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Spatial flood analysis to determine possible economic damage: Case study of the European side of Istanbul

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ABSTRACT

Floods are one of the natural disasters that affect people's lives and cause enormous environmental and economic damage. Istanbul has been frequently exposed to the devastating effects of floods from past to present, especially in terms of human losses and damage to infrastructure. Although various precautions have been taken by the authorities to prevent losses, such as improving stream and infrastructure, none of them have been able to mitigate the effects of floods to a great extent. One of the solutions is to collect spatial and economic data obtained from different sources into a single spatial database and present this synthesized information to decision-makers in an understandable form using Geographic Information Systems (GIS). In this study, a possible flood disaster that may occur on the European side of Istanbul is simulated using spatial flood analysis methods and the results of the disaster are presented. After the inundated areas are identified, the economic dimension is calculated and compared with past events for the validation of risk assessment. According to the results, total damage of more than $500 million is estimated for a possible full-scale flood event on the European side of Istanbul.

1. INTRODUCTION

Istanbul, one of the most densely populated metropolises in the world, has experienced many flood disasters between 1989-2009 (Turoglu 2011). In the study of flood disasters, climate change, increasing concretion, unplanned urbanization, insufficient infrastructures, flood proclivity of topography, and settlements in riverbeds can be mentioned as the main causes. According to Sahin and Sag (2015), soil structure, economic activities, land use and population characteristics are also effective on occurrence of flood. Flooding is often caused by heavy rainfall and, depending on the infrastructure, can cause severe damage to roads, buildings, and the residents of the affected neighborhoods. The main reason why these impacts of disasters could not be prevented is not the determination of possible flood zones or the failure to perform necessary analyzes, but the fact that different sources of information are not presented and analyzed in a spatial environment.

The proposed solution to prevent or manage the impact of a possible flood event is to collect spatial and economic data from different sources in a single spatial database, analyze this information using Geographic Information Systems (GIS) and present it to decision makers in an understandable form. In this study, flood analyzes are carried out in the GIS environment and a spatial risk assessment is made by using economic input data for the areas identified as the result of the analyzes. The costs of several affected components of the infrastructure are estimated for the European side of Istanbul and compared with past events to validate the methodology. A temporal comparative pricing strategy is followed by using the economic dimension of past floods, such as the Ayamama flood that occurred in 2009 (Ozcan 2017). All types of data used in the study are obtained from open-source database. Since detailed information on infrastructure (type, construction material, etc.) could

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not be obtained from any open-source database, this dimension of risk assessment could not be merged with the results of this study.

Further sections are organized as follows: In the next section, the study area, data, flood analysis methods, and the economic dimension of the analysis are described. In section 3, spatial and quantitative estimations are presented and findings are interpreted. Finally, the subject is concluded in the last section.

2. METHOD

2.1. Study Area and Data

Istanbul is the most populous city in Turkey and due to its high population, it holds many problems related to flooding. One of these problems is the impact of flooding on residential areas resulted from the unplanned urbanization. Flood disasters in recent years have caused many casualties and millions of dollars of damage. When the past events of Istanbul were examined, it was found that the floods caused more damage on the European side than on the Asian side according to the Istanbul Development Agency (2010). Also, there is more quantitative economic data about past events. Therefore, the European side of Istanbul was selected as the study area to implement and validate the methodology.

The data used in the study were obtained entirely from open-source database. OpenStreetMap data were used to identify water bodies, buildings, roads, and Point of Interests (POI). For such studies, Digital Elevation Model (DEM) is an important input to determine the characteristics of topography and flood impacts. One of the most important factors affecting the accuracy of flood analyzes is the resolution of DEM. Paid data such as LIDAR DEM have higher resolution than Shuttle Radar Topography Mission (SRTM) or other freely available DEM data. The use of high-resolution DEM could significantly increase the accuracy of the analysis. However, in this study, to follow the open-source approach, the SRTM DEM with a spatial resolution of 30m x 30m was chosen as the most suitable data and obtained from USGS Earth Explorer. The unit prices needed for the economic analysis were obtained from Cost Table of the Department of Revenue Management. This analysis can be applied to any region where the required data are available. Study area and data are shown in Fig. 1.

