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Research Article

Flood Hazard Mapping by Using Geographic Information System and Hydraulic Model: Mert River, Samsun, Turkey

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In this study, flood hazard maps were prepared for the Mert River Basin, Samsun, Turkey, by using GIS and Hydrologic Engineering Centers River Analysis System (HEC-RAS). In this river basin, human life losses and a significant amount of property damages were experienced in 2012 flood. The preparation of flood risk maps employed in the study includes the following steps: (1) digitization of topographical data and preparation of digital elevation model using ArcGIS, (2) simulation of flood lows of different return periods using a hydraulic model (HEC-RAS), and (3) preparation of flood risk maps by integrating the results of (1) and (2).

1. Introduction

Flooding, as a major natural disaster, affects many parts of the world including developed countries. Due to this natural disaster, billions of dollars in infrastructure and property damages and hundreds of human lives are lost each year. These hazards and losses can be prevented and reduced by providing reliable information to the public about the flood risk through flood inundation maps [1]. Flood inundation maps are very essential for municipal planning, emergency action plans, flood insurance rates, and ecological studies [2]. Samsun is the largest and densely populated in the north of Turkey. This area is almost under threat of flooding in each year. In this region, the main reason of devastating flood is the influence of the Mert River especially during March, April, and July and due to seasonal rainfall which eventually makes the district vulnerable to flooding. In addition, the human based constructions and the collapse of water retaining structures are among the main causes of flooding.

Geographic Information Systems (GIS) are successfully used to visualize the extent of flooding and also to analyze the flood maps to produce flood damage estimation maps and flood risk map [3–5]. The GIS must be used together with a hydraulic method to estimate flood profile with a given return period. After 1970, Hydrologic Engineering Centers River Analysis System (HEC-RAS) software developed by United States Army Corps of Engineers (USACE) is widely used in Europe and America. In our country, it was first applied on Bartin River in 1998 by Yazıcılar and Önder [6]. GIS and HEC-RAS models were successfully used for obtaining flood maps of Waller River in Texas [7], Ohio Swan River Basin [3], Atrato River in Colombia [8], Vistula River in Warsaw, Poland [4], Gordon River in France [9], northwest of Colombia [8], mid-eastern Dhaka in Bangladesh [10], and Onaville in Haiti [11]. Çelik et al. analysed the 2004 flood of Kozdere Stream in Istanbul using HEC-RAS and GIS [12]. Sole et al. produced risk maps of Basilicata region (Italy) by acquiring water surface profiles according to different repetition flow in the main distributary (30, 200, and 500 years) [5]. Masood and Takeuchi used HEC-RAS and GIS for assessing flood hazard, vulnerability, and risk of mid-eastern Dhaka [10]. They obtained inundation map for flood of 100-year return period. Sarhadi et al. obtained flood inundation maps of ungauged rivers in southeastern Iran by using HEC-RAS and GIS [13]. Heimhuber et al. used HEC-RAS and GIS to perform one-dimensional, unsteady-flow simulations of design floods in the Ravine Lan Couline, which is the major drainage channel of the area [11]. To the knowledge of the authors, the HEC-RAS and GIS methods were not previously applied to Mert River Basin. Due to its proximity to numerous homes, businesses, and industrial area, the location of Mert River's flood plain is of great interest to city planners,

