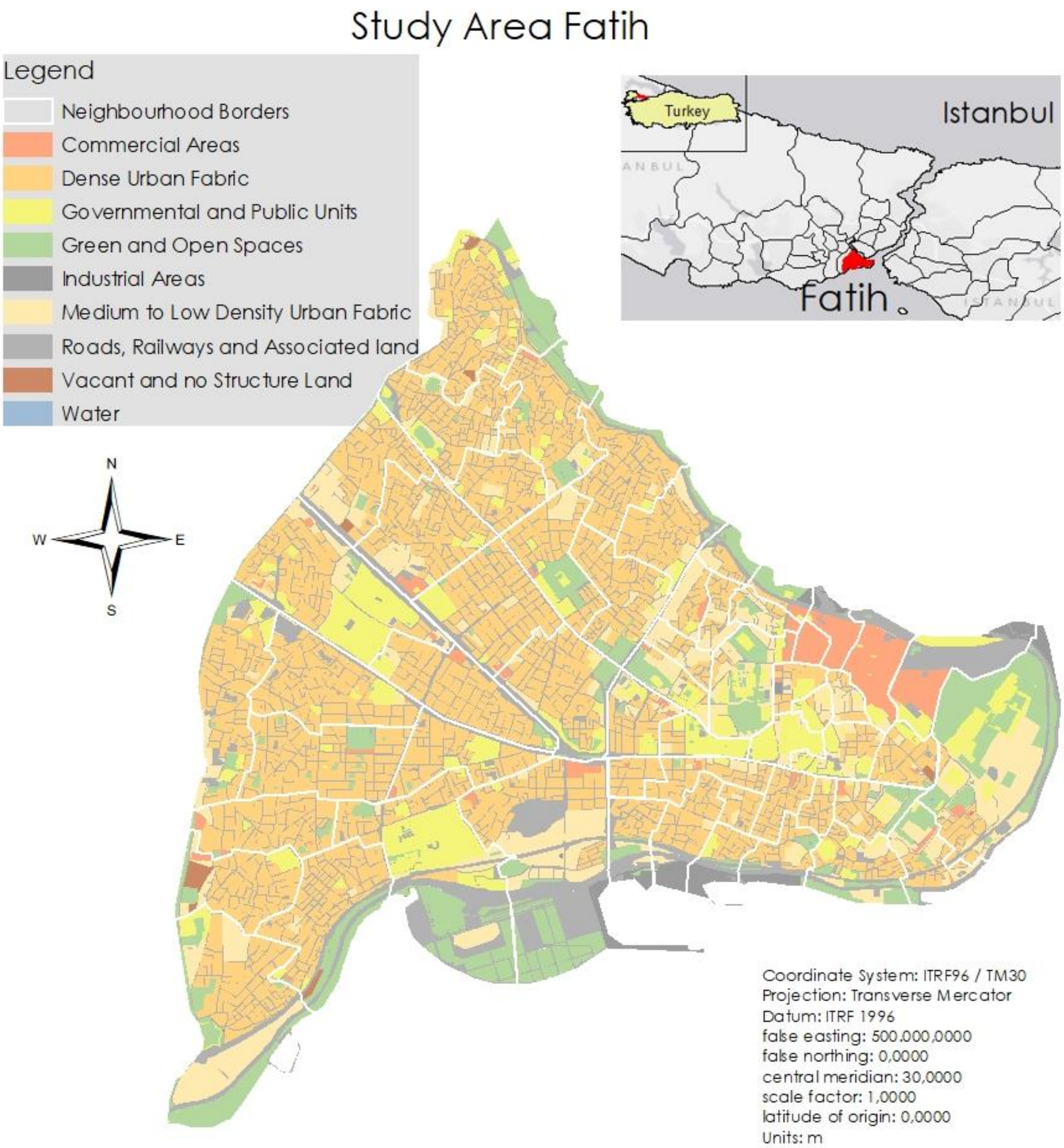

Figure 5: *Case Study Map with landcover types*

3.2. Indicators

As explained in section 1.3., flood resilience is sustained by robust, adaptive, and transformative pillars. ES delivered by GI mainly support transformative resilience, because of its responsive and flexible nature. Therefore, the focus of the resilience task of GI is more on containing the urban surface water flood risk, with special importance of regulating this water flow, into an improved state.

Based on the literature review in 2.1, the methodology for this thesis is as follows. A geographical analysis through GIS is conducted, with the use of a multi-criteria framework. First, the flood sensitivity of areas in Fatih will be modelled and assessed. Secondly, using this assessment, priority areas for GI investments can be identified. For this analysis, the five indicators are based on the research by Lit, Uyttenhove and Van

Eetvelde (2020). As aforementioned in 2.1, this research is chosen, as it focuses on identifying priority areas for GI development based on flood sensitivity. Additionally, the indicators focus not just on physical features of the area, but also on social dimensions related to flood sensitivity which makes the research more holistic. Once the priority areas are identified, certain types of GI interventions are proposed, in addition, an analysis will assess whether it is feasible to meet local flood resilience using GI only.

3.3. Flood Sensitive Areas

In order to identify the priority areas, the flood sensitive areas in Fatih have to be assessed. A flood sensitivity map of the watershed of the historic creek of Lykos is provided by AKOM on behalf of ISKI. AKOM is the Disaster Coordination Centre Directorate of the IBB, which was contacted for cooperation for this research. To reiterate, ISKI is the water and sewage administration in Istanbul, and in communication with AKOM, the institution provided the flood map of the Lykos basin to be used in this research.

Figure 6: *ISKI project boundary Lykos watershed flood map (Tuskan et al., 2011)*

The basin (Figure 6) covers about 737.38 ha. Most of the basin is in Fatih and the stream axis runs along Vatan Street and passes by Aksaray Square and downstream towards Yenikapi Beach. The highest point of this stream is at 107m and the lowest is where it flows into the Marmara Sea, south of Fatih.

For this research, floods with different recurrence periods are analysed. The flood maps created have a recurrence period of 25, 50, 100 and 500 years (Tuskan et al., 2011). The maps of 50 years and 500 years are specifically used in this thesis to help determine priority areas (see 3.4.3 and 3.4.4). The flood maps used in this thesis are a result of the Mockus Method, which is used for rainfall areas with a collection time of up to 30 hours. Details of how the authors used this method to generate the flood maps can be seen in Appendix C.

3.4. Priority Areas

As seen in figure 4, the research design for identifying the priority areas for GI investments will be as follows. The indicators are taken from the paper by Li et al. (2020), as they proved their method is useful to identify where GI has the biggest potential to enhance flood resilience (Li et al., 2020). The objective of their paper is to identify the priority areas concerning urban flood risk. The indicators used to allow for GIS analysis and the data required for such research is possible to obtain. The weighting for this multicriteria analysis can be seen in table 4, based on the Analytical Hierarchy Process (AHP) Matrix, assessed by Li et al. (2020). An AHP Matrix is where the criteria are compared in such a manner when decision-makers can value one criterion higher than the other one. They have made a pairwise comparison from a 1/9 to 9 scale and came up with the following weights (Hlavatý, 2014). The priority areas will be based on the neighbourhoods in Fatih (Figure 7). All results will be normalised from 0-10, using the geometrical interval option in ArcGIS. In order to evaluate the AHP matrix used for the overlay of the scores for the priority areas, a sensitivity analysis was conducted in which the indicators have an equal weight.

These variables are overlaid and multiplied by their weight, resulting in the final map of priority areas for GI planning in relation to flood resilience. In the calculations taken from (Li et al., 2020), stormwater runoff mitigation and flood sensitive social group indicators are considered the most decisive indicators in this analysis, followed by the flood sensitive infrastructures and the 'environmental justice' indicator. All data with calculations can be viewed in Appendix D.

Table 4: *Method of priority areas for GI investment (Li et al., 2020)*

Indicator	Method	Weight	Data sources
Stormwater runoff mitigation	Rational method	0.45	Open Street Map (OSM, 2020) Corine Landcover 2012 (Corine, 2021)
Flood sensitive social group	Identify the spatial location of the social group vulnerable to flooding	0.25	(Endeksa, 2020)
Flood sensitive roads	Identify the location of potential flood-prone roads	0.17	Open Street Map (OSM, 2020) AKOM
Flood sensitive buildings	Identify the location of potential flood-prone buildings	0.09	Corine Landcover 2012 (Corine, 2021) Open Street Map (OSM, 2020) AKOM (Tuskan et al., 2011)
Environmental justice	Identify areas lacking green space	0.04	Open Street Map (OSM, 2020) Corine Landcover 2012 (Corine, 2021)

