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Extreme Weather Events: The Impact of Flooding on Transportation Network: Case Study of Buyukcekmece Basin

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Abstract – Transportation is a critical sector which is vulnerable to hazardous events like urban floods. The disruption in transportation infrastructure affects the whole community in terms of loss of life and property. A resilient transport system is fundamental for resilient communities, and considering the adverse impacts of climate change, it becomes even more important. The Büyükçekmece Basin is a densely populated and economically significant area that also includes regions of natural importance requiring preservation. Thus, a flood hazard can affect more people, cause greater monetary losses and have negative impact on the environment and nature.

The purpose of this research is to present the disruption of road network in Büyükçekmece Basin due to flooding and create an analytical framework. Vulnerability of road systems to rainfall-induced floods is quantified by integrating different models. An integrated framework linking hydrological model and inundation model is established and the relation between flood depth and road network vulnerability is determined. Flood hazard maps are created for two different rainfall events with 1 in 50 year and 1 in 100-year return period and flooded road lengths are determined. The flood levels have shown that there are road segments that will face moderate and major flooding. In Büyükçekmece Basin where serious floods have occurred in the past, measures need to be taken regarding the road network for possible flood risks.

Keywords – Flood Hazard, Hydrological And Hydrodynamic Modelling, GIS, Inundation Map, Transportation Infrastructure

I. INTRODUCTION

Floods are natural disasters that can cause extensive damage to both human lives and property. Flood risk is a growing concern for communities worldwide since the extreme weather events become more frequent and their effects are exacerbated by climate change [1]. According to [2] the frequency of heat waves, droughts, and floods has increased globally over the past few decades and will continue to increase in the future due to warming climate.

Urbanization and population growth have also contributed to the recent threat of floods. According to a study [3] changes in land use patterns and drainage systems increased runoff and reduced infiltration rates. When the permeability of the ground is reduced and impervious surfaces such as roads and buildings increase, water can accumulate rapidly and exceed the capacity of drainage systems, leading to flooding. Moreover, degrading wetlands and forests, which are the natural flood protection systems, can reduce their resilience and ability to absorb and mitigate the impacts of floods, further increasing the flood risk. Population growth also putting more people at risk of flooding especially who live in areas such as floodplains and coastal regions [4,15].

The urban transportation network is one of the infrastructures most affected by floods and this research aims to provide an integrated analytical approach on this subject. Floods can create public safety hazards by causing damage to roads, bridges and disrupting transportation. Inundation of roads and bridges can result in traffic congestion, increased travel times, and reduced accessibility to emergency services. Accessing emergency services in time during hazardous event has a crucial importance for saving lives and preventing injuries [5].

The broader effects of the floods on urban life can be costly repairs for damaged transportation infrastructure, long-term closures, impeded flow of goods and services, limited access to healthcare and education, closure of businesses and displacement of residents [6]. Therefore, investing in effective flood mitigation strategies carries great importance

Büyükçekmece basin is a subbasin of the Marmara Sea basin located the European part of Istanbul. It is situated between the latitudes 40° 57' and 41° 12' N and longitudes 28° 23' and 28° 46' E and covers an area of approximately 444 km². The primary watercourse is Buyukcekmece River and Buyukcekmece Lake is a part of the basin. Büyükçekmece Lake was once a lagoon connected to the Sea of Marmara, in order to address the increasing water needs of Istanbul it was transformed into a dam. It is the one of the largest drinking water sources in Istanbul with annual water production capacity [12].

This basin is characterized by a mix of urban, agricultural, and natural areas. Due to rapid urbanization and population growth, water management and flood control in the region has significant importance. This area has experienced multiple instances of flooding, which can be attributed to factors like urbanization, land use practices, and inadequate infrastructure and drainage systems [7].

II. Materials and Method

In the view of discussion presented above a flood risk assessment framework for transportation is developed to assess the potential impact of flooding on road transportation system. This framework can be used as a decision support tool by decision makers and transport planners. Vulnerability of road systems to rainfall-induced floods will be quantified by integrating different models. An important point of using models is that they can be also applied in different areas or for different cases.

The framework of the study combines a hydrological model and flood inundation model; the methodological steps for these models are presented in the subsequent sections of the paper.

A. *Hydro-climatological analysis*

The primary cause of floods is excessive rainfall therefore weather variables must be examined in order to mitigate the risks associated with extreme events. Rainfall intensity, duration and frequency are considered as driving parameters for urban floods. In order to determine the extent and the severity of the hazard it is important to analyze these parameters.

Meteorological data must be obtained in a format suitable for use in hydrological and hydraulic modeling tools. In this study, the data of meteorological observation stations located within or near the basin boundaries have been used. Hourly and daily precipitation data have been obtained for these stations also meteorological stations with available "Precipitation Intensity-Duration-Frequency curve" and "Precipitation Intensity-Duration analysis table" are identified. Using this data, precipitation intensities for different recurrence intervals and catchment areas have been determined. Meteorological observation station data provided by General Directorate of Meteorology (MGM).