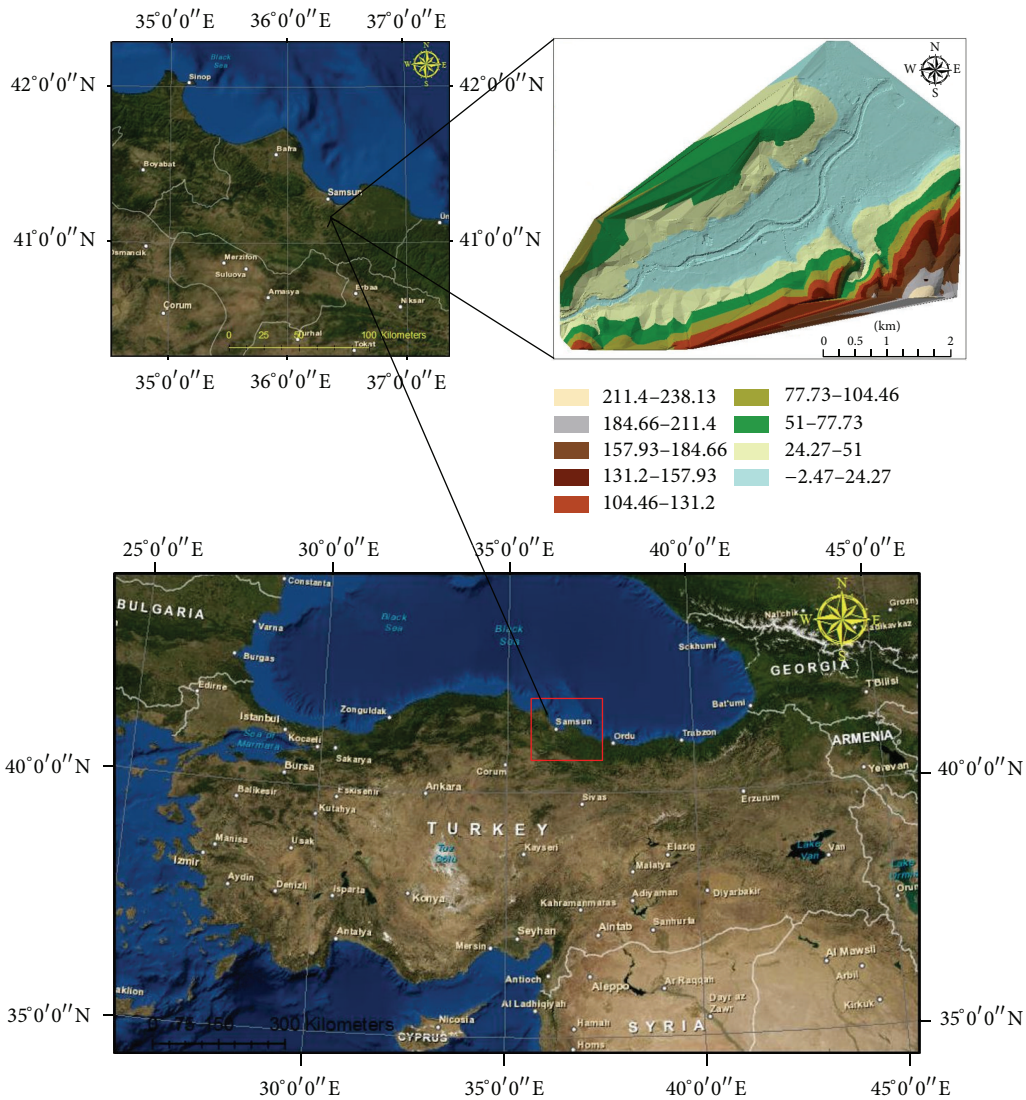

Figure 1: The location of the study area in Turkey.

developers, and property owners. To the knowledge of the authors, the GIS and HEC-RAS were not previously applied to this area where devastating floods happened.

The aim of this study is to obtain flood hazard maps of the Mert River Basin using GIS and HEC-RAS for floods of different return periods (10, 25, 50, 100, and 1000). First, topographical data were digitized and digital elevation model was prepared using ArcGIS. Then, flood flows of different return periods were simulated using a hydraulic model (HEC-RAS). Finally, flood risk maps were obtained by integrating the results of ArcGIS and HEC-RAS. The obtained flood map for 10-year return period was also tested by 2012 flood in which 12 people lost their lives.

2. Study Area

Mert River is located in the center of Samsun. Geographic location of the study area is between Latitude 41.279 and Longitude 36.352. Samsun is the largest city in the Central Black Sea Region of Turkey. This district faces devastating floods which have a destructive effect on humans, buildings, and substructure systems. The Mert River which is about 8 kilometers long flows into the Black Sea. Mert River was selected for this study because it had a great loss of life and property in the recent floods (e.g., July 3, 2012). This river has five highway bridges and one pedestrian bridge. First, second, and third bridges of this river are located in the Black Sea coastline and provide ease of transport between cities. The study area is shown in Figure 1.

2.1. Methodology. In the present study, flood hazard maps were obtained by using HEC-RAS, HEC-GeoRAS, and ArcGIS. The methodology for developing a flood hazard map can be explained by the following three phases: (i) preparing digital elevation model using ArcGIS, (ii) simulation of flood flows of different return periods using HEC-RAS hydraulic model, and (iii) preparing flood risk maps by integrating phases (i) and (ii). The flow chart of the methodology is