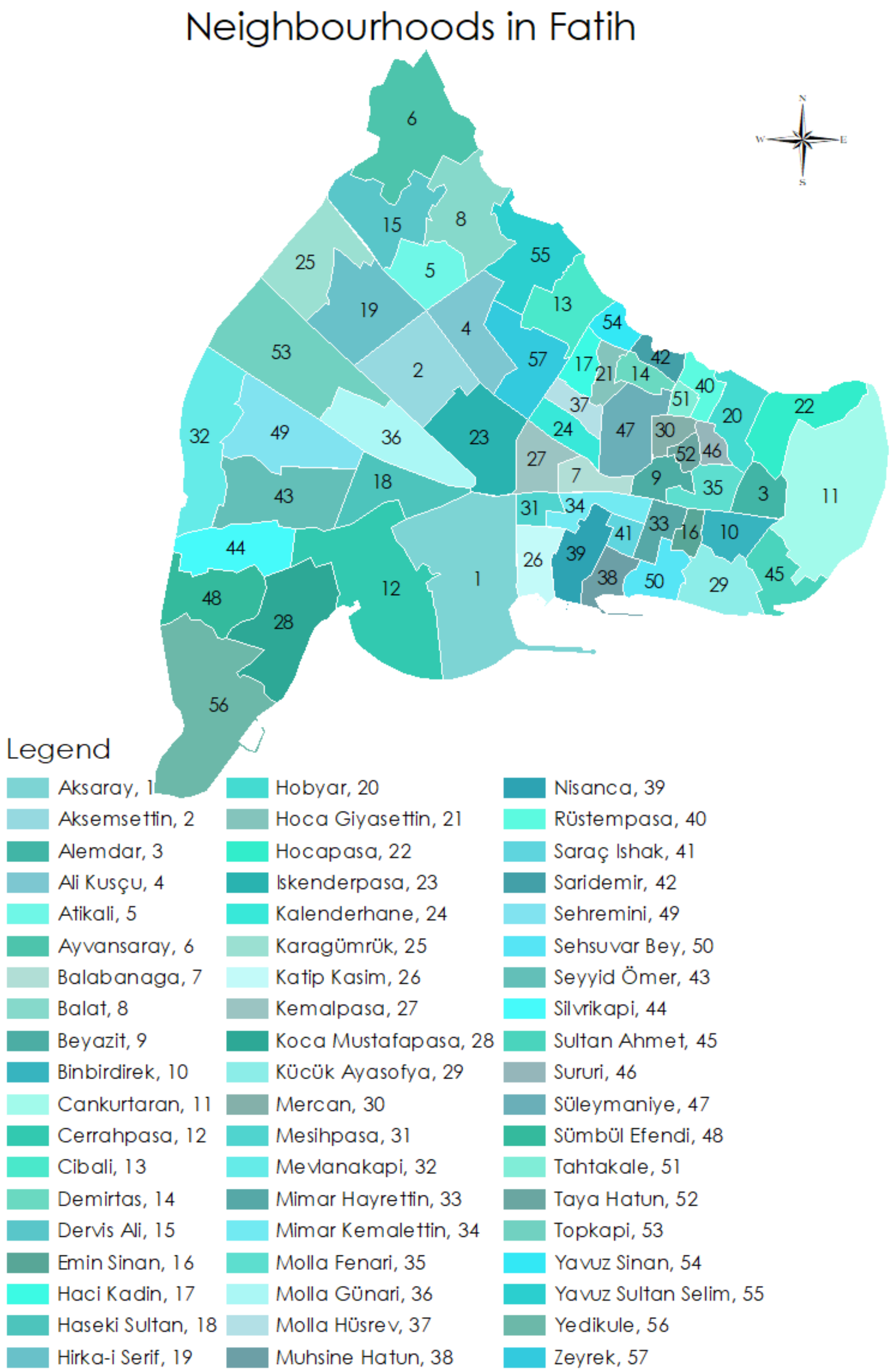

Figure 7: *The 57 Neighbourhood Areas in Fatih*

3.4.1. Urban Stormwater Runoff

The Urban Stormwater Runoff indicator will focus on hazard mitigation to ensure flood resilience (Li et al., 2020). Landcover types are taken and their stormwater runoff coefficient (SRC) integrated into GIS (Table 5). Together with the administrative borders, stormwater runoff performance per neighbourhood can be assessed. Just as in the paper by Li et al., the runoff coefficient is adapted from Thompson (2006), which is based on the rational method. The rational method is often used to calculate peak flows from precipitation in small drainage areas and estimates runoff scores of impervious areas (Thompson, 2006).

Which different landcover classes of the data sources Corene and the Open Street Map (OSM) belong to what landcover type can be seen in Appendix D. The stormwater runoff mitigation is calculated using the area in m² of the shapes and multiplying these with the runoff coefficient of the corresponding landcover type of the shape.

Table 5: *SRCs per landcover type (Li et al., 2020; Thompson, 2006)*

Landcover type	SRC
Roads, railways and associated land	0.85
Industrial Areas	0.80
Commercial Areas	0.70
Dense Urban Fabric	0.65
Governmental and Public Units	0.60
Medium to Low Density Urban Fabric	0.45
Vacant and No Structure Land	0.30
Green and Open Spaces	0.20
Water	0

3.4.2. Social group vulnerable to flooding

The second indicator is focusing on the social group vulnerable to flooding. The social group considered vulnerable to flooding are in this study, women, children under the age of 5, people above 65 years and inhabitants with a low socioeconomic status (SES). Women are considered more vulnerable to flooding as opposed to men, because of the traditional socialisation and work-related practises (Rakib, Islam, Nikolaos, Bodrud-Doza, & Bhuiyan, 2017). Children under the age of 5 are considered vulnerable to flooding because it is argued that their demographic would not be able to fend for themselves in case of flooding. The same counts for people above the age of 65. Lastly, inhabitants from low SES are considered to belong to the vulnerable social group, as it is argued that this group would have less of the monetary means to cope with flooding (Azad, Hossain, & Nasreen, 2013). The indicators 'people from low SES' replace the Li et al. (2020) indicators of 'proportion of foreigners' and 'unemployed' respectively, since this data is unobtainable for the Fatih neighbourhoods. The proportion of this group will be geographically assessed, to indicate the neighbourhoods which show considerable percentages of flood vulnerable social groups. This would mean that these areas require more attention to enhance flood resilience.

The data is taken from Endeksa, which is the only (partly English) website that contains demographic data per neighbourhood in Fatih. Their data is based on the data from the official Turkish Statistical Institute (TSI). Getting the data directly from the TSI, was not possible. The indicators are weighted according to the AHP matrix assessed by Li et al. (2020). These can be viewed in table 6.

Table 6: *Weight of the social indicators (Li et al., 2020)*

Indicator	Weight
%population under 5	0.55
% population above 65	0.27
% population of low SES	0.14
% female population	0.04

The outcomes of the different indicators are overlaid and multiplied by their weights in order to construct the flood social sensitive neighbourhoods of Fatih. Especially for the smaller neighbourhoods, some of the demographic data needed could not be obtained, hence, some of these neighbourhoods have 'No Data'. For the neighbourhoods only missing one demographic variable, the average of all neighbourhoods for that variable is taken to generate the results. Doing this strategy for the neighbourhoods missing more than one variable would most possibly not result in the correct demographic representation of that neighbourhood, as otherwise accurate data would be underrepresented. The average is taken instead of the median because it considers all values and the data set does not contain any significant outliers.

3.4.3. Buildings vulnerable to flooding

Buildings are taken as more vulnerable, as it causes great losses to the population, especially considering a lot of buildings in Fatih are historical buildings. Vulnerable buildings are identified by overlaying the building shapefile to the flood sensitive map (Li et al., 2020). Therefore, the indicator is based on the area of buildings within the flood sensitive areas. This overlay will generate three groups of vulnerable building infrastructure, serious flood vulnerable buildings, possibly flood vulnerable buildings and non-flood vulnerable buildings. Weighting is added to these groups and can be seen in table 7. Then, the area percentage of each type is calculated and then multiplied by its weight.

***Table 7:** Weighting of flood vulnerable building groups and roads (Li et al., 2020)*

Group	Weight
Serious flood vulnerable	0.71
Possible flood vulnerable	0.24
Non-flood vulnerable	0.05

3.4.4. Roads vulnerable to flooding

The roads are especially vulnerable, as flooding not only results in infrastructure damage but also disruption of transportation. Evidence suggests that most of the flood casualties involve people who were driving on the road that has been flooded, unable to escape from the open water (Li et al., 2020). This indicator will be conducted in the same manner as buildings vulnerable to flooding (Table 8), in which the road areas within the flood sensitive areas are calculated. Instead, the categories will be serious flood vulnerable roads, possible flood vulnerable roads and non-flood vulnerable roads. The weighting and analysing are done the same as well.

The areas that are 'serious flood vulnerable' are intersected with the flood layer M25. The areas that are 'possible flood vulnerable' are intersected with the flood layer M500, as this layer was a projection with the latest return period, hence are not immediately a priority but will be in the future. The roads and buildings that did not make any intersection with the flood map at all are considered to be non-flood vulnerable in this analysis. The M that stands before the years of the flood maps stands for the Mockus method that is used for the making of these flood sensitivity maps.

3.4.5. Environmental justice

This indicator is about identifying areas that are already lacking green space. It is claimed that land is more exposed to flooding when it lacks green space. This indicator is subsequently named environmental justice, as it is unjust to have an area more exposed based on the absence of green space due to poor city planning (Li et al., 2020). The percentage of existing GI per neighbourhood is calculated, which results in an estimation of neighbourhoods with the least green spaces.

3.5. Different Green Infrastructure investments for local Flood Resilience

Once the priority areas can be identified, the neighbourhood most in need of GI investments is analysed. It is assessed how this priority area performs after 3 GI investments. To identify the most suitable GI types, they are based on the physical environment of the areas. E.g. for buildings, green roofs would be most suitable, while in open spaces, vegetated swale would be the most proper investment (Mei et al., 2018). The types of these interventions in relation to their most suitable land cover type can be seen in table 9 and is based on the study on 'sponge' cities by Mei et al. (2018). The three investment types are selected because they are recommended as interventions to create 'sponge' cities. However, more GI types exist that could decrease stormwater runoff, but are left out of this study due to time constraints. The urban runoff coefficient is adapted from various sources (Table 8). These 3 interventions were selected because these investments were more feasibly for the GIS analysis of this study. This does not mean that other types would not be suitable, but due to time and data constraints, more investments are left out.

The flat roofs are identified using satellite imagery of the neighbourhood. Roofs that appear to be flat are selected for possible green roof investment. The vegetated swale is focused on greeneries around the busy road areas (Figure 15). 30% of all roads and associated land are calculated to be permeable pavement and is assumed no permeable pavement was present.

Table 8: *Gi Investments*

GI control	Where	SRC
Green roof	Flat roofs/urban fabric and areas	0.4 (Kaiser, Köhler, Schmidt, & Wolff, 2019)
Permeable pavement	Roads, railways, and associated land	0.3 (Ball & Rankin, 2010)
Vegetated swale	Open spaces	0.15 (Bureau of Watershed Management, 2006)

The construction costs of these investments can be assessed, using the average construction price per m² (Table 9). The construction costs of green roof per m² are 50$/m² which is an estimation of green roof construction costs from three different Turkish roofing contractors and in other parts of the world with similar climate and economic characteristics. The plants are set to be 10$/m², growth medium 50$/m² and labour of roofing and planting 10$/m², which results in a total of 120$/m² (Çelik, Retzlaff, Morgan, Ogus Binatli, & Ceylan, 2010). The average costs of permeable pavement construction are between 28 to 150 $/m², with design and planning costs of 3.36 $/m². This results in a total cost of 31.36-153.36 $/m². The construction costs for vegetated swale is determined as 25.25$/m², with design and planning costs of 0.36$/m². This totals 26.61$ (Mei et al., 2018).