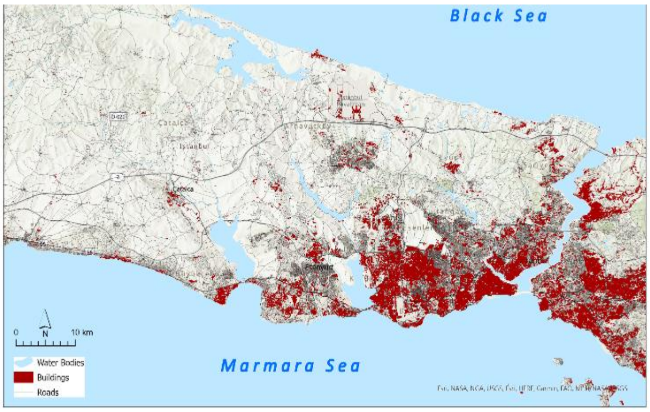

Figure 1. Study area and Data

2.2. Methodology

2.2.1. Flood analysis

The analysis process starts with the determination of inundated areas using the DEM and continues with the estimation of the economic dimension for roads and buildings using unit costs of these components. Workflow is shown schematically in Fig. 2.

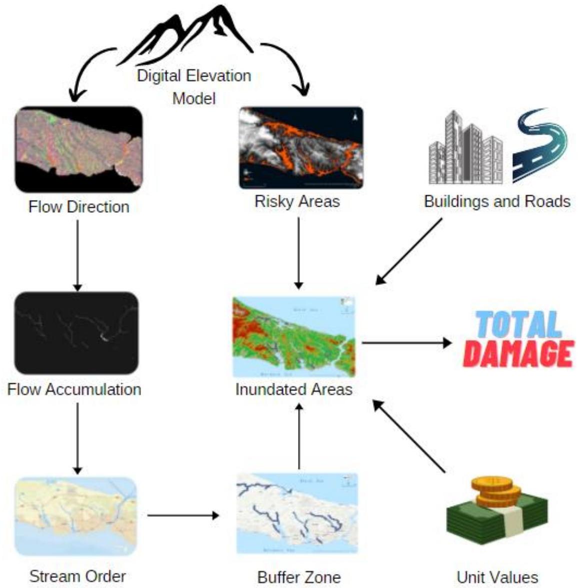

Figure 2. Schema of followed workflow

To perform the analyses shown in Fig. 2, ArcGIS Pro Hydrology Toolbox was used. By using fill operation, small imperfections of the DEM data have been removed. Then, the flow direction from one cell to the others and the amount of water collected in each cell were calculated with flow accumulation and direction analysis. Finally, stream orders representing a kind of evacuation line of Istanbul during the flood disaster were determined. In the further steps, the flood impact distance was determined to be 500 meters with the help of legal regulations (Legal Gazette, 1984). This distance was used to perform the buffer analysis for the stream orders. According to Ozcan (2017), the water had risen 6-7 meters during the last flood in Ayamama Stream in 2009. Based on this information, the heights of the streams in Istanbul were obtained from the DEM and the rise height of the water was added to the elevation of the streams. As a result of this process, areas below 25 meters were determined as risk zones in the DEM data. Then, the inundated areas were obtained at the intersection of the buffer zone and the at-risk areas. Finally, the flooded roads and buildings were determined by intersecting the inundated areas with the buildings and roads.

2.2.2. Economic analysis

Within the scope of this study, an economic analysis was conducted using the unit damage costs for buildings and roads identified in Legal Gazette of Turkey No: 31231 (Legal Gazette, 2021). Although there are many types of buildings affected by flooding, they were classified into four main classes as house, workplace, shopping center, and educational buildings.

By using unit prices for different types of buildings, the total cost per unit square meter of each affected building was determined. Roads were also examined under 3 main classes, referred to as primary, secondary, and tertiary. Primary roads consist of high-cost highways, secondary roads are two-way roads that connect to primary roads, and tertiary roads are smaller and simpler roads outside of urban areas. Damage costs for the three main types of roads were calculated based on the cost of roads built in the past years. In this way, the structural economic damage costs of buildings and roads were calculated.

3. RESULTS

The inundated areas determined by the flood analysis are shown in Fig. 3.

Figure 3. Map of inundated areas

As shown in Fig. 3, there are mainly five different regions to be affected by the flood. According to map of inundated areas in Fig. 3, affected districts are Arnavutköy, Avcılar, Büyükçekmece, Çatalca, Eyüpsultan, Kağıthane and Küçükçekmece. To see the effects of the flood, a 3-dimensional model was also created for the illustration of the flood as shown in Fig. 4.