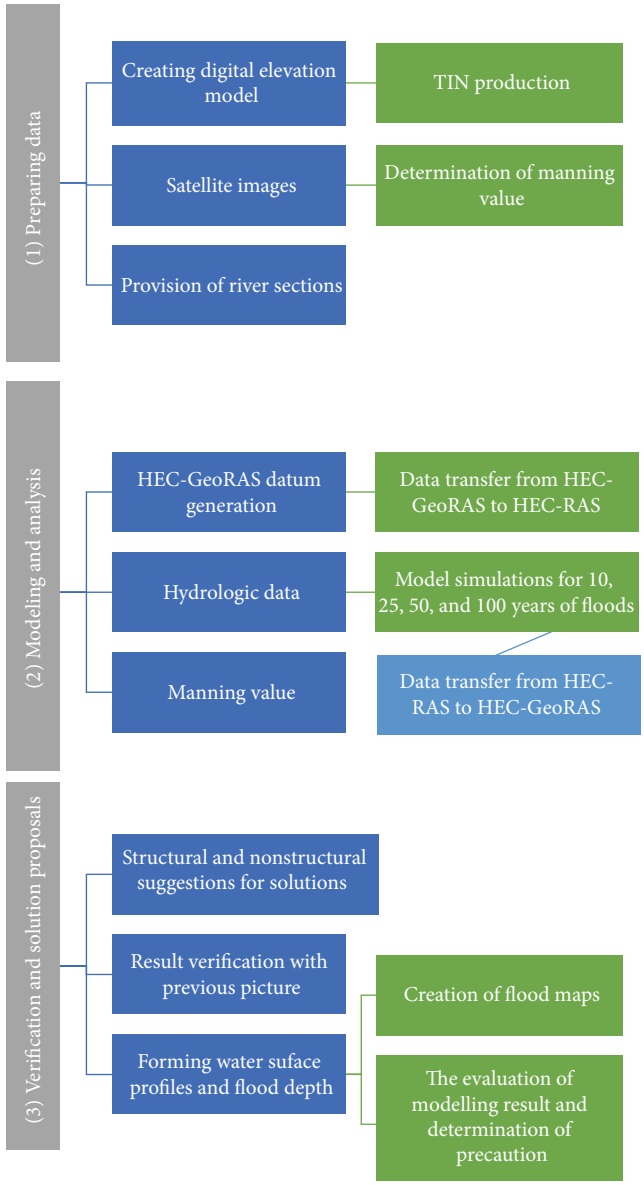

Figure 2: Flow chart of methodology.

illustrated in Figure 2. Next, brief information is provided for the HEC-RAS and HEC-GeoRAS. Detailed information for these methods can be obtained from related literature [14, 15].

2.2. HEC-RAS Model. HEC-RAS, a hydraulic model developed by the USACE, is extensively applied in calculating the hydraulic characteristics of rivers [16, 17]. It is an integrated program and uses the following energy equation for calculating water surface profiles [14, 18]:

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e, \quad (1)$$

where Y, Z, V, α, h_e, and g represent water depth, channel elevation, average velocity, velocity weighting coefficient, energy head loss, and gravitational acceleration; and subscripts 1 and 2, respectively, show cross sections 1 and 2.

This program provides user to input data, data correction, to receive output display and analysis. HEC-RAS model needs details of river cross sections and upstream flow rate. The water depth and mean velocity are calculated for a given cross section using the energy conservation equation [14].

HEC-RAS calculates the water levels' variation along the channel and the water level values are overlaid on a digital elevation model (DEM) of the area to get the extent and flood depth using GIS [19]. Spatial data like cross section, river reach, stream network, flow paths, and others have been obtained using HEC-GeoRAS (Arc-GIS extension) and these data then transferred to HEC-RAS [15].

2.3. HEC-GeoRAS Model (GIS). HEC-GeoRAS is developed for the treatment of geographic data with the HEC-RAS and is working on an extension to ArcGIS (module). Other supplemental information with geometric data files is obtained