Table 9: *construction costs of GI investments*

GI Investment	Costs $/m²
Green Roofs	120
Permeable Pavements	31.36 – 153.36
Vegetated Swale	26.61

4. Results

4.1. Flood Sensitive Areas

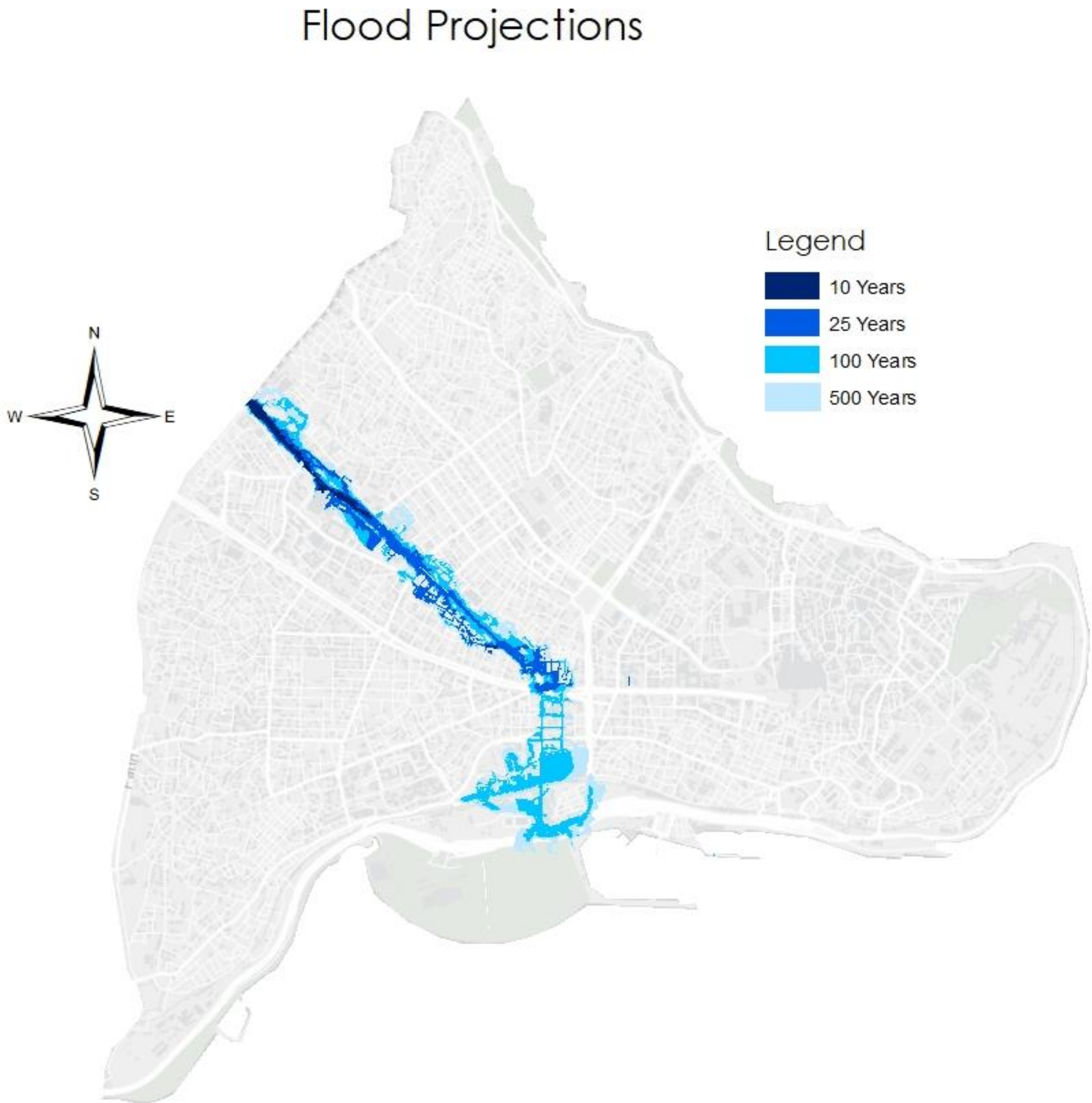

Figure 8: *Flood sensitivity map of the Lykos watershed provided by AKOM on behalf of ISKI visualised in ArcGIS. The numbers in the Legend refer to return periods.*

Looking at figure 8, it is noticeable that especially the areas surrounding the boulevard within the watershed seem vulnerable to future flooding, but the analysis of the priority areas will determine this. The most sensitive areas go along the Vatan Caddesi, to the top of Aksaray neighbourhood, where it almost meats the coast to the Marmara sea.

4.2. Multi-Criteria Analysis

4.2.1. Stormwater Runoff Mitigation

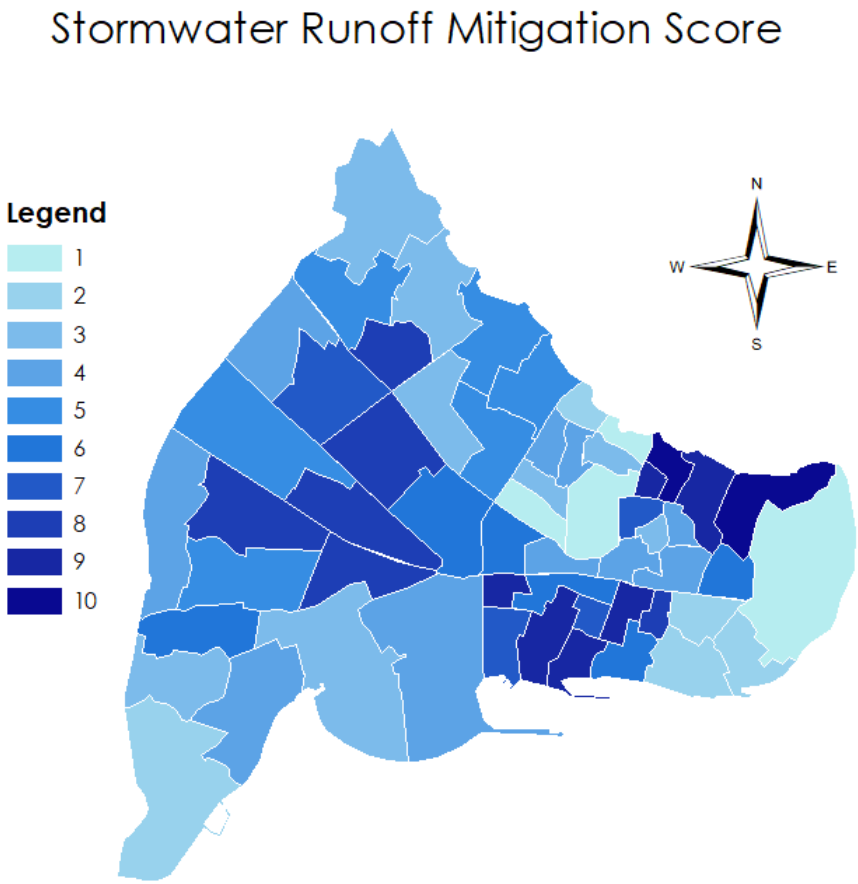

Figure 9: *Results of the Stormwater Runoff Mitigation indicator*

Figure 9 determines the neighbourhoods that score highest on the stormwater runoff mitigation indicator. The higher the score, the more priority for GI investment it can have. It is especially noticeable that the neighbourhoods northeast of Fatih, Rüstempasa and Hocapasa score relatively high, but Cankurtaran relatively low. This is due to that Cankurtaran houses many historic sites that are surrounded by green areas, whereas Rüstempasa and Hocapasa are mainly commercial and industrial areas (Figure 5).

4.2.2. Flood Sensitive Social Group

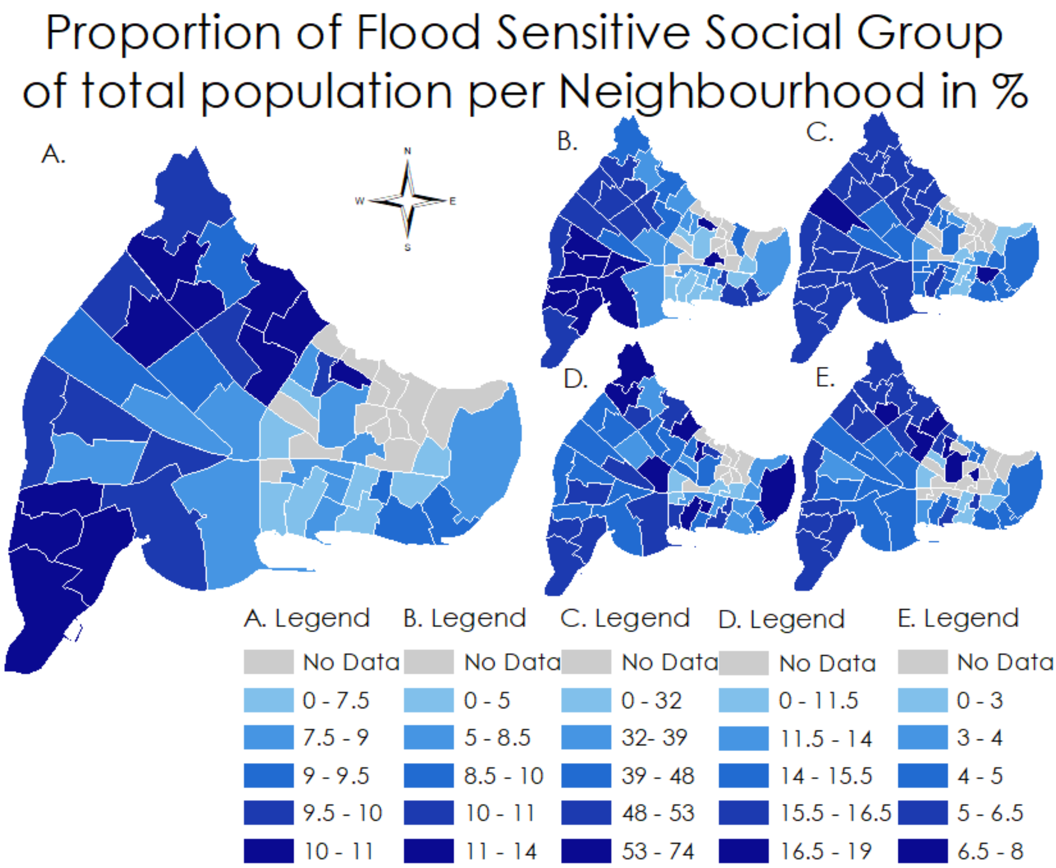

***Figure 10:** Flood Social Sensitive Neighbourhoods of Fatih*
***A:** Weighted proportion of social sensitive population per neighbourhood **B:** Percentage of population over 65 per neighbourhood **C**: percentage of female per neighbourhood, **D**: percentage of the population with low social-economic status per neighbourhood, **E**: percentage of population below 5 per neighbourhood.*

The demographic data for social sensitive groups resulted in the layers illustrated in figure 10. The neighbourhoods in the South West, Beyazit and Cerrahpasa appear to reside most senior citizens whereas neighbourhoods mainly up north of Fatih have the youngest children. According to the demographic data, the proportion of the female population is highest in Binbirdirek and Topkapi. The neighbourhoods that house the most people with low SES are Cankurtaran and Iskenderpasa.

4.2.3. Flood vulnerable buildings and roads

Figure 11 visualises the situation of the buildings and roads that are most sensitive to flooding. Especially the infrastructures surrounding the main boulevard are vulnerable to flooding. Floods could lead to more damage to some roads than others as some roads are used more than others but this is left out of the analysis. Section 5.1.2. will further discuss this.

