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Numerical modeling of Samsun Mert River floods

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Abstract: Floods are considered one of the most important natural disasters after earthquakes in Turkey. As a result, there is currently great public interest in this issue and it is necessary to intensify research activities in order to understand natural disasters better and to reinforce risk management. The effect of climate change on meteorological events causes an increase in extreme events such as excessive precipitation in some regions. An extreme natural event becomes a disaster when it has a large impact on human settlements and activities. Study area Samsun city is placed in the north of Turkey in the middle of Blacksea region where Kizilirmak and Yesilirmak rivers poured deltas. Samsun with a height of 735 mm mean annual precipitation is above the national average. Samsun is exposed to flooding every two to three years. In this study, flood risks of Samsun Mert river downstream area determinate with numerical modeling method. Numerical analysis has become the most basic tool recently used in modeling floods. Numerical model selection for studies provides advantages in developing and changing the solutions with time. Hydrological models were also created corresponding to 100 and 500 year return period floods. 1D and 2D hydrodynamic modeling was created with MIKE powered by DHI software; MIKE 11 and MIKE 21.

Key words: Flood modeling, MIKE 11, MIKE 21, Samsun, Turkey

1. INTRODUCTION

In recent years the economic damage from flooding has greatly increased due to rapid urbanization coupled with possible climate change impacts. The Intergovernmental Panel on Climate Change (IPCC) special report on managing the risks of extreme events and disasters emphasized that continuation of the observed Earth warming would change the frequency, severity and spatial pattern of climatic extremes (Field and Ed 2012; Cheng et al. 2014). The effect of climate change on meteorological events causes an increase in extreme events such as excessive precipitation in some regions. Extreme rainfall increases the influenceability against floods and causes extra stresses on infrastructure systems.

Nowadays flood inundation maps are essential for urban planning, urban renewal, disaster insurance rates, urgent action plans and environmental protection. Inundation maps depend on the numerical solution of shallow depth flow equations using topographical data, cross-sections along the channel and the discharges having different return periods. The flood problem is not a recent issue neither for Turkey nor for other countries. Therefore, the need for the flood protection and flood management are not new too (Akyurek et al. 2015).

Numerical analysis has become the most basic tool recently used in modeling floods. Numerical model selection for studies provides advantages in developing and changing the solutions with time. Therefore, changes in the model conditions, such as riverbed rehabilitation or structural adjustments, affect model result accuracy directly since flood model represents the present situation of the river and the study area.

Hydraulic modeling of floods is affected by many uncertainty sources like input data, model structure, model parameters etc. Besides several factors in each source of uncertainty affect the flood modelling process and mapping results that increase or decrease the uncertainty of outcome (Papaioannou et al. 2016). There are many studies in literature about flood modelling and flood mapping (Ahmed 2010; Webster et al. 2014; Delaney et al. 2015; Papaioannou et al. 2016).

The aim of this study is to modeling of Mert River floods and to obtain flood inundation maps for floods of different return periods.

2. STUDY AREA

Study area Mert River is located in the center of Samsun shown in Figure 1. The geographic location of the study area is between Latitude 41.279 and Longitude 36.352. The Mert River, which is about 7.0 kilometers long, flows into the Black Sea. There are six highway bridges and a pedestrian bridge over the river. First three bridges are located in the Black Sea coastline and provide transport between cities. Structural features of the bridges are given in Table 1. In July 2012, the city of Samsun experienced important flooding, shown in Figure 2012. Mert River flooding occurred over a majority of the study area; impact on transportation networks and other technical infrastructures, damaging homes, displacing residents, and taking lives (Ulke et al 2013). There is the E22A062 Corak Gaging Station on the Mert River with a 740 km^2 precipitation area and average annual total discharge value for the 2007-2012 period is 137,59 hm^3. The selected watershed maximum precipitation is 70.8 mm in November, the minimum precipitation is 29.4 mm in August, and the annual average precipitation is 674.8 mm. Flood values of different return periods and annual instant maximum flows that calculated with SCS unit hydrograph method obtained from the Turkish General Directorate of State Hydraulic Works and given in Table 2. Also manning roughness coefficients that computed by Cowan’s method (Cowan, 1956), are obtained from the Turkish General Directorate of State Hydraulic Works.