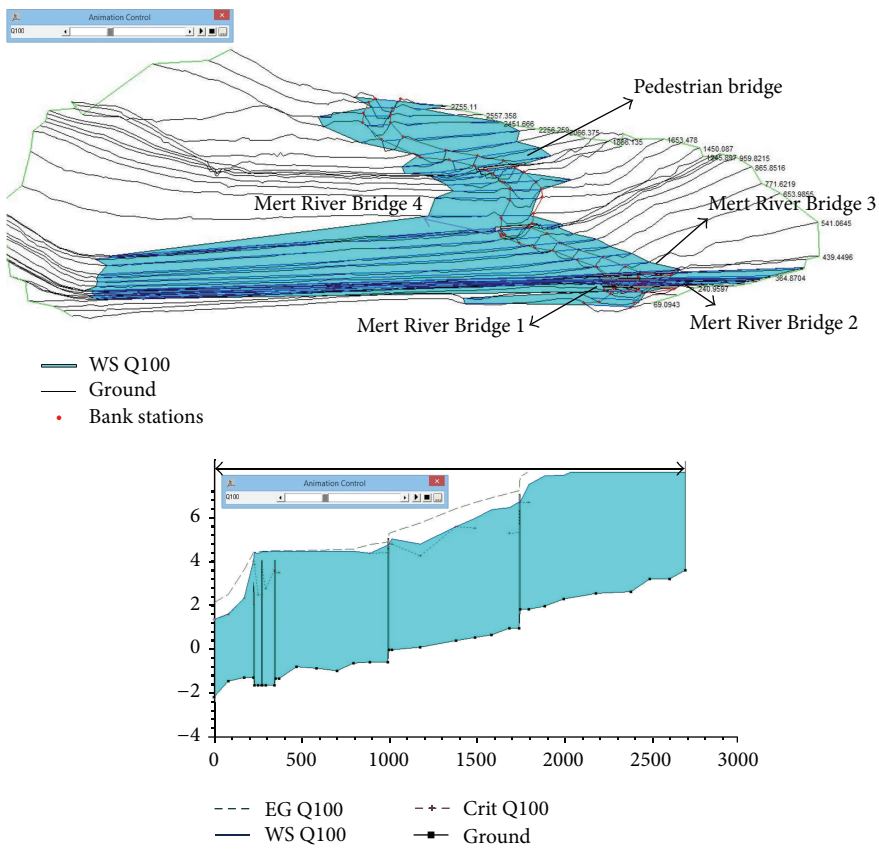

Figure 3: Water surface profile for the Q100 flood.

from the Digital Terrain Models. This module can convert the format of HEC-RAS software and can read the obtained format. After analyzing the data with HEC-RAS, water surface profiles, water level, and water velocity can be obtained. The results obtained from hydraulic model can be converted to GIS format by using HEC-GeoRAS and thus flood mapping and flood depth map can be obtained [20].

The mixture of processing topographical information and other GIS data in ArcMap utilizing GeoRAS provides us with the capacity to create and export a geometry file to be investigated by RAS. The created geometry document holds information on river, catchment, and station cross section cut lines, bank stations, flow path. It achieves lengths for left and right overbanks and channel and roughness coefficients and furthermore can contain blocked obstructions. The results of RAS reproduction, for example, river profiles, can be sent specifically to a GIS environment, where they can be analyzed further by the assistance of the GeoRAS toolbar. A particularly arranged GIS information exchange document (∗. sdf) is utilized to perform the GIS data import and export between RAS and ArcMap [21].

3. Application and Results

In this study, HEC-RAS 4.10 was utilized for hydraulic analysis and ArcGIS 10.2 was used for mapping. First, 3D model of study area was prepared utilizing ArcGIS. Digital Elevation Model (DEM) was produced by 1/1000 scale topographical contour lines. Then, topographic data obtained from ArcGIS were transferred to HEC-RAS via Hec-GeoRAS module. Flood values of different return periods (10, 25, 50, and 100 years) and Manning roughness coefficient values were also entered into the HEC-RAS program for calculating water level for each cross section. Finally, the hydraulic analysis results were entered into the ArcGIS via Hec-GeoRAS module and flood hazard maps were obtained for each return period.

Manning roughness coefficients of 0.022, 0.026, and 0.045 were used for concrete, bush-wooded, and woodland river banks and 0.03 was utilized for the river base. Flood values of diverse return periods and annual instant maximum flows were obtained from the Turkish General Directorate of State Hydraulic Works. All these values are reported in Table 1. Table 2 gives the annual instant maximum flows of Mert River. As can be clearly seen from Table 2 a flood (near Q10, flood of ten-year return period) was seen in the studied area in 2012 and loss of life and property occurred.

Flood simulations were conducted using hydrodynamic program for the floods of 10, 15, 50, and 100 return periods. As an example, water surface profiles for the Q100 flood and the location of the bridges on Mert River are shown in Figure 3. Bridges were numbered according to their proximity to the

Table 1: Flood values of different return periods of Mert River.