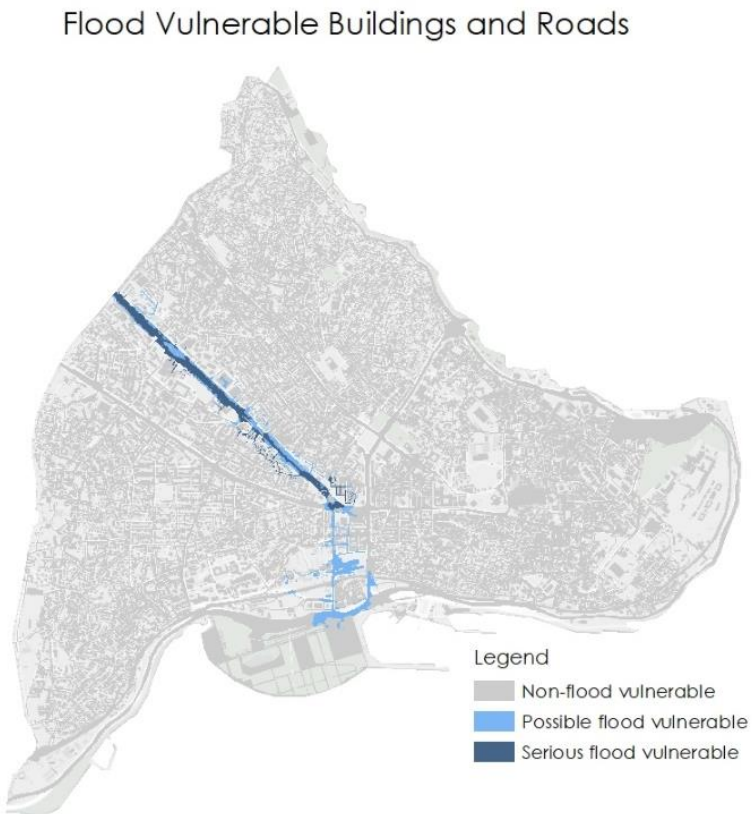

Figure 11: *Flood Vulnerable Buildings and Roads in Fatih*

4.2.4. Environmental Justice

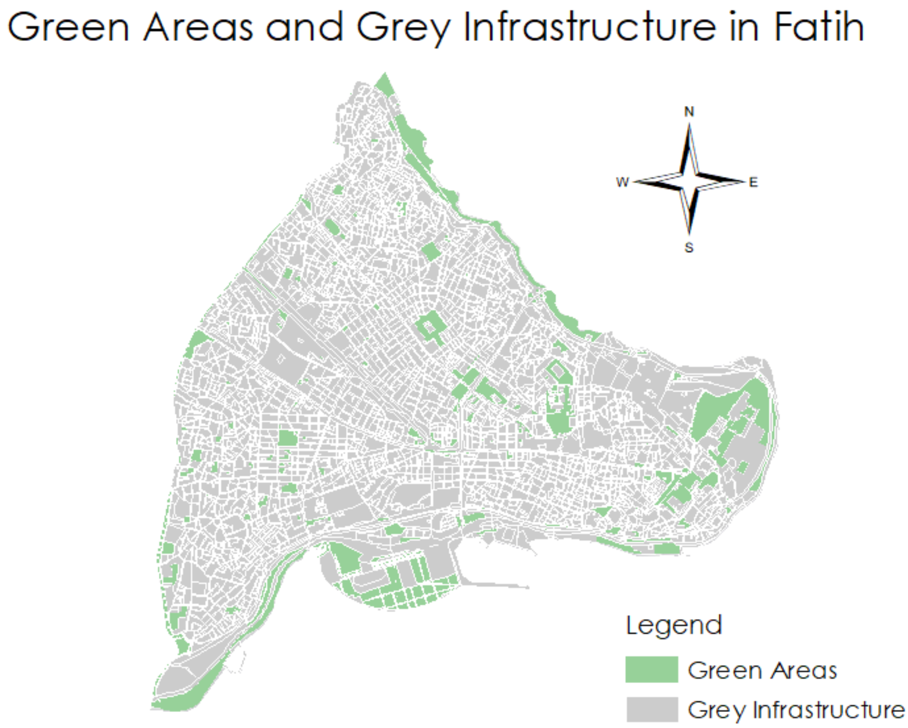

Figure 12: *Green areas and grey infrastructures in Fatih*

Classifying the landcover types into green areas and grey infrastructure result in figure 12, the data for the environmental justice variable. As one can see, green areas are mainly around the coast of Fatih and historic sites and seem underrepresented in the centre of Fatih. Comparing this with the flood sensitive maps, the areas in the Lykos Basin appear to have relatively few green areas. Only 11,62% of the whole area of Fatih is considered to be green areas and are mainly concentrated around the coast.

4.2.5. Priority Areas

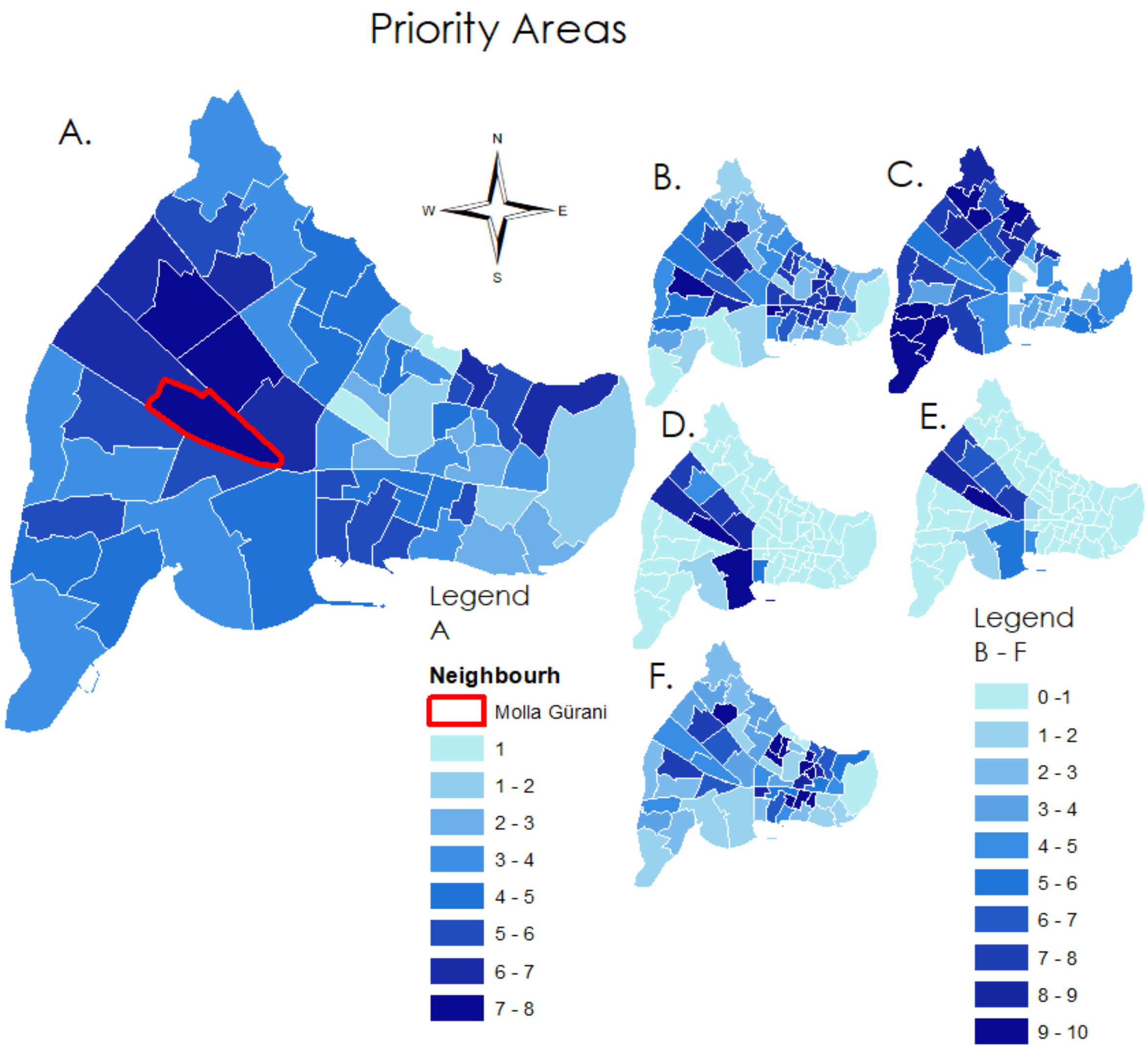

***Figure 13: A**. Priority Areas, 8 being the highest priority. **B**: Priority score of Runoff indicator. **C**: Priority score of flood sensitive social group indicator. **D**: Priority score of flood vulnerable buildings indicator. **E**: Priority score of flood vulnerable roads indicator. **F:** Priority score of environmental justice indicator. **B-F:** 10 being the highest priority score.*

In this map, the normalised scores 0- 10 of all variables are illustrated, with 10 being the worst (Figure 13). The results show that some areas have a greater priority for GI development than other areas Fatih concerning flood resilience. According to the results, the current green areas in Fatih do not correspond with where it is most needed in terms of surface water flood risks. Most areas that can benefit from GI investments are situated around the Vatan Caddesi boulevard, the heart of the Lykos Watershed, which does not contain enough GI to alleviate flood risks (Figure 11). Most of the current green areas are mainly concentrated around the coast of Fatih (Figure 12), where it is expected that these areas do not have a high risk of flooding according to the results.

Molla Gürani, Hirka-I Serif and Aksemsettin seem to be most problematic with Molla Gürani scoring the highest with 7.65. Therefore, Molla Gürani is the neighbourhood used in 3.3 for GI investments, in order to better the score and proof the effect of GI on flood resilience.

4.2.6. Sensitivity Analysis

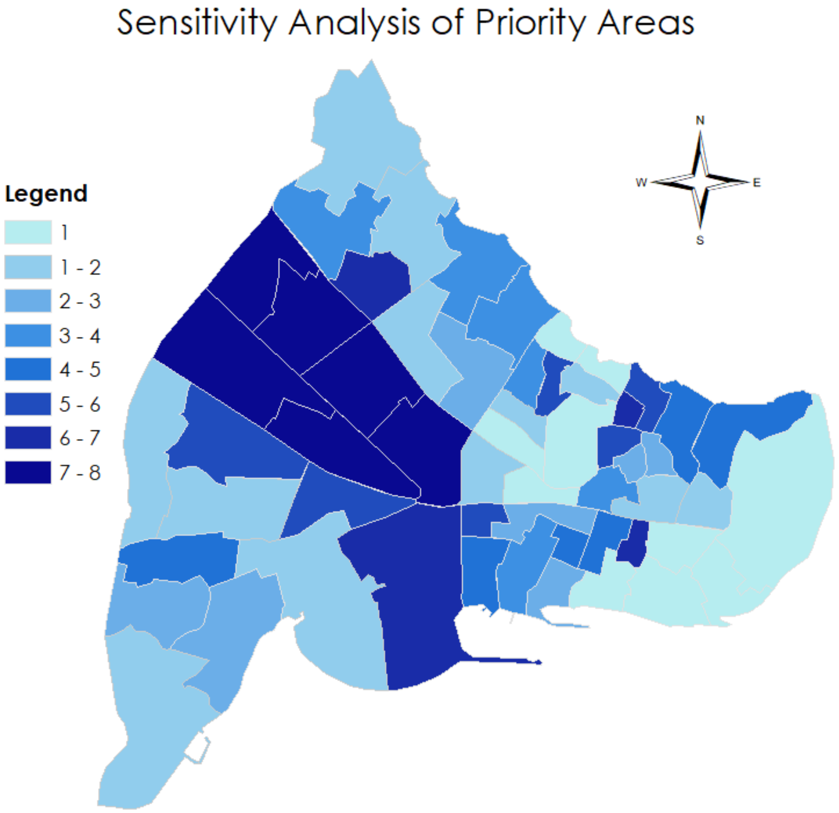

Figure 14: *Sensitivity Analysis of normalised results, with equal weights of indicators*

In order to evaluate the AHP matrix used for the overlay of the scores for the priority areas, a sensitivity analysis was conducted (Figure 14). For this analysis, equal weights of the variables are assumed which results in the following 'priority areas' illustrated on the map above. Again, Molla Gürani scores highest, and especially the neighbourhoods within the Lykos Watershed, indicating that the flood sensitive buildings and roads variables made a deeper impact on the results. Therefore, this sensitivity analysis indicates that the AHP matrix used to determine previous priority areas made for more representative results as the neighbourhoods Northeast are problem areas, even though they are not situated in the Lykos watershed. Whereas in the sensitivity analysis map, these areas appear less of a priority which should not be the case due to their lack of GI.