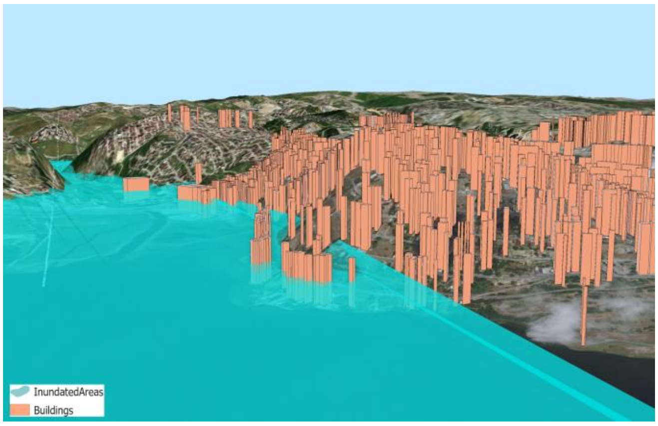

Figure 4. 3D model example of flood

With the help of the 3D model, it is possible to have a better view of the flood by observing the land shape and the flood together. In the context of this study, the analysis performed with the 3D model is not detailed. However, when sufficient data is available, it enriches the study by adding a different perspective to the analysis.

When the simulated flood area is examined in detail, it was found that 1326 buildings, 139.31 km^2 of the residential area, and 586 km of roads are affected. A part of the affected roads and buildings are shown in Fig. 5.

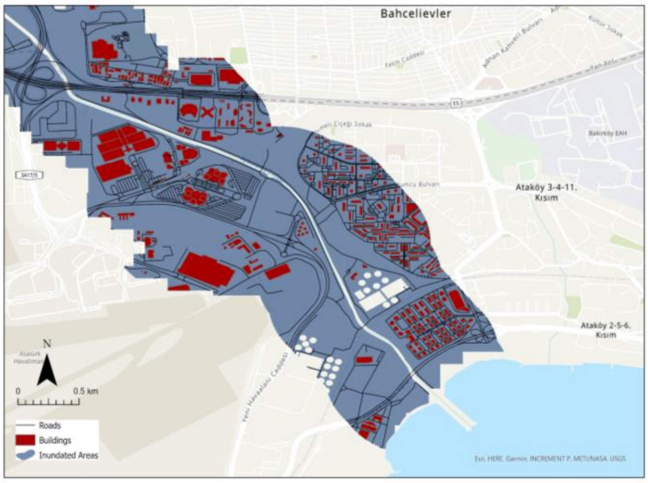

Figure 5. Inundated roads and buildings in the Ayamama region

While calculating the economic damages caused by the flood, the road and building data were calculated separately by using the unit prices for roads and the prices for building repairs obtained from the Cost table of the Department of Revenue Management. Damage to primary, secondary, and tertiary roads was calculated as $ 420 million and damage of different building types was calculated as $ 100 million in total. The costs of the different types of roads and buildings are shown in Fig. 6 and the comparison of these components is shown in Fig. 7. The total damage caused by the flood was determined to be $ 520 million, as shown in Fig. 7.

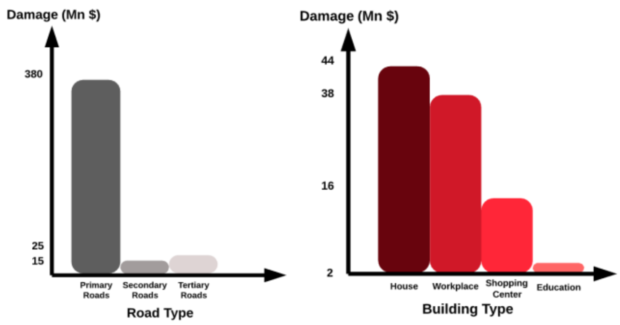

Figure 6. Calculated damage for roads and buildings

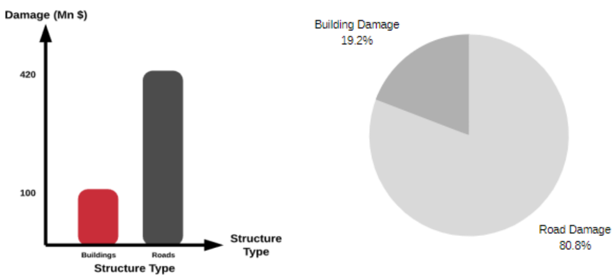

Figure 7. Graphical representations of the total damage of roads and buildings

Finally, to make the accuracy assessment, the calculated economic damage was compared with the real economic damage of the flood that occurred in the Ayamama River region in 2009 (Ozcan 2017), and the accuracy rate of 87% was obtained.

4. CONCLUSION

Determination of the inundated areas that occurred due to flooding and their economic damage is very important in terms of taking measures to minimize the impacts. In this paper, the areas that will be inundated by possible flooding on the European side of Istanbul are spatially determined and the economic impacts are calculated to be presented to decision-makers by using completely open-source data. The applied methodology can be implemented for any city in the world where data is available and the results can be shared with decision-makers. By using such spatial decision-making systems, precautions should be taken to reduce the destructive power of floods that seriously harm people.

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