Return period, also called recurrence interval, demonstrates the average time between events of a specific magnitude, generally it is expressed in years. In this study 50-year and 500-year return periods are used in order to demonstrate the worst possible scenario and take precautions accordingly.

The IDF (Intensity-Duration-Frequency) curve provides information on the expected rainfall intensity for a given duration and frequency. IDF curve is utilized in hydrological model in order to estimate the probability of occurrence and magnitude of extreme precipitation events in Buyukcekmece Basin. In this research meteorological station data for precipitation on an hourly and daily basis from 1926 to 2022, provided by MGM is utilized.

B. *Land Use and Land Cover Analysis*

Land use and land cover characteristics have an impact on the flow characteristics of the channel. For instance, flow characteristics will be different in urban areas due to presence of man-made structures such as buildings, roads, and sidewalks. these structures can create additional roughness in the channel and decrease the flow velocity. On the other hand, agricultural areas have smoother channel boundaries that are consist of vegetation or natural terrain features etc.

The manning number (n), also called as manning's roughness coefficient, is related to the land use and land cover and describes the roughness of the channel boundary that affects the resistance to flow. In this study x different land use class is used and different manning numbers are assigned for these different classes.

Curve number (CN) is a parameter used in hydrological models to estimate the amount of direct runoff. It demonstrates the combined effects of land use and soil type. In this study land use and soil types in Buyukcekmece Basin have been overlaid, and different curve numbers have been determined for their combinations [13].

Muskingum method is used for flood routing in hydrological studies. It is possible by using Muskingum method to predict the effects of changes in land use like urbanization or deforestation on downstream flood levels. The Muskingum "K" parameter demonstrates how long it takes for floodwater to travel through a particular section of a river. By knowing the K value, it is possible to predict how floodwater will move through a river and take mitigation measures accordingly. During this analysis Manning n, curve number and Muskingum k parameters are utilized in HEC-HMS hydrological model.

C. *Hydrological Model and Inundation Model*

Initially, Buyukcekmece basin, its subbasins and streams are created by utilizing hydrological model in order to represent the natural water systems and to simulate their behavior. In hydrological model, a 30-meter resolution digital elevation model (DEM) data obtained from SRTM is used.

Following this, peak runoff rate (Q peak), water depth for 50 and 500 years return period and river width for each stream segment is determined. The mentioned analyses are carried out in HEC-GeoHMS. HEC-HMS which is a hydrological modeling program used to determine rainfall-runoff relationships, based on watershed characteristics and it has a HEC-GeoHMS extension works with GIS software [14].

The outputs obtained from the HEC-GeoHMS software are transferred to ArcGIS in order to create a flood inundation model.

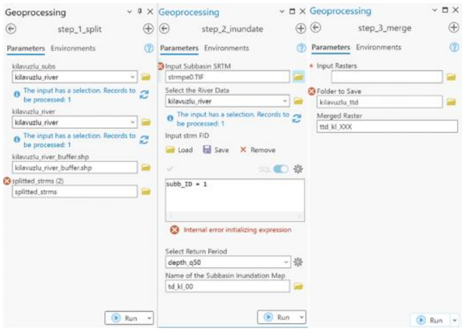

Fig. 1 ArcGIS Inundation Model Steps

In the first step, the SRTM data has been clipped for each Buyukcekmece subbasin. In the second step, the outputs acquired from the hydrological model are utilized in order to determine the extent of inundation. In the final step, the subbasins are merged and gridded flood maps that present maximum flood depth are created for the Buyukcekmece Basin (Fig.1). Flood depth maps are generated for both rainfall events; one in fifty years and one in five hundred years (Fig.2 and Fig.3).