4.3. Green Infrastructure Planning

As can be concluded from 4.2, Molla Gürani is the neighbourhood scoring highest for being least flood resilient. Hence, the neighbourhood can benefit most from GI investments. The neighbourhood is surrounded by main roads from the upper part and the south parts, the former being the Vatan Caddesi boulevard sensitive to flooding. Additionally, there are limited green areas, mainly in the southeast where the Murad Pasa mosque and park is located.

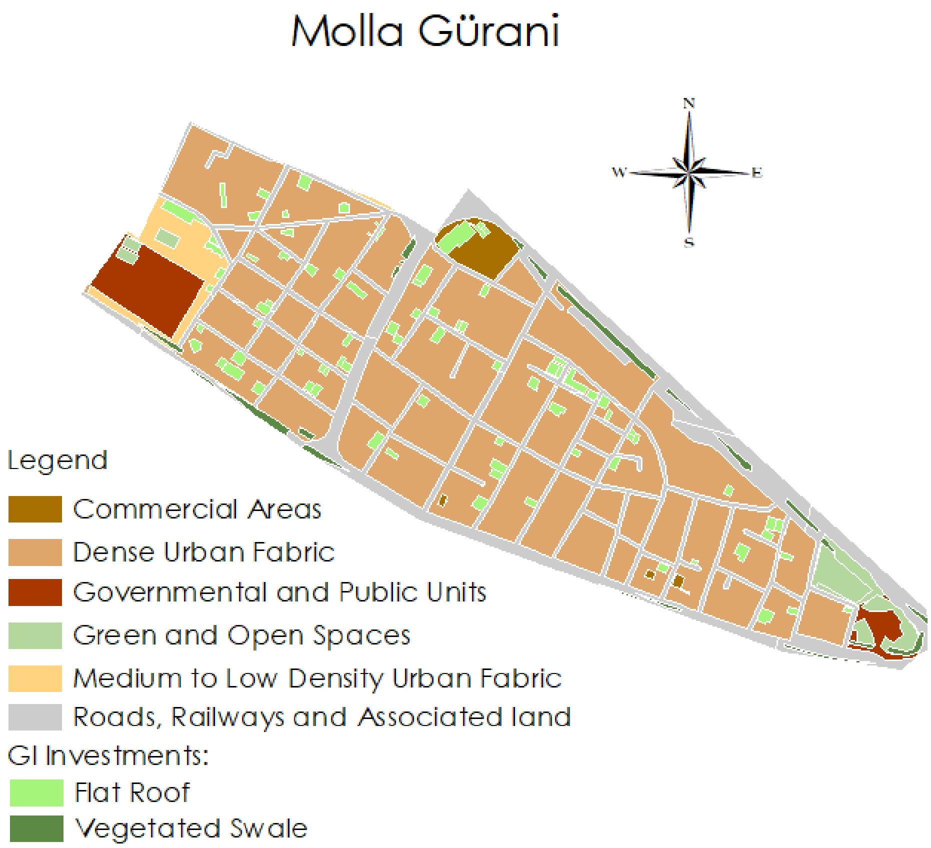

Figure 15: *Molla Gürani with GI investments, excluding permeable pavement*

The potential location for GI investments are identified (Figure 15) which increased the GI share of the neighbourhood. The figure excludes permeable pavement because it is not possible to visually show this type on the map, as 30% of the roads areas are analysed to be permeable pavement. These GI investments resulted in the following runoff score for Molla Gürani: 61,32, 68,04 being the score without the GI investments. This is a considerable decrease of 9.88%. The overall normalised score is then 5.85, being a decrease of 23.53%, resulting in less of a priority area. The construction costs of these investments are determined to be between 3 million to 6,5 million (Table 10), depending on the type of permeable pavement.

Table 10: *Results of the construction costs of GI investments*

GI Investment	Area in m²	Costs $/m²	Total costs in $
Green Roofs	16778.59	120	2,013,430
Permeable Pavements	27958.9	31,36 - 153,36	876,791 – 4,287,777
Vegetated Swale	7307.714	26,61	194,458.30
Total:			3,084,679.30 – 6,495,665.30

5. Discussion

5.1. Discussion of Results

5.1.1. Flood Sensitive Areas

The results suggest that the areas within the Lykos watershed are most sensitive to flooding. Therefore, these areas are prioritised for GI development in this thesis. As previously mentioned, the Vatan Caddesi in Molla Gürani is especially prone to flooding. The reason for this is that the boulevard is situated right on top of where the historic creek Lykos used to flow. Historically, the Lykos creek (or Bayram Pasha Creek) runs through the centre of Fatih (Gülhan, 2013). Nowadays, this creek is no longer a waterway, as it dried up due to anthropogenic developments (Eris, Beck, & Çagatay, 2009). The boulevard and its surroundings are subject to flash floods because it is situated right on top of the old river and its slope. With a lack of green areas, these flood sensitive areas could be prioritised for GI development to enhance its flood resilience.

Since the flood sensitive area maps are provided by the IBB, the focus for GI development is mainly within the areas of that watershed. The municipality did not possess flood sensitivity maps of the whole peninsula, which suggests that it is more crucial to protect the areas within the Lykos watershed. However, evidence shows that there were incidents of flash floods in Fatih outside of the watershed, e.g. flash floods in Rüstempasa in 2018 and around the Grand Bazaar Market of Beyazit in 2019 (nr. 40 and nr. 9 on Figure 7)(FloodList News, 2019; Hurriyet Daily News, 2018). Hence, the evidence suggests that areas outside of the Lykos watershed are also prone to floods, and reveal that the flood sensitivity maps of the IBB are incomplete.

5.1.2. Priority Areas

According to the outcome of the priority areas, certain neighbourhoods require greater need for obtaining GI investments. In particular, the neighbourhoods Molla Gürani, Aksemsettin and Hirka-I Serif, are in need of GI planning. ISKI's adaptation plan claimed that it aims to redesign infrastructures to withstand extreme weather events (ISKI, 2015). However, GI is not located in the areas that need it most. For instance, Molla Gürani is the neighbourhood most prone to being flooded and contains almost no green spaces for natural urban water drainage (Figure 15).

A comparison between figures 9 and 12 clearly illustrate the relation between existing GI and the stormwater runoff score. Rüstempasa and Nisanca are examples of neighbourhoods that score especially high on the stormwater runoff mitigation indicator. Looking at figure 12, one can see that these neighbourhoods are lacking GI, which clearly shows the relation between a high stormwater runoff mitigation score and GI. However, these neighbourhoods are not prioritised for GI planning in relation to flood resilience. The reason for this is that the roads and buildings in these areas are not found to be flood sensitive in this thesis. In other words, the neighbourhoods with the highest stormwater runoff and environmental justice scores are still not prioritised for GI development. These findings are similar to those of Li et al. (2020). The explanation for these findings is due to the weighting of the indicators, where especially the environmental justice indicator weights lightest with 0.04. Stakeholders can influence these weighting of the multi-criteria framework to prioritise indicators they find most important. Different priority areas result from this. Additionally, the indicators used in this thesis can be applied to other areas as well, since the original paper focused on a city in Belgium (Li et al., 2020).

As for the flood vulnerable social group, it is debatable whether the utilised indicators, adequately reflect the social group most sensitive to floods. To reiterate, the indicators chosen for the flood vulnerable social group are the proportion of the population under 5 years old, above 65 years old, with low SES and females. It is debatable whether females are more sensitive to flash floods. Existing literature indicates that females are more sensitive, but most of this research is focused on developing countries (Ajibade, McBean, & Bezner-Kerr, 2013; K. De Silva & Jayathilaka, 2014). The weighting of this indicator is 0.04, which is too minimal to make much impact on the results. Stakeholders can discuss the weighting of these indicators and prioritise those they feel are more important.

Moreover, it would be interesting to see results with complete data on foreigners, as suggested by Li et al. (2020). This might show different outcomes and could shed light on areas where most the flood vulnerable inhabitants live. Furthermore, this would identify the location of the most flood vulnerable people and could help finding solutions to reduce flood vulnerability, i.e. by raising awareness on how to cope with floods, which can increase social flood resilience. Raising flood awareness is currently not part of Istanbul's flood plan. Hence, one can argue that social flood resilience needs more attention in Istanbul's flood governance.

On another note, only the buildings and roads situated within the flood sensitive areas were analysed in terms of flood vulnerability. However, this excludes important characteristics of the buildings and roads which influence flood protection. For instance, busy roads have arguably a higher priority to protect against floods because these need to be accessible. Additionally, flooding of busy roads would do more damage because it could result in a higher amount of casualties. Moreover, buildings with an important function such as hospitals and historic sites have a higher urgency for flood protection, considering these are crucial infrastructures for the community.

Furthermore, due to the flood sensitivity maps used in this research, most priority areas for GI development are located within the watershed. This does not mean that the areas outside cannot be prioritised for GI development, just not in terms of flood management, according to the results of this study. As previously mentioned, GI can have positive impacts on other functions benefiting the urban environment such as combatting heat and air purity.

5.1.3. Green Infrastructure Investments

The three GI investments in Molla Gürani noticeably decreased its priority for GI investment score. Hence, it demonstrated that the proposed integration of the GI types can assist flood control. These findings are similar to those of Mei et al. (2018), but they stress that these investments should be combined with 'gray' infrastructure flood measures to reach optimal stormwater runoff mitigation. Gray infrastructure is man-made infrastructure which assists in flood mitigation, examples being levees and dredging rivers, but also sewers and wastewater treatment plants (Daigneault, Brown, & Gawith, 2016; Terraza, 2013). This study agrees with the statement of Mei et al. (2018), as GI interventions should not address flood impacts in isolation, but rather complement existing flood mitigation mechanisms in place.