Return period	5	10	25	50	100	500	1000	10000
Flood (m^3/s)	508	641.8	839.7	1011.6	1207.6	1709.5	2028.5	3139.5

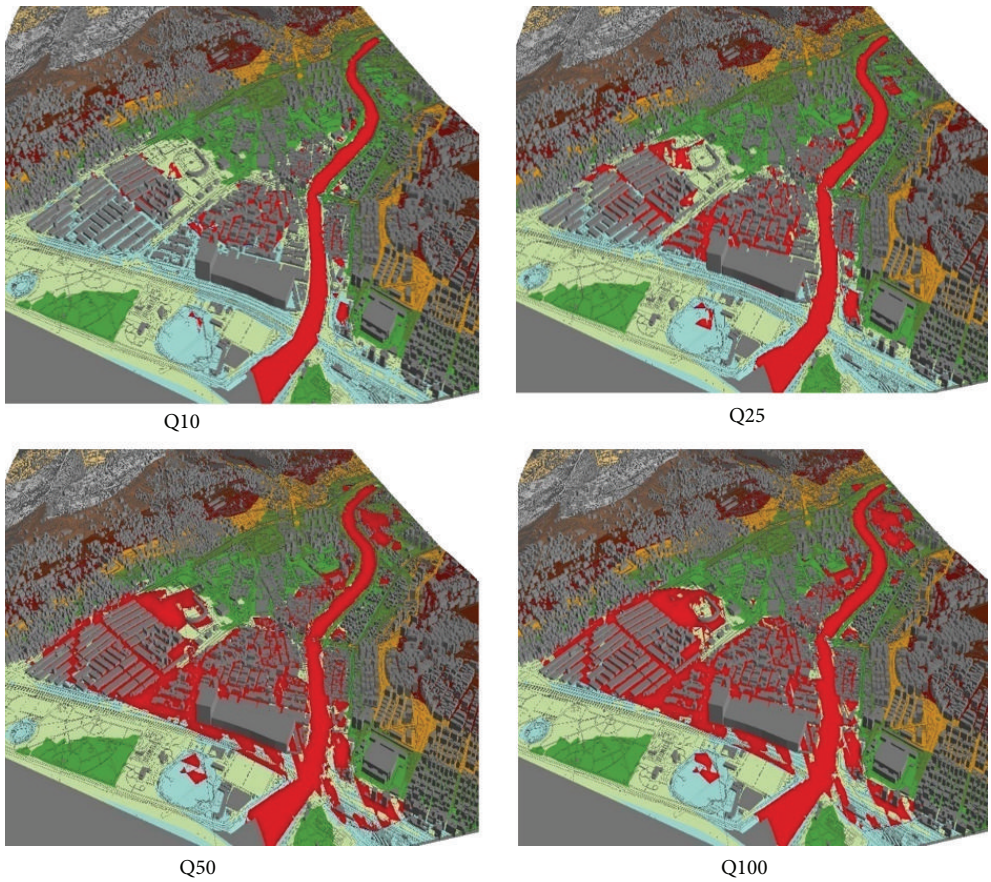

Figure 4: 3D hazard maps of the Mert River obtained for the Q10, Q25, Q50, and Q100 floods.

Table 2: Annual instant maximum flows of Mert River.

Year	2007	2008	2009	2010	2011	2012	2013
Flow (m^3/s)	158	102	66.3	87.1	73	570	66.1

Black Sea. Mert River flows into the sea after Mert River Bridge 1. It is clear from the figure that the last three bridges stay under water in the case of Q100 flood. 3D hazard maps of the Mert River acquired for the Q10, Q25, Q50, and Q100 floods are illustrated in Figure 4. As obviously seen from the figure, there are residential and industrial areas in the studied region which are significantly affected by flood disaster.

Flood depths for each return period were illustrated in Figure 5. The maps clearly demonstrates that when Q10 flood happens, the maximum depth is 6.2 m and affected area is approximately 30% (according to the urban area) in the downstream of the Mert River and the maximum depth and flooded area, respectively, increase to 7.6 m and 60% in the case of Q100 flood. This indicates the flatness of the study area. Concerning the quantity of affected residential area, 650 housings were affected by the 10-year event. This increases to 780, 840, and 960 housings in the case of Q25, Q50, and Q100 floods, respectively.

2012 flood where loss of life and property occurred was also simulated in the present study. Flood hazard map and a photograph indicating a flood instant are outlined in Figure 6. It is clear from the figure that the influenced area is approximately 30% like the Q10 flood. The greatest hazards occur on the right side of the river which is mostly covered by industrial area. The flood magnitude alters a little on the left side of the river and the water reaches just a small number of houses near the river bank. It is clear from the hazard map prepared according to the 2012 flood which appeared in Figure 6 that the maximum depth is around 1 and 1.9 m in the residential area. A flooded building demonstrates that the water level in this area increased to 1–1.5 m when 2012 flood occurred. 619 housings were affected by the 2012 flood. This indicates that the simulation results obtained in this study correspond to the real flood hazard.