3. METHODOLOGY

3.1 MIKE 11 – One-Dimensional hydraulic model

MIKE 11 is a professional engineering software package for the simulation of flows, water quality and sediment transport in rivers, channels and other water bodies. MIKE 11 HD applied with the dynamic wave description solves the vertically integrated equations of conservation of continuity and momentum (the ‘Saint Venant′ equations). The solution of the equations of continuity and momentum is based on an implicit finite difference scheme developed by Abbott and Ionescu (1967) (DHI 2016a). Hydraulic structures (*e.g.* bridges, weirs, culverts) are defined with MIKE 11 and flow above that structures can be calculated. The equations of continuity and momentum, as used by MIKE 11 are presented Equations 1 and 2.

$$(dq/dx)+(dA_{fl}/dt) = q_{in} \quad (1)$$

$$(dq/dt)+(d\,(\alpha q^2/A_{fl}))/dx+gA_{fl}(dh/dx)+(gq|q|)/(C^2A_{fl}R) = 0 \quad (2)$$

In these equations the meaning of the notations are; A; flow area (m^2), q; lateral flow (m^2/s), h; depth above datum (m), C; Chezy resistance coefficient ($m^{1/2}/s$), α; momentum distribution coefficient, x; Cartesian coordinates, g; acceleration due to gravity (m/s^2).

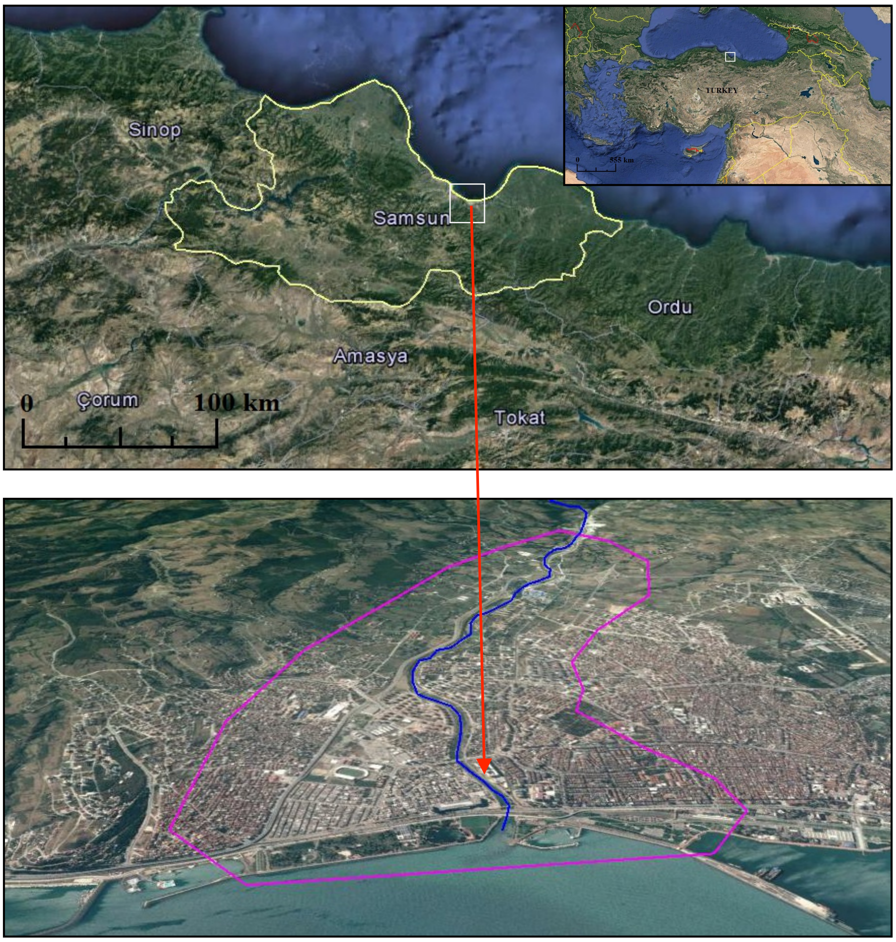

Figure 1. Study area.