5.4. Societal Implications

As aforementioned, the value of GI goes beyond enhancing flood resilience. GI can serve many benefits to society due to the ES that it provides. GI enhances local biodiversity, which in turn can provide economic value. It is argued that a higher share of GI will increase tourism, as well as real estate values as people are happier to live among green areas (Kramer, 2014). Green areas can provide spaces for recreation and provide benefits to the mental well-being of the community (Guéguen & Stefan, 2016; Hartig & Ulrich, Roger, 2004). Therefore, areas that are well endowed with GI generally provide better living conditions for society.

This could mean that neighborhoods with an abundance of green areas result in higher housing rents. This indicates that areas with very little green areas are cheaper and the proportion of poorer people is higher. Especially as it is argued that areas with a population with a relatively lower SES are usually deprived of access to green spaces (Silva, Viegas, Panagopoulos, & Bell, 2018). However, when comparing the areas in Fatih in which there is a low SES however a high environmental justice indicator score (Figure 10 D and 13 F), there does not seem to be a strong correlation in this instance. This could be due to the incomplete data of low SES as well as the incomplete green areas data, since not all green areas could be included in the datasets. Section 5.5. will further discuss the limitations of the study. On the other hand, it could also be that there is simply no correlation in Fatih regarding the environmental inaccessibility of low SES groups at all. However, further research in this goes beyond the scope of this thesis. Notwithstanding, if it is the responsibility of private property owners to construct certain GI investments such as green roofs, areas with a high proportion of low SES should receive additional incentives.

5.5. Limitations and Future Research

Regarding the quality of landcover data, the data collected from Corine was from 2012. Hence, that data is not fully up to date. Additionally, the accuracy of the data collected from the OSM is unclear, since it is open-source and anyone could make modifications. Additionally, when comparing these landcover maps to satellite maps, none of the landcover data types seems to accurately include all the green areas since some trees, shrubs and grass seemed to not be included.

Another limitation is that there was no flood map covering the whole peninsula. Only half of the area was situated in the available flood map of the basin. The areas not included in the basin could still be subjected to flooding due to heavy weather events but this involves data that could not be obtained for this research. It would be interesting to see what the results would have been if a complete flood sensitivity map was available for the whole peninsula, as previously mentioned, some areas outside the watershed have experienced flash floods.

This report has only focused on green roofs, permeable pavements and vegetated swale interventions. However, other types of GI such as wetlands and increasing tree canopy represent investments that could mitigate stormwater as well (Foster, Kuhn, & Langille, 2015). Having a higher variety of GI will diversify the ES and added benefits. As previously mentioned, these benefits go beyond flood control and are interesting to include in future research as well.

On the other hand, it is uncertain whether the location of the proposed GI investments is suitable. Further research on the relationship between the different GI flood control types and the local environment is necessary, as the local condition of the environment is not visible using satellite imagery. Hence, it is not sufficient to only use satellite imagery when analysing the right location for these investments. Local investigation is needed for this, which was not possible in light of the scope of this thesis. Additionally, more focus on water uses and site requirements is necessary in order to more effectively ascertain the most appropriate GI investments and successfully implement GI types. Furthermore, roofs which were identified to be flat may still not be suitable for being green roofs.

Moreover, the results show the construction price of the three proposed GI investments (4.3). The price of these investments seems rather large for the neighbourhood, depending on the type of permeable pavement. It has to be explored whether the municipality has the funding for such investments and what the return of investment could be. Especially as the research did not find whether the municipality has any budget for these types of investments regarding flood control.

Another interesting aspect of Fatih that this research did not fully focus on was the historical relevance of many areas of Fatih. As previously mentioned, it houses many important cultural and historic constructions that have a higher priority for flood protection. For example, there is a 15th-century mosque in Molla Gürani, the Murat Pasa Cami (Fatih Kaymakamligi, n.d.). Even though it is surrounded by GI, it is highly vulnerable to being flooded when comparing it to the flood map. Higher priority could be given to protect this mosque due to its historical importance. Additionally, GI measures such as green roofs would also not be appropriate for sites like these, as it damages the integrity of the historical architecture.

5.6. Recommendations for Istanbul's Flood Governance

There is no one-size-fits-all response to enhance flood resilience. Especially since flood resilience is not only based on flood mitigation but also coping with and transforming from floods (Akhmouch & Clavreul, 2019). Furthermore, the cross-boundary nature of the multiple actors involved in the flood resilience network, as well as infrastructure ownership and management make governing and planning of GI for flood management challenging (Carter et al., 2018). However, from the results and discussion of this thesis, a few recommendations can be suggested for Istanbul's flood governance to enhance flood resiliency.

The IBB should facilitate collaboration between different actors including local actors and their departments, in order toto integrate GI as a measure for flood resilience. A way to do this is to incentivize local building owners to construct green roofs where possible. In addition, the IBB should communicate the benefits these investments can have among stakeholders in the flood resilience network. Not only in terms of flood management but also in terms of the other ES they provision. This increases community awareness and reduces social flood vulnerability as well.

Additionally, in urban planning, the municipality should increase the integration of permeable pavements and vegetated swale and include such GI investments in its flood risk management plan. What Istanbul should do to combat climate change challenges regarding water, is to assume an active role in the development of GI projects for the realisation of water management with a holistic approach. In addition, legal arrangements to implement GI as an active way to control and protect water cycles is key (ISKI, 2021).

At the moment, ISKI is the main actor involved in Istanbul's flood management strategy, but this research makes it clear that flood resilience goes beyond the control of ISKI. Local initiatives are needed to construct certain ES measures, for local building owners, businesses and community groups. Furthermore, the IBB Department of Parks, Gardens and Green Areas as well as the Department of Road Maintenance and Infrastructure Coordination should be more involved in Istanbul's flood resilience network, as these can contribute to scaling up the implementation of GI to enhance flood resilience. Private owners must be incentivised to adopt these investments, as the most suitable places for GI investments may not fall under the control of the municipality (Pappalardo et al., 2017). Market-based instruments and funding of projects are policy mechanisms which can drive the adoption of such interventions.

Management strategies should help reveal priority areas for GI development, which would help foster flood resilience and add value to the urban environment. Hence, the outcome of this research could help Istanbul's policymakers implement the same analysis to its other districts in order toto potentially enhance flood resilience using GI investments (Li et al., 2020). Decision-makers can alter the different weights of the different indicators to prioritise variables they consider more critical, which would produce different results in terms of priority areas.

6. Conclusion

Over the past decade, urban planning and design approaches changed in respect to new challenges cities face considering climate change. New theories fill the gap between ES and the urban environment and propose new frameworks to tackle climate change hazards using GI. The role that green and open spaces play in terms of flood hazards are being redefined for the urban environment and contain multifunctional benefits.

This research specifically focused on the relation between GI and flood resilience. It evaluates local GI investments as part of enhancing stormwater retention. A spatial planning framework that focuses on ES is proposed that consequently leads to flood adaptive policies concerning GI which could help Fatih to become flood resilient. The indicators proposed by Li et al. (2016) are appropriate to use when analysing the priority areas for GI investment. These indicators reflect a system approach as they include technical, environmental as well as social variables. This is important for the city of Istanbul, as a holistic framework is provided with these indicators.

Using the flood map provided by ISKI, flood sensitive areas in Fatih have been identified, the infrastructure surrounding the main boulevard have been found to be particularly prone to flooding. The priority areas for GI infrastructure development have been identified using the flood map and the multi-criteria evaluation of the indicators. Molla Gürani was found to be the most flood vulnerable neighbourhood, and should therefore be prioritized for GI development. Hence, Molla Gürani is used as a case for scaling up GI. The results show a significant reduction in flood vulnerability, which highlights the role GI plays in enhancing flood resilience.

There is no perfect formula to enhance flood resilience for all situations since every location is unique. GI investments prove useful in enhancing resilience, as these investments provide benefits that have the ability to transform the resilience and adaptiveness of urban flood management due to the nature of the provisioned ES. However, decision-making for GI planning for flood management is challenging due to the various actors involved in the flood resilience network, as well as differences in ownership of the environment. This research proposes several recommendations for decision-makers in Istanbul to take into consideration.

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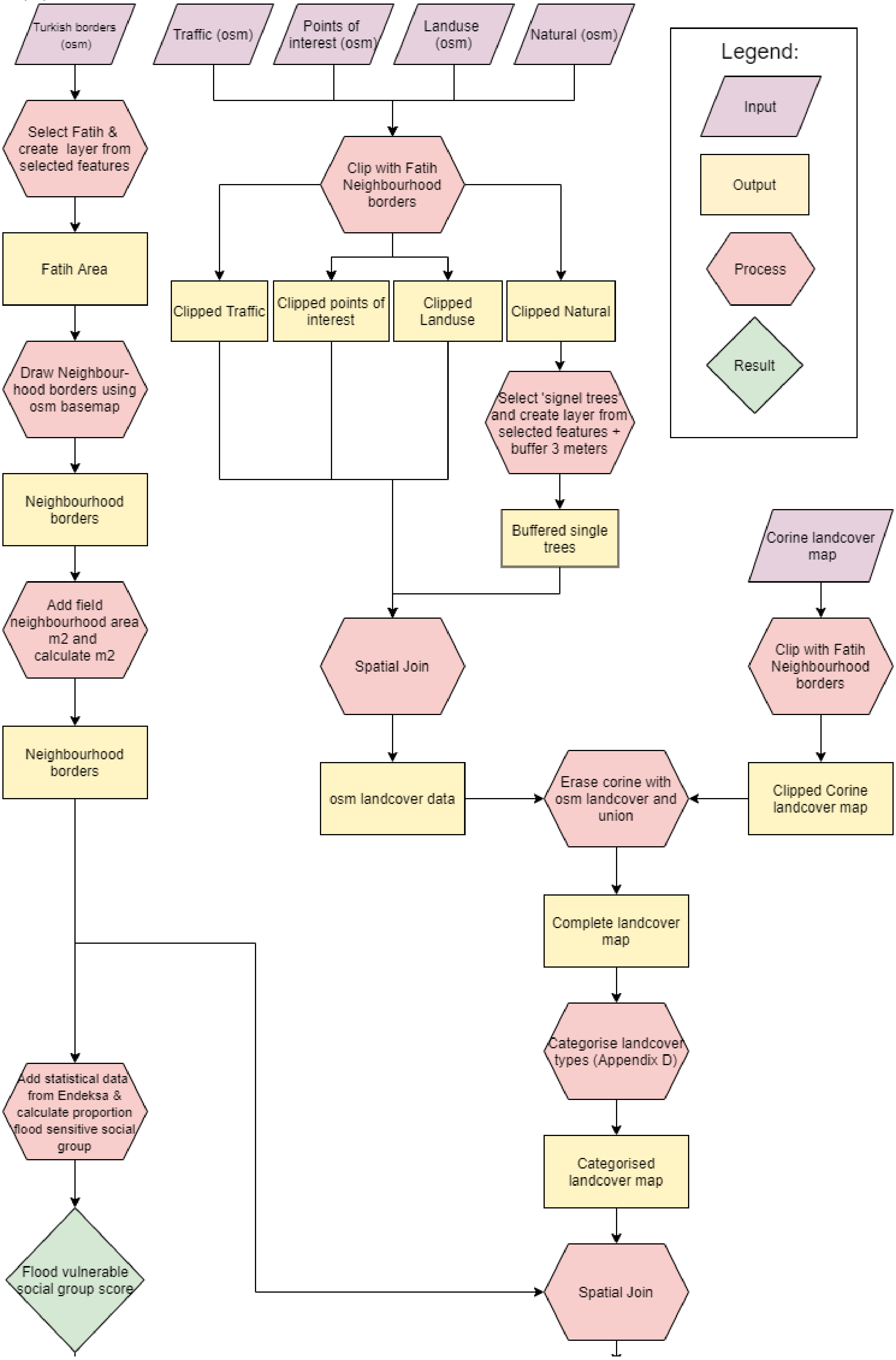
8. Appendix