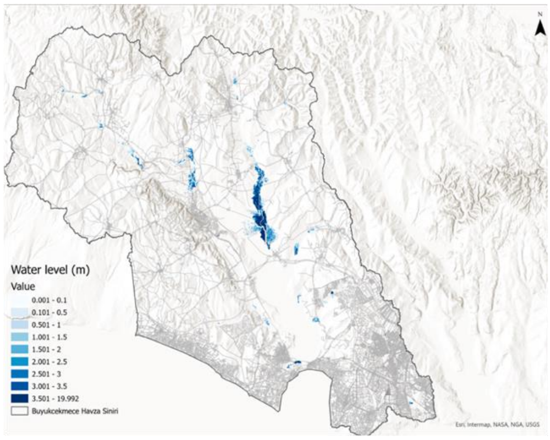

Fig. 2 Flood depth 50 year return period

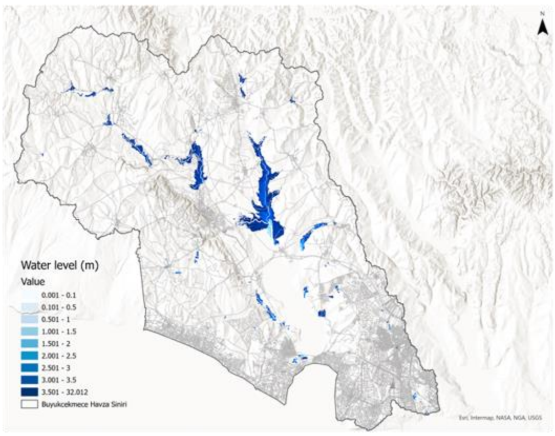

Fig. 3 Flood depth 500 year return period

D. *Flood Exposure*

Flood exposure on urban networks has become a pressing concern in recent years as the escalating impacts of climate change and rapid urbanization have significant challenges to urban infrastructure and transportation systems. Especially, densely populated cities with aging infrastructures and inadequate drainage systems are more vulnerable to flood hazards [8].

In this study the impact of flooding on road network in Büyükçekmece Basin is quantified. Initially, road network of Istanbul is obtained and the area that covers the basin boundaries are selected. Afterwards, the roads are intersected with the gridded flood depth map for the basin, is created by using hydrological model and flood inundation model, in ArcGIS environment. By doing so, the road links that will be inundated and their corresponding water levels have been determined. These analyses are carried out for two different rainfall events; one in fifty years and one in five hundred years.

III. RESULTS

A flood stage is defined as the depth of flood level that a body of water has risen to the point where it overflows its and causes flooding in the surrounding areas. Flood stages are classified into three groups; which are minor flooding (water level between 0.1 m to 0.5 m), moderate flooding (water level between 0.5 m to 1 m) and major flooding (water level 1 m and above). Areas where the water level remains below 0.1 meters have not been classified as flooded areas [9].

Table 1. Flood stage distribution in terms of flooded road length - 50 year return period

50 year return period	Flow Level (m)	Flooded Road Length (km)
No flood	0 – 0.1	4763,1
Minor flood	0.1 – 0.5	28
Moderate flood	0.5- 1	32,3
Major flood	Above 1.0	48,6
	Total	155,6

Table 2. Flood stage distribution in terms of flooded road length – 500 year return period

500 year return period	Flow Level (m)	Flooded Road Length (km)
No flood	0 – 0.1	4716,4
Minor flood	0.1 – 0.5	32,5
Moderate flood	0.5- 1	33,5
Major flood	Above 1.0	89,6
	Total	108,9

According to Table 1 and Table 2 , for a one in fifty-year rainfall event, a 108.9 km road segment is estimated to be inundated, while for a one in five-hundred-year rainfall event, a 155.6 km road segment is estimated to be inundated. These road segments include primary, secondary, tertiary, link roads, express ways and service roads.

When a road is inundated with water, it can become hazardous for driving and cars. If the water level rises too high, it can create a significant risk to drivers and their vehicles [10]. high water levels can cause the car to stall, making it difficult or impossible to continue driving. In some cases, the car may even be swept away by the water, putting the driver and passengers at risk. There are studies on safety for the driving of inundated roads. According to [11], if the inundation level is above 0.3 meters cars are likely to experience severe disruption and roads will become impassable. Therefore, in our analysis, a threshold of 0.3 meters is also considered, and the road segments where the water level is above 0.3 meters are calculated separately. For a one in fifty-year rainfall event, a 104 km road segment, and for a one in five-hundred-year rainfall event, a 140.1 km road segment, is estimated to be above the 0.3-meter water level.

IV. DISCUSSION

This study has shown that Büyükçekmece Basin, and other basin areas, should be thoroughly examined in terms of flood risk. Istanbul is a densely built-up city, and the same situation applies to Büyükçekmece, particularly in these areas' risks are even greater. Disruptions on the road network can result in accidents and injuries and require high repair costs. As can be seen from the study results, there is a moderate and major flood risk for some roads. Flood management and adaptation intervention can be targeted for these road segments.

The findings of this study can serve as valuable input for urban planning and infrastructure projects.

V. CONCLUSION

Büyükçekmece Basin, Istanbul as whole city, is highly likely to experience flooding in the future, as a result of rainfall events that have both high intensity and longer duration. Therefore, mitigating flood risks on road networks, particularly in basin areas, is crucial for ensuring public safety, maintaining transportation infrastructure. In order to reduce flood risk some measure can be taken. Key measures include flood risk assessment, which is also the subject of this study, land-use planning, natural flood management techniques and early warning systems. Also, continuous monitoring and adaptive management is vital for effective flood management.

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