Table 1. Bridges on Mert River

Km (from downstream)	Code	Upper elevation	Bottom elevation	Bridge deck thickness(m)
0+260	(C1)	4.05	2.35	1.70
0+300	(C2)	3.50	2.50	1.00
0+350	(C3)	3.80	3.00	0.80
0+400	(C4)	4.00	3.10	0.90
1+000	(C5)	7.00	5.40	1.60
1+800	(C6)	5.90	4.40	1.50
2+150	(C7)	14.70	13.50	1.20
4+500	(C8)	21.40	19.90	1.50

Table 2. Flood values of different return periods of Mert River.

Return Periods	5	10	25	50	100	500	1000	10000
Discharge (m^3/s)	296.0	441.3	552.3	719.4	863.9	1029.1	1453.3	2660.0

3.2 MIKE 21 – Two-Dimensional hydraulic model

MIKE 21 Flow Model FM is a new two-dimensional modeling system based on a flexible mesh approach for free surface flows. The Hydrodynamic Module is the basic computational component of the entire MIKE 21 Flow Model FM modeling system. The Hydrodynamic Module is based on the numerical solution of the two-dimensional shallow water equations - the depth- integrated incompressible Reynolds-averaged Navier-Stokes equations. Thus, the model consists of continuity, momentum, temperature, salinity and density equations. In the horizontal domain, both Cartesian and spherical coordinates can be used. However, being a general modeling system for 2D and 3D free surface flows it may also be applied for studies of inland surface waters, e.g. overland flooding and lakes or reservoirs (DHI 2016b).