Appendix A



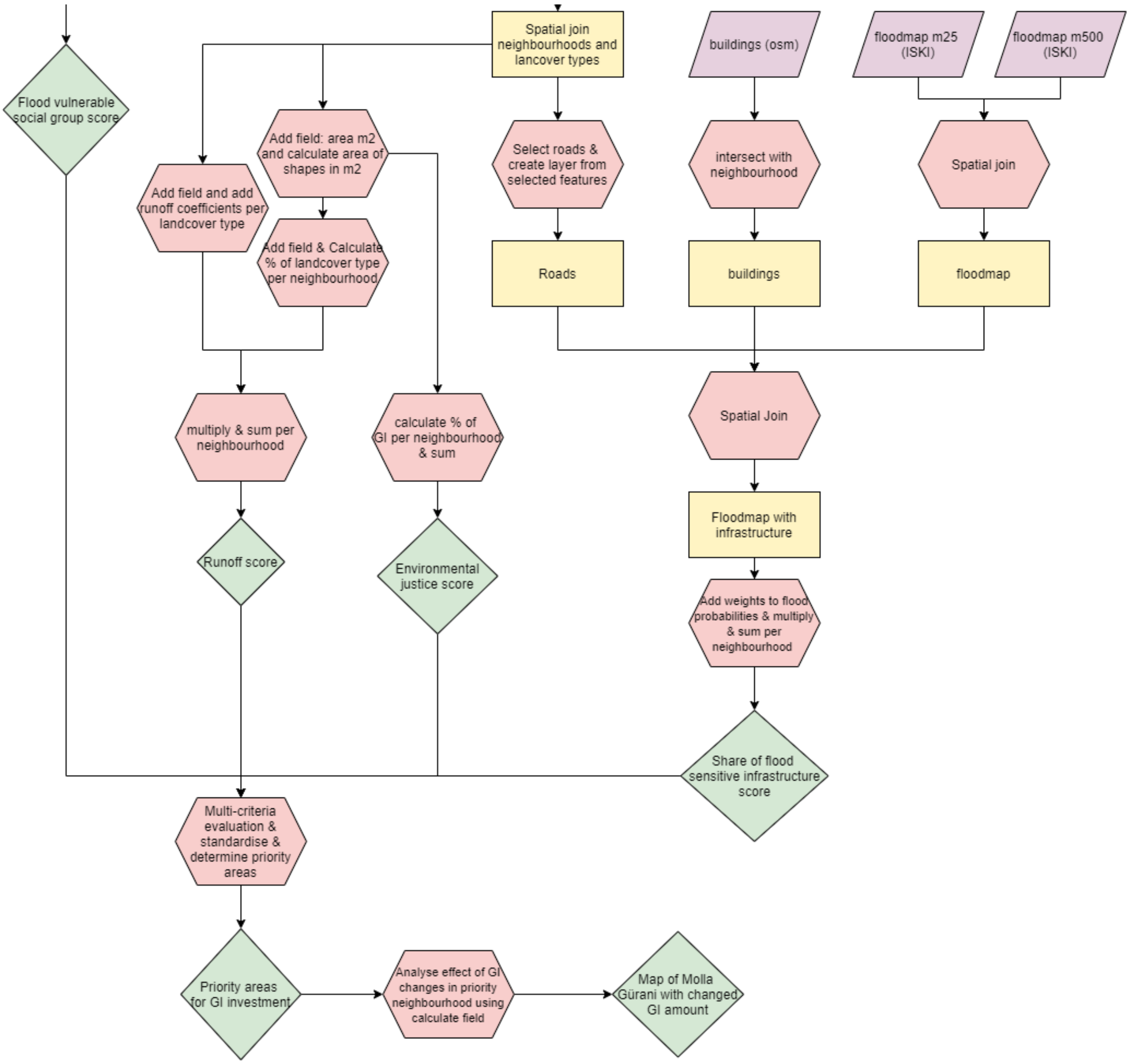


Figure 16: *Overview of Geoprocessing workflows used in ArcGIS*

Appendix B

3.3.3 and 4.1.2 From the flood sensitivity paper received from ISKI, on behalf of AKOM. Translated into English using google translate (Tuskan et al., 2011).

3.3.3 Mockus Method: explanation of method

This method was developed by Victor Mockus in the U.S Soil Conservation Service (Mockus 1957). In this method, the unit hydrograph is accepted as a triangle. (Figure B1) This method can be used in rainfall areas with a collection time of up to 30 hours. Larger rainfall areas can be divided into parts and calculated with the same method.

In the Mockus unit hydrograph, the duration of the net precipitation is shown as td, the time elapsed between the center of gravity of the precipitation and the time of the peak flow, that is the lag time of the basin, tL, the abscissa of the peak, that is the rise time of the hydrograph as tp, the time of descent after the peak tr and the base length as tb. . Peak flow rate is expressed as Qp (m, flow volume as V.

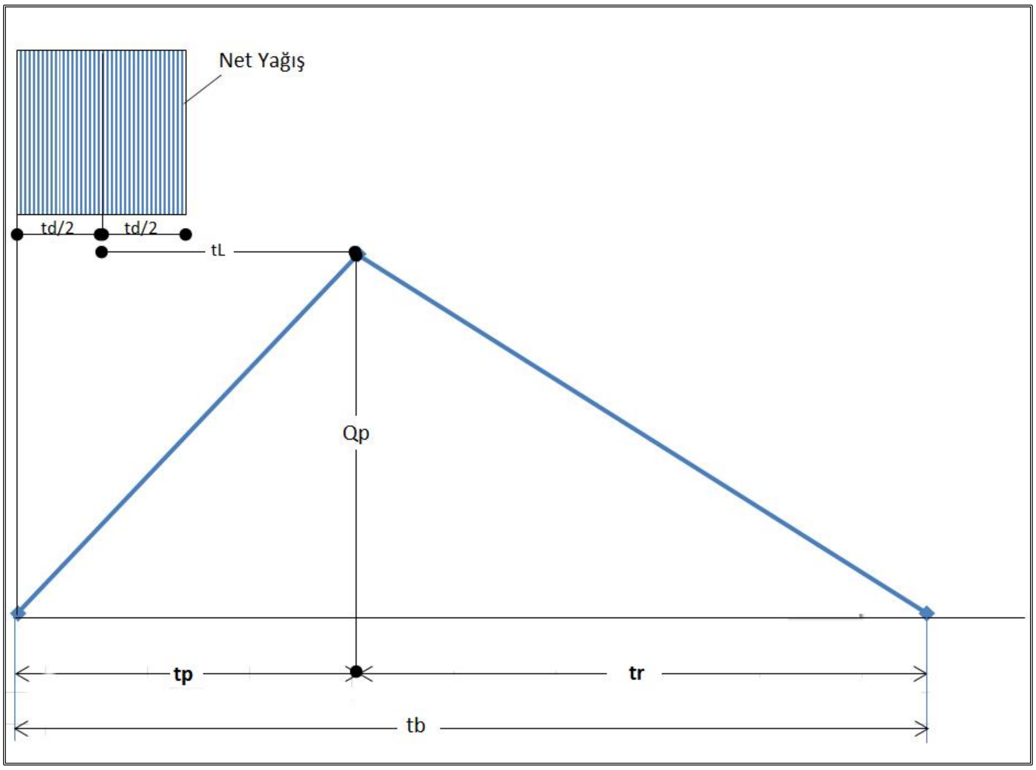


***Figure 17**:Mockus Unit Hydrograph Curve*

The assumptions and formulas used while applying the Mockus (triangle) unit hydrograph method are given below.

Determination of Pike Transportation Time (tp)

The collection time (tc) is calculated by Kirpich's formula.

t_c (hr) = 0.00032x [L ^ 0.77 / S_h] ^ 0.385

D (hour) (= td): Effective rainfall period causing flood

D = 2√ (T_c)

Unit Downfall Time □D (hour) is given below depending on the gathering time (tc).

If tc <3 hours □D = 0.5 hours

If 3 hours <tc <10 hours □D = 1 hour

If 10 hours <tc <15 hours □D = 2 hours

If 15 hours <tc <30 hours □D = 3 hours

Accordingly, the time to reach the peak of the flow (tp);tp = 0.5ΔD + 0.6tc

It is calculated by the formula.

BHG peak flow rate Qp (m³ / sn-mm) for the Project Rainfall area:Q_p = ((KxA)) / t_p

K: Basin parameter depending on the physical characteristics of the basin can be taken between (K = 0.208 K = 0.167. If desired, it can be calculated with the formula K = 0.201 + (0.01183 x L / A0.5) - (0.2646 x H / A0.5). However, this value is given as K = 0.2083 in the ISKI Stream Improvement Specification.

HG Descent Time (tr):T_r = 5/3 t_p = 1.67 t_p

Tb (hour): HG continuation timeT_b = 2.67 t_p

Total peak flow Q (m³ / sec) in the Project Rainfall area: Q = Qp ● Pe

Here:
tc: Transition Time (hrs)
D: Net precipitation time (h)
L: Length of longest main stream branch (m)
dH: Height difference between the beginning and the end point of the main stream branch (m)
Sh: Harmonic slope (This was used in the project.)
tr: Descent time (h)
tp: Time to reach peak (h)
tb: Total duration of the hydrograph (hr)
Qp: Unit Hydrograph Peak Flow Value (m³ / sec-mm)
Pe: 1 mm incremental flow height (as given in DSI Method.)

4.1.2 Mockus Method: Calculation of the flood flows

Mockus Method is the synthetic method recommended in basins with tc <30 hours. The smaller of the tc calculated by two different methods was chosen. (Table B1) The flow height (Pe) calculated by finding the effective precipitation duration (D), unit downpour duration (D) at the downstream of the basin and sub-basins, unit peak flow rate (qp) for 1 mm (m³ / sec-km²- mm) and unit peak flow (Qp) (m³ / sec-km²) and HG coordinates were calculated and given in Table B1.