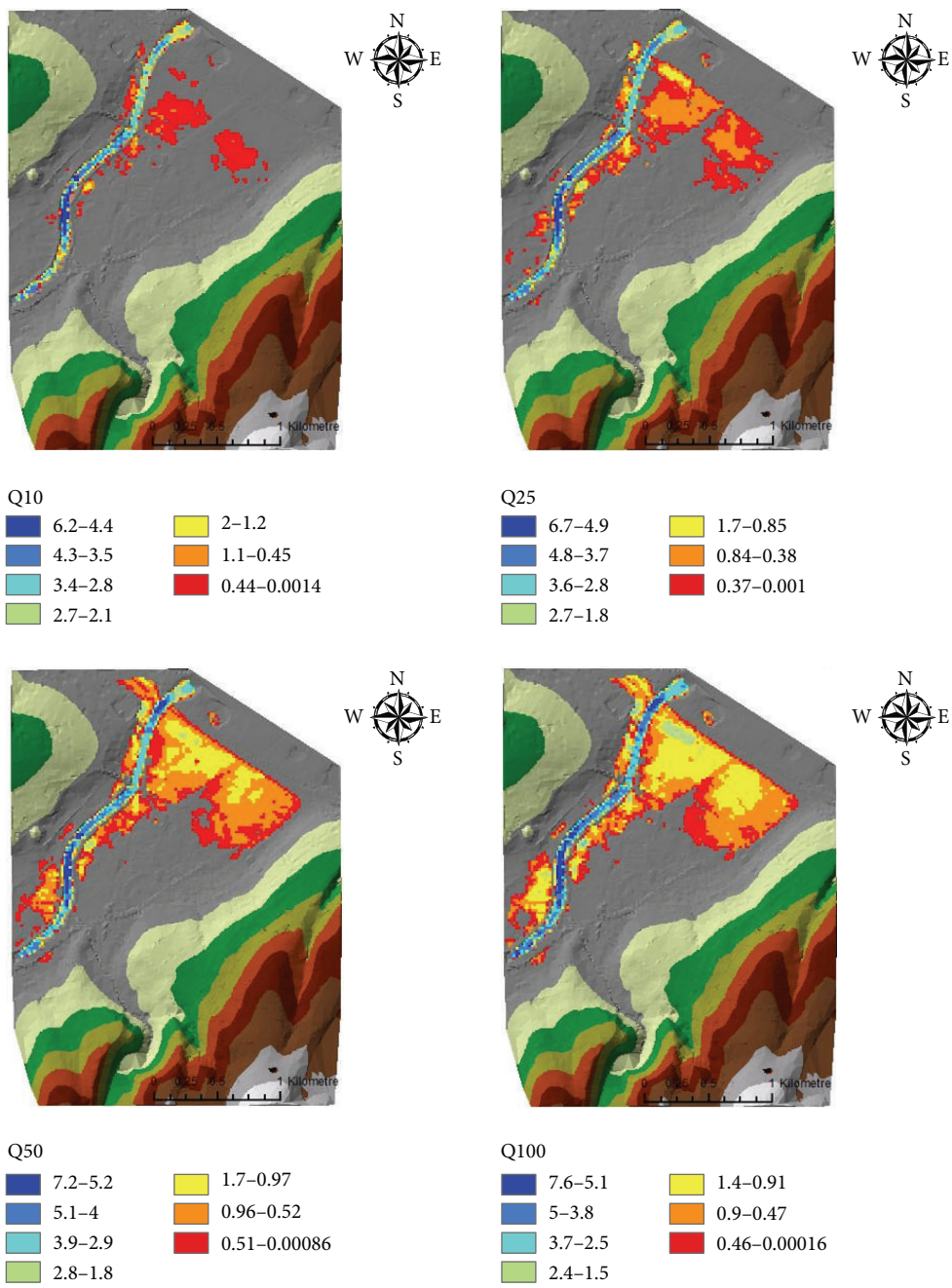

Figure 5: Water elevation maps of the studied area for the Q10, Q25, Q50, and Q100 floods.

Flood of July 3, 2012, demonstrated that some areas (traffic roads and buildings surrounding the Mert River) are highly affected even though they have a low recurrence period (close to Q10). The flooded area is located in downstream of Mert River and includes industrial region and residential buildings. It ought to be noticed that the buildings are placed near watercourses. All these indicate a deficient urban planning which results in occupation of river and/or natural flooding areas [22].

The analyzed cross sections of Mert River and flooded area in the case of 2012 flood are represented in Figure 7. The flood impact additionally appeared for the selected section (red line) in this figure (see Figure 7(a)). Figure 7(b) shows the prevention of flood by adding levee and regulation of river bottom. Dotted line in cross section indicates the swell height of the flood.

