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COMPARISON OF 2D HYDRAULIC MODELS FOR FLOOD SIMULATION ON THE MERT RIVER TURKEY

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ABSTRACT

As