The 24-hour repetitive precipitation heights given and the precipitation heights and flood recurrence peak flow rates created for the effective rainfall period by selecting PLV are given in Table B1. Precipitation heights are corrected by the maximizing factor. Water holding capacity of the ground

Calculated by the equation S (mm) = (1000 / CN-10) x2,54

The rainfall height was calculated with the formula P_e = (P-0,2S) ^ 2 / (P + 0,8S).

In the calculations, the curve number CN = 82 was selected for Condition II and Condition III. (see Table B1).

Table 11: *Flood Recurrence Flow Rates Calculated by Mockus Method (Downstream Point)*

Tekerrür (YIL)	Etkin Yağış (D=2 saat)			Toplam Pik Debi (Q) (m^3/sn)
	Yağış Yüksekliği (P) (mm)	Düzeltilmiş Yağış Yüksekliği (P) (mm)	Akış Yüksekliği (P_e) (mm)	
10	39.27	44.38	15.63	24.01
25	51.34	58.01	25.63	39.36
100	74.35	84.02	46.99	72.18
500	98.63	111.45	71.30	109.52

The hydrograph was created using the total recurrence peak flow rates (Q) calculated in Table B1. Mockus (Triangular) BBH values were used for the hydrograph. Accordingly, the values used in unit hydrograph coordinates are

Appendix C

Categories of landcover types and adhering runoff coefficients.

Table 12: Landcover categories with adhering SRC

Category	Runoff Coefficient
Commercial areas	0.7
Dense Urban fabric	0.65
Governmental and public units	0.6
Green and open spaces	0.2
Industrial Areas	0.8
Medium to Low Density Urban Fabric	0.45
Roads, railways and associated land	0.85
vacant and no structure land	0.3
Water	0

Table 13: Landcover Groups with categorised data

Commercial areas	Dense Urban fabric	Governmental and public units
bank	Continuous urban fabric (S.L. : > 80%)	attraction
cafe	Discontinuous dense urban fabric (S.L. : 50% - 80%)	castle
clothes		college
commercial		community_centre
fast_food		courthouse
guesthouse		hospital
hairdresser		kindergarten
hostel		library
hotel		lighthouse
ice_rink		monument
mall		museum
post_office		police
restaurant		public_building
retail		school
supermarket		toilet
theatre		tower
		town_hall
		university

Green and open spaces	Industrial Areas
Arable land (annual crops)	Industrial and business areas
Green areas and open spaces	Port areas
Green urban areas	fuel

Herbaceous vegetation associations (natural grassland, moors…)	industrial
Pastures	parking_multistorey
beach	
forest	
grass	
graveyard	
meadow	
park	
pitch	
playground	
recreation_ground	
track	
tree	

Medium to Low Density Urban Fabric	**Roads, railways and associated land**
Discontinuous low density urban fabric (S.L. : 10% - 30%)	Railways and associated land
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	Roads, railways and associated land
Discontinuous very low density urban fabric (S.L. : < 10%)	parking

vacant and no structure land	**Water**	**Depending on satellite data:**
Land without current use	Water	Industrial, commercial, public, military and private units
ruins	fountain	Sports and leisure facilities
	spring	archaeological
	water_well	sports_centre
		swimming_pool

The landcover classes of the OSM (Table C3) can fall under specific types of Corine's. However, own landcover categories are created and these classes are assorted into these based on their types and satellite imagery (Table C2).

***Table 14:** Different Landcover Types of the Data Sources*

Corine ITEM2012	**OSM: fclass**
Arable land (annual crops)	archaeological
Continuous urban fabric (S.L. : > 80%)	attraction
Discontinuous dense urban fabric (S.L. : 50% - 80%)	bank
Discontinuous low density urban fabric (S.L. : 10% - 30%)	beach
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	cafe
Discontinuous very low density urban fabric (S.L. : < 10%)	castle
Green areas and open spaces	clothes

Green urban areas	college
Herbaceous vegetation associations (natural grassland, moors…)	commercial
Industrial and business areas	community_centre
Industrial, commercial, public, military and private units	courthouse
Land without current use	fast_food
Other roads and associated land	forest
Pastures	fountain
Port areas	fuel
Railways and associated land	grass
Roads, railways and associated land	graveyard
Sports and leisure facilities	guesthouse
Water	hairdresser
	hospital
	hostel
	hotel
	ice_rink
	industrial
	kindergarten
	library
	lighthouse
	mall
	meadow
	monument
	museum
	park
	parking
	parking_multistorey
	pitch
	playground
	police
	post_office
	public_building
	recreation_ground
	restaurant
	retail
	ruins
	school
	sports_centre
	spring
	supermarket
	swimming_pool
	theatre
	toilet
	tower
	town_hall

track
tree
university
water_well

Appendix D

Indicator weightings and normalised scores of neighbourhoods.

Table 15: *Weighting of Indicators*

Criteria	Weight	Weights with no social data
Runoff	0.45	0.5625
social	0.25	0
buildings	0.09	0.1125
roads	0.17	0.2125
environment	0.04	0.05

Table 16: *Normalised Scores. Yellow squares of the social indicator indicate no data.*

Neighbourh	Runoff	Social	Buildings	Roads	Environmental	Priority	Sensitivity_Analysis
Aksaray	4	4	10	6	2	4,8	5,2
Aksemsettin	8	5	8	7	7	7,04	7
Alemdar	6	2	1	1	5	3,66	3
Ali Kusçu	3	7	1	1	2	3,44	2,8
Atikali	8	10	1	1	10	6,76	6
Ayvansaray	3	8	1	1	3	3,73	3,2
Balabanaga	4		1	1	4	2,775	2,5
Balat	3	6	1	1	3	3,23	2,8
Beyazit	4	5	1	1	9	3,67	4
Binbirdirek	2	3	1	1	2	1,99	1,8
Cankurtaran	1	5	1	1	1	2	1,8
Cerrahpasa	3	7	2	2	2	3,7	3,2
Cibali	5	9	1	1	4	4,92	4
Demirtas	3	8	1	1	3	3,73	3,2
Dervis Ali	5	10	1	1	4	5,17	4,2
Emin Sinan	8	6	1	1	10	5,76	5,2
Haci Kadin	4	5	1	1	10	3,71	4,2
Haseki Sultan	8	7	1	1	7	5,89	4,8
Hirka-i Serif	7	8	5	7	8	7,11	7
Hobyar	9		1	1	7	5,7375	4,5
Hoca Giyasettin	4	8	1	1	10	4,46	4,8
Hocapasa	10		1	1	6	6,25	4,5
Iskenderpasa	6	5	9	8	4	6,28	6,4
Kalenderhane	1		1	1	2	0,9875	1,25
Karagümrük	4	8	8	8	4	6,04	6,4
Katip Kasim	7	2	6	5	3	5,16	4,6
Kemalpasa	6	1	1	2	5	3,58	3
Koca Mustafapasa	4	10	1	1	3	4,68	3,8
Kücük Ayasofya	2	6	1	1	2	2,74	2,4
Mercan	7		1	1	10	4,7625	4,75
Mesihpasa	9		1	1	9	5,8375	5
Mevlanakapi	4	7	1	1	3	3,93	3,2
Mimar Hayrettin	9	1	1	1	10	4,96	4,4

Mimar Kemalettin	6	4	1	1	6	4,2	3,6
Molla Fenari	4		1	1	6	2,875	3
Molla Günari	8	5	10	10	5	7,65	7,6
Molla Hüsrev	3	1	1	1	10	2,26	3,2
Muhsine Hatun	9	3	1	1	5	5,26	3,8
Nisanca	9	3	1	1	7	5,34	4,2
Rüstempasa	10		1	1	7	6,3	4,75
Saraç Ishak	7	3	1	1	10	4,56	4,4
Saridemir	1		1	1	1	0,9375	1
Seyyid Ömer	5	3	1	1	3	3,38	2,6
Silvrikapi	6	10	1	1	5	5,66	4,6
Sultan Ahmet	2	6	1	1	2	2,74	2,4
Sururi	4		1	1	9	3,025	3,75
Süleymaniye	1	4	1	1	2	1,79	1,8
Sümbül Efendi	3	10	1	1	4	4,27	3,8
Sehremini	8	7	1	1	8	5,93	5
Sehsuvar Bey	6	1	1	1	3	3,33	2,4
Tahtakale	9		1	1	10	5,8875	5,25
Taya Hatun	3		1	1	10	2,5125	3,75
Topkapi	5	6	9	9	5	6,29	6,8
Yavuz Sinan	2		1	1	1	1,5	1,25
Yavuz Sultan Selim	5	9	1	1	4	4,92	4
Yedikule	2	9	1	1	2	3,49	3
Zeyrek	5	8	1	1	4	4,67	3,8

Table 17: *Normalised Scores per Indicator*

normalised Scores	Runoff score	Social score	Buildings score
1	44,790582 - 51,379218	5,167390 - 6,205034	5,000000 - 5,003798
2	51,918935 - 56,359659	6,675830 - 7,089342	5,003882 - 5,011144
3	57,560561 - 60,124442	7,186990 - 7,842974	5,02535
4	60,214103 - 62,970293	8,285990 - 8,485240	5,052826
5	63,174601 - 65,121511	8,538770 - 9,032597	5,054028 - 5,105964
6	65,254476 - 66,747646	9,040720 - 9,499069	5,167948 - 5,208732
7	66,957075 - 67,976864	9,565780 - 9,896610	5,407488
8	68,043045 - 69,602999	9,910060 - 10,235405	5,772846 - 5,791884
9	69,680289 - 71,754217	10,249800 - 10,524136	5,808941 - 6,535308
10	73,706329 - 74,600068	10,581100 - 10,770200	6,962445 - 7,973097

normalised Scores	Roads score	Env Justice score
1	5,000000 - 5,035958	58,331464 - 66,678665
2	5,036167 - 5,124351	67,213867 - 83,148138
3	5,341642	83,192460 - 91,495338
4	5,875798	91,718392 - 95,725938
5	6,968496 - 7,188883	95,738257 - 97,870127
6	8,829872 - 10,416767	98,099981 - 98,956863
7	14,947771 - 18,351694	98,964011 - 99,507652

8	18,489314 - 21,579578	99,508714 - 99,786808
9	22,297052 - 22,892664	99,863241 - 99,928292
10	23,426819	99,968484 - 100,000000

Appendix E

Molla Gürani Results

Table 18: *Permeable Pavement Calculation*

GI investment	m2	% of neighbourhood	Runoff Coefficient	Runoff Score
permeable 30% of road area	27958.9	6,986969	0.3	2.096091
'Normal' roads	65237.43	16,30293	0.8	13.04234
Other landcover types				46.17812
			Total	61.31656

Table 19: *New Normalised Score for Molla Gürani*

Neighbourh	Runoff	Social	Buildings	Roads	Environmental	Total Priority	Sensitivity Analysis
Molla Günari	4	5	10	10	5	5.85	6.8