For the duration of an intense storm, real-time analysis includes using observed rainfall or gauged stage upstream as input for hydrologic modeling, utilizing output flow rates to hydraulic modeling, and finally mapping the output (flood hazard mapping) by a GIS program. Then, this information is utilized to manage flood warning activities such as voidances and road closures. However, the stream velocities are usually too great during a flood to make the flood hazard mapping

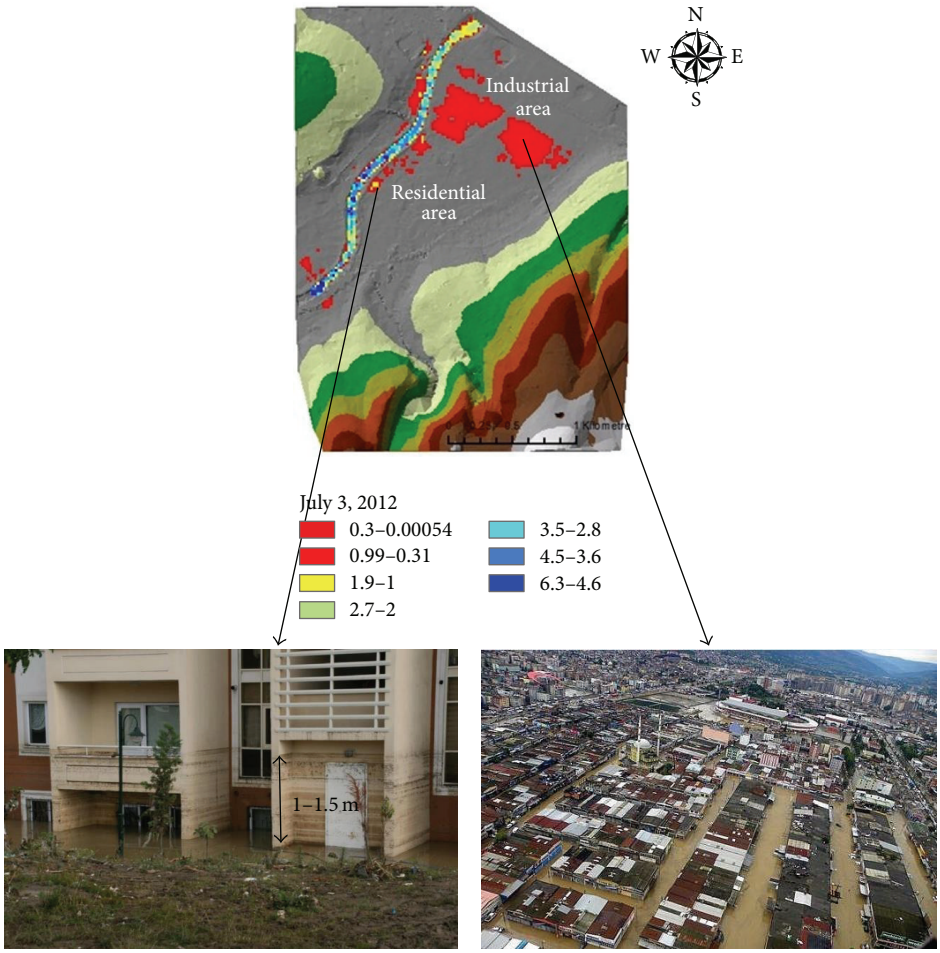

Figure 6: Flood hazard map and a photograph indicating the flood instants in industrial and residential area for the flood of July 3, 2012 [1, 24–26].

practical. For solving this problem, the flood hazard mapping procedures employed in this study may be utilized to prepare a series of flood hazard maps taking into account diverse return periods. In the duration of an intense storm, the flood warning controller can choose the most appropriate digital flood hazard map that corresponds most closely to the real-time measured stream flow [23].

Numerous existing flood hazard maps require revision since they are outdated. The flood hazard mapping outlined in this study saves time and money versus traditional flood hazard delineation on paper maps. By this way, flood hazard maps can be regularly updated as variations in hydrologic and hydraulic conditions warrant [23].

4. Conclusions

Flood hazard mapping of Mert River Basin, Samsun, Turkey, was investigated using GIS and HEC-RAS in this study. 3D hazard maps were obtained for the Q10, Q25, Q50, and Q100 floods. The flood maps demonstrated that some areas are highly affected from flood for low return period (Q10) event. Through Q10 flood, the maximum depth reached 6.2 m and affected area was approximately 30% in the downstream of the Mert River. In addition, 650 housing were affected by this flood. All these indicated an insufficient urban planning in this area. Significant floods occurred for the 100-year return period on the downstream of the Mert River and three bridges out of five remained under flood. Flood hazard map of the 2012 flood where human life losses and a significant amount of property damages were experienced was additionally prepared utilizing GIS and HEC-RAS programs. The simulation results of the Q10 and 2012 floods were compared with each other and similarity was found between them. The studied area generally covers industrial and residential areas. It was seen that floods can be prevented in this region by adding levee and regulation of river bottom. Otherwise, the majority of this flooded area ought to be forested and/or kept as park area.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

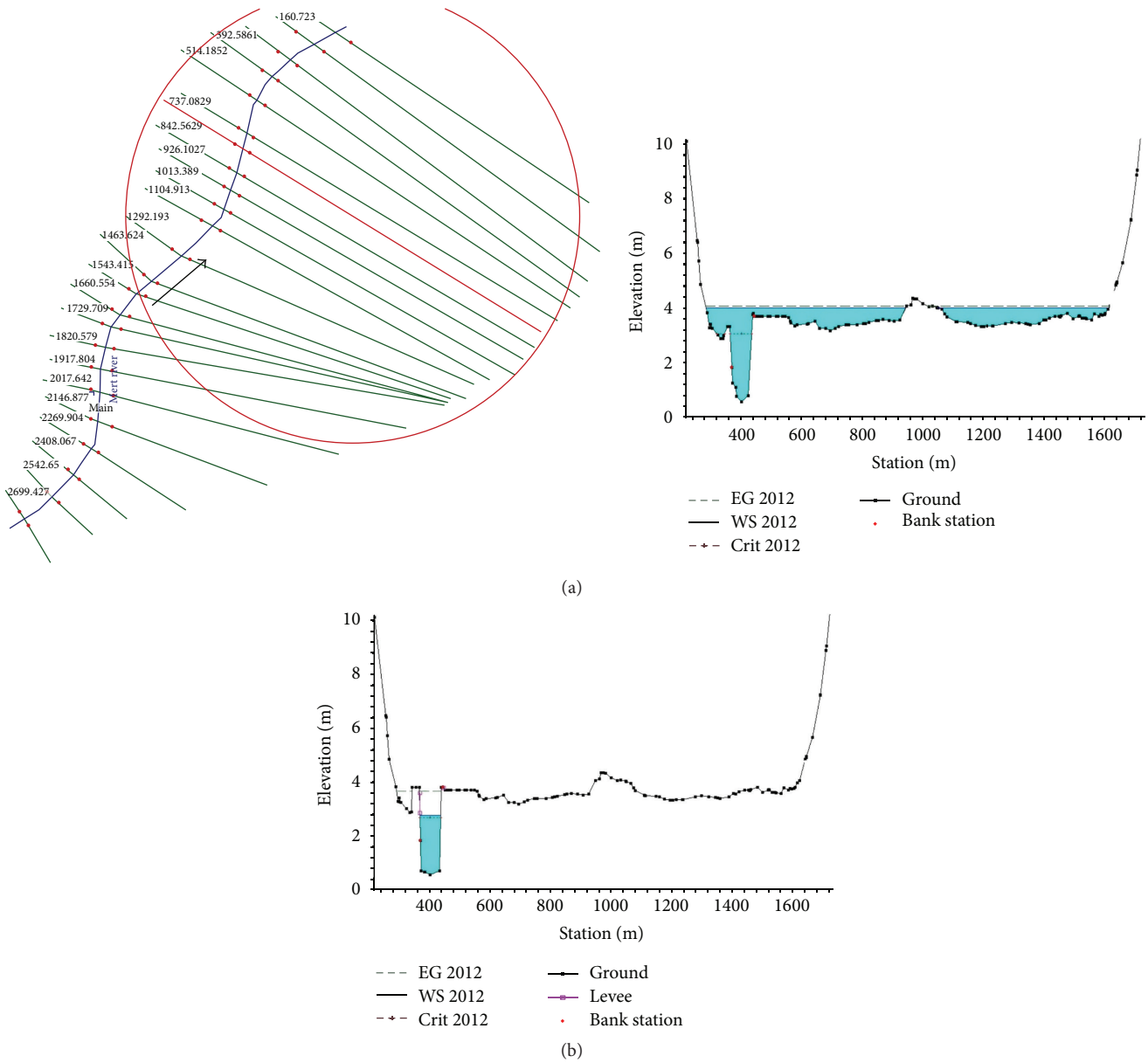

Figure 7: The analyzed cross sections of Mert River and flooded area in the case of 2012 flood: (a) flood effect for the selected section; (b) prevention of flood by adding levee and regulation of river bottom.

Acknowledgment

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