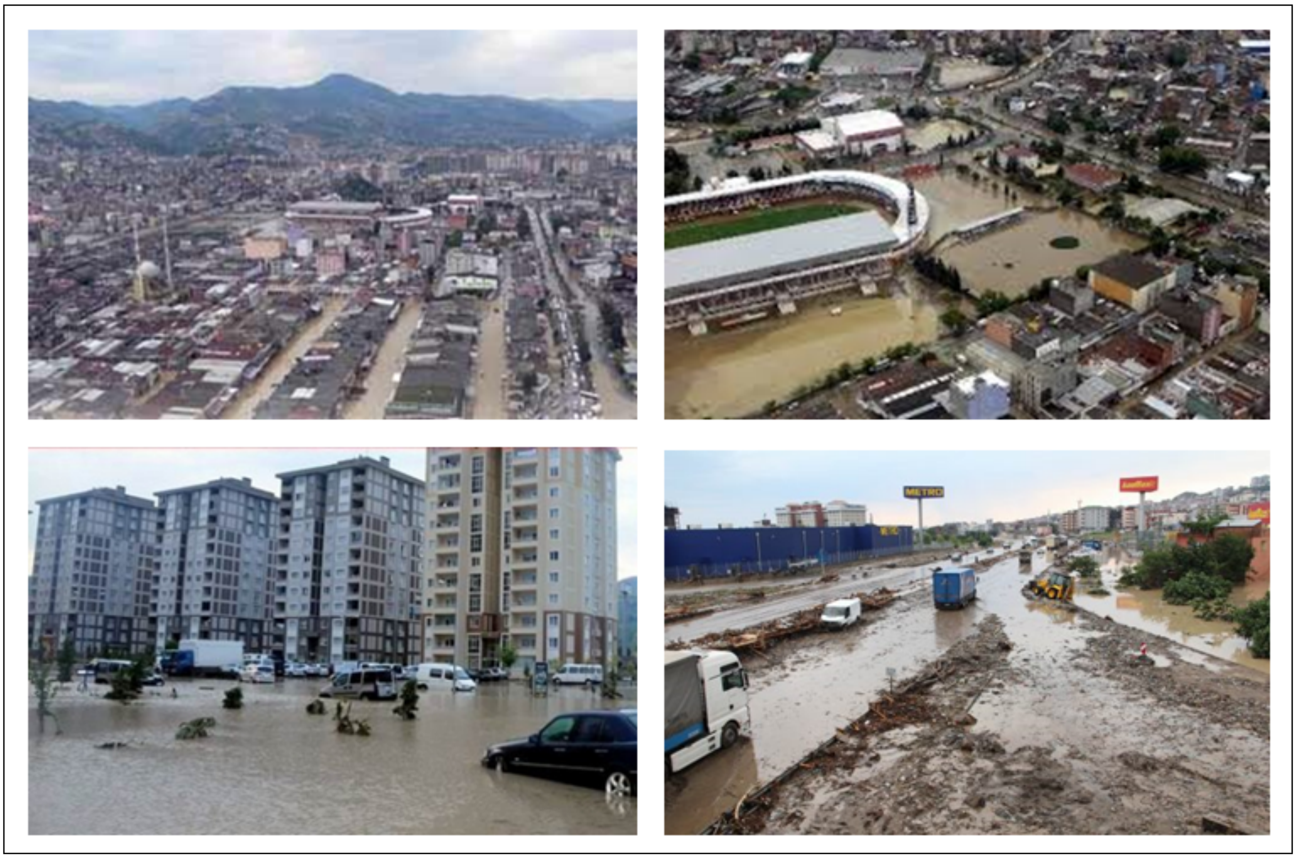

Figure 2. 2012 Samsun flood disaster

4. APPLICATION

4.1 Mapping

The required digital elevation model (DEM) was created from 1/1000 scale topographical contour lines and supported with the field measurements at the study area. The obtained (x, y, z) point values were used to create a combined DEM. Bathymetry term is used for the DEM as a model map of MIKE (Bozoglu 2015).

4.2 1D modeling

In this study flood analysis carried out along the river line with the networks created both structured and unstructured. The river cross-sections have been created every 50 m. Considering the location of structures and topography of river, the sections have been taken in 20-30 m intervals in some places. For 7013 m river network, 150 cross-sections have been generated. The capacity of the river banks was evaluated with one-dimensional model.

4.3 2D modeling

MIKE 21 model compares model inundation on study area with different discharge volumes. 2D model inputs are; bathymetry of the area, defined input and output discharge points, Manning's roughness coefficient, boundary conditions and some other default calculation effects (density, viscosity, precipitation etc.) MIKE 21 FM is a flexible mesh model and uses triangular mesh for model calculations. DEM was transformed to flexible mesh with Mesh Generator interface in MIKE. Triangular mesh for the model was created from these elevation values. With flexible mesh, variable sized elements can be defined for multiple parts of the maps. Thus variable sizes of mesh elements provide advantages for modeling. The riverbed was created with small area size quadrilateral compared to the remaining parts.

5. RESULTS

5.1 MIKE 11 model results

The flow rate according to the results of one-dimensional model tends to spread over the urbanized regions beyond the floodplain. Since the model to be used for the solution purposes is 2D modeling. Structured and unstructured results of Mert River profile for Q100 and Q500 discharges are shown in Figures 3 and 4. As shown in Figure 3(b) and 4(b), structures attenuate the cross sections and increased the water level during both the discharges of Q100 and Q500.

The flow rate according to the results of one-dimensional model tends to spread over the urbanized regions near the floodplain. Here result in maps of Q100 and Q500 maximum water depth with structures and without structures, Figure 5.

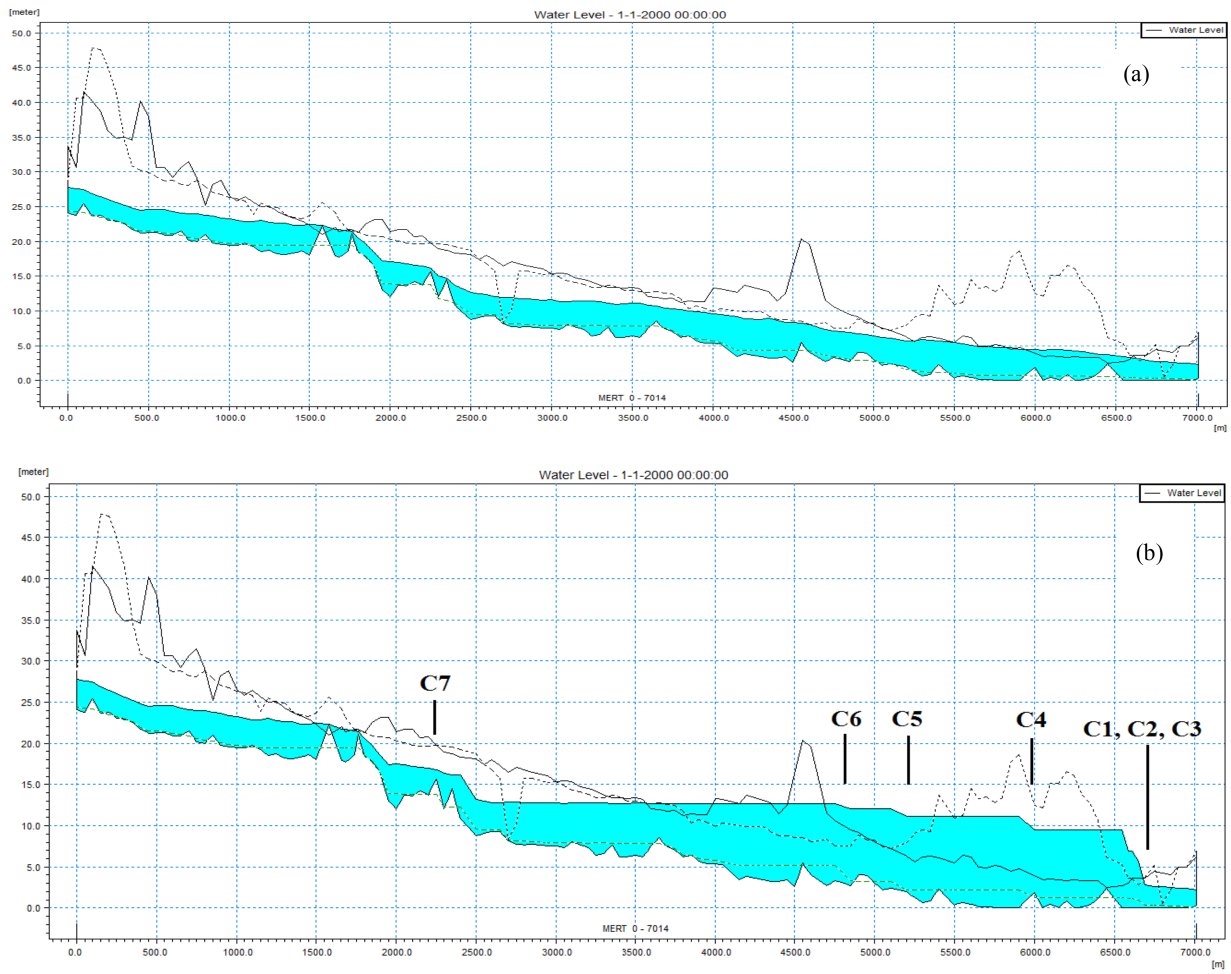

Figure 3. River profile for Q100 (a) without structures, (b) with structures

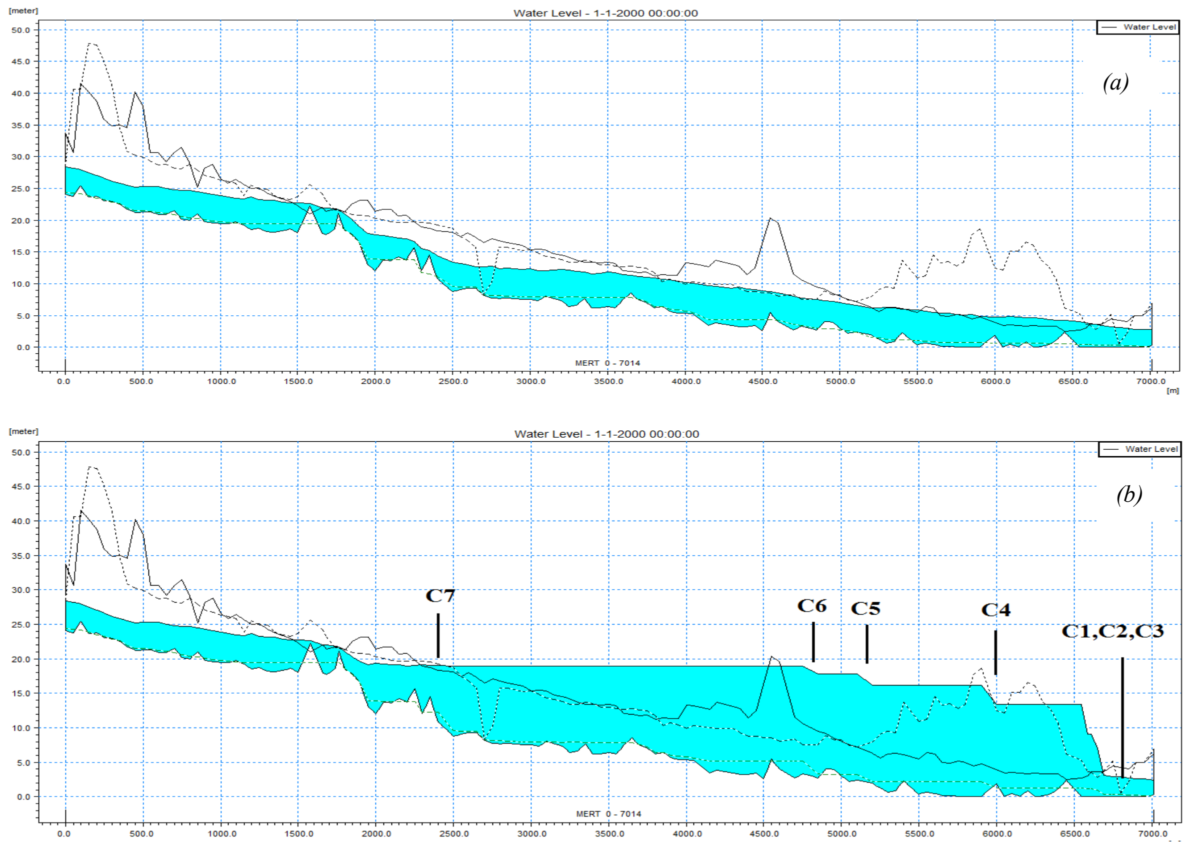

Figure 4. River profile for Q500 (a) without structures (b) with structures

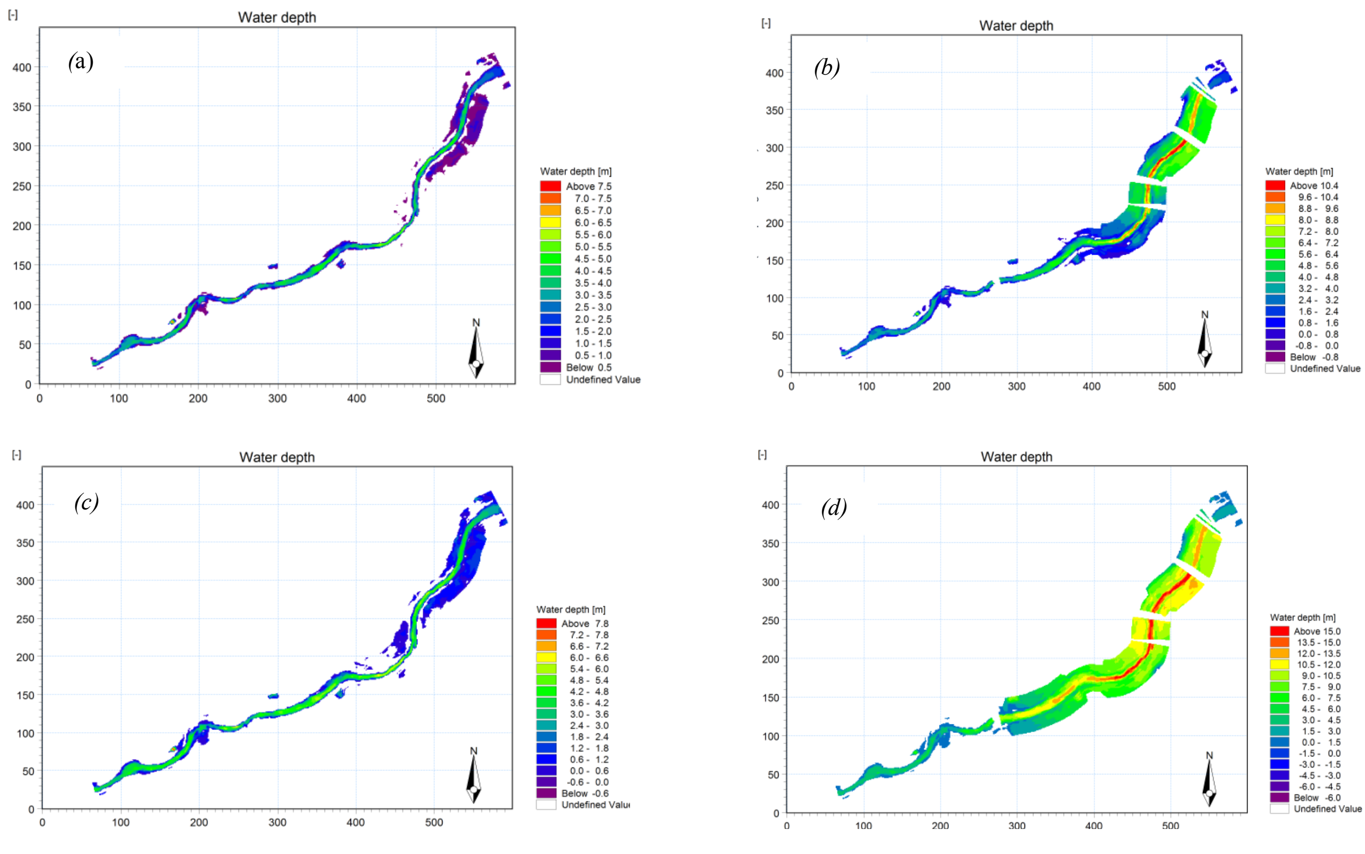

Figure 5. 1D results for Q100 maximum water depth ((a); without structures, (b) with structures), for Q500 maximum water depth ((c); without structures, (d) with structures)

5.2 MIKE 21 model results

The cross-sections along the river do not pass the Q100 and Q500 discharges in the one-dimensional hydrodynamic model. If water levels overcome river banks, one-dimensional hydrodynamic model perceives water as a water column and elevates the water column along the defined sections. In this case, one-dimensional model become meaningless, therefore a two-dimensional model should be used to shown flood inundation in the study area realistically.

2D model's output flood inundation map for Q100 and Q500 are seen in Figure 6. The figures show that study area is under threat of flood disasters. It is expected that downstream of the Mert River where the industrial area is located will suffer great damage from floods.

It is clear that the results obtained in 2D studies are more detailed than 1D study results. One dimensional model applicable for river channels, floodplains, however, two-dimensional models running entire boundaries that user choose.

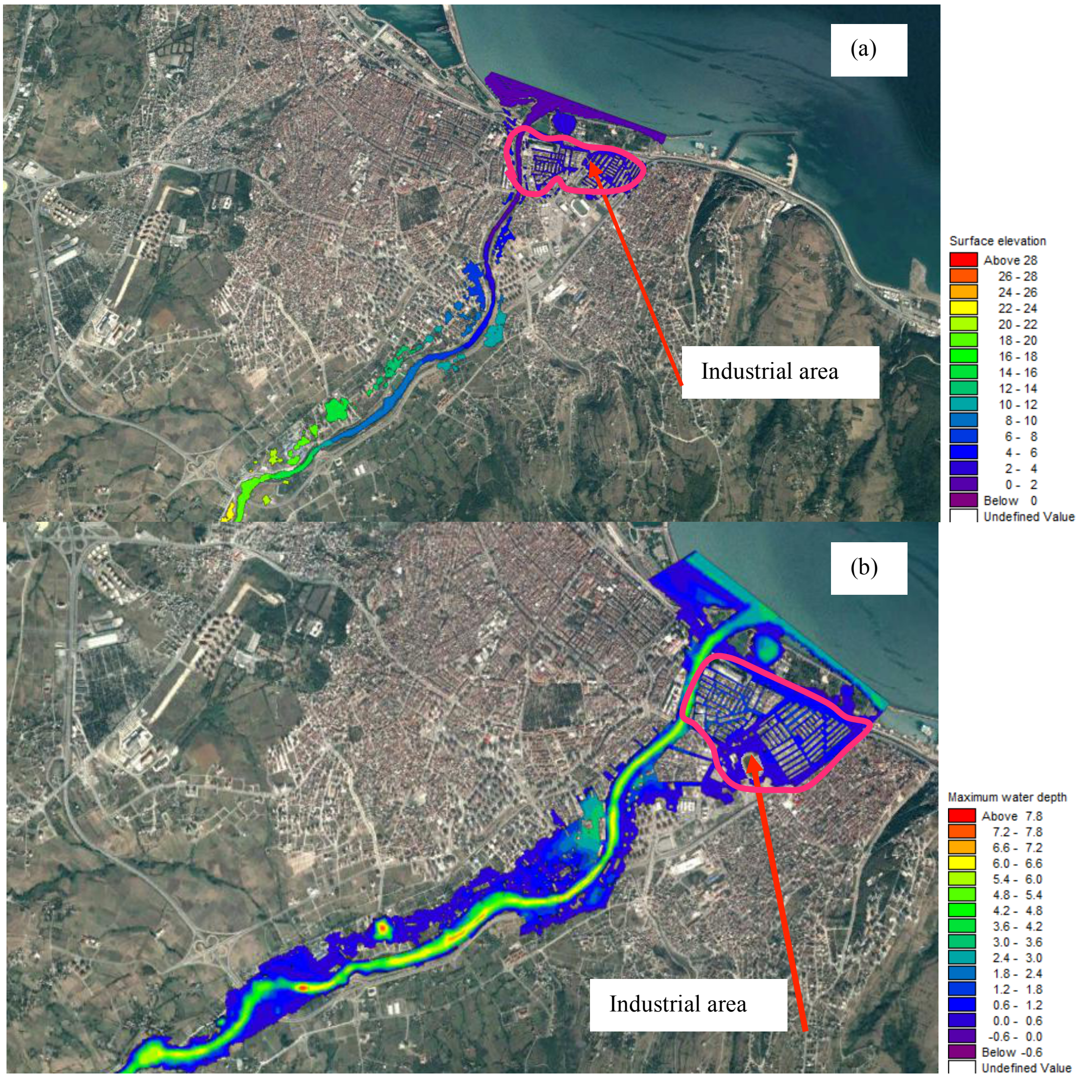

Figure 6. 2D results on study area (a) Q100 maximum water depth (b) Q500 maximum water depth

6. CONCLUSIONS

The flood inundation maps demonstrated that some areas, from the upstream to downstream of the Mert River basin, are highly affected from 100 year and 500 year return period events. Through Q100 discharge, the maximum water depth reached 7.25 m and affected urban area was approximately 60 % in the downstream of the Mert River. In addition, over 1000 buildings were affected by this flood. The largest inundations are seen in the industrial area at the right side of the river. There isn't a certain measurement for Mert River at 2012 flood hazard. The recent and recorded event that caused damage in the Mert River was the flood event that took place on 1967. At this time there wasn't a field measurement about the fill rate of the river or the flood marks at the reference structures, therefore the model calibration cannot be carried out preferred. Also; there have been many changes that affect the inflow on the land, and interventions have been made in the floodplain. All these factors are taken into account, there is no valuable data available for model calibration from past flood reports. Limitation of this study is the calibration of the models.

As a result, in order to ensure safety during the floods that may occur in the study area, there must be taken preventive precautions. Sand accumulations should be cleaned periodically to prevent the rise of thalweg level in downstream where the river merged with the sea. Especially since the first four bridges negatively affected the water profile in one-dimensional model, existing bridges should be reviewed. Sediment accumulation, environmental wastes and excavation wastes along the riverbed may cause detention of inflow. Thus the riverbed should be cleaned. With all that upstream master plans should be an overhaul for Mert River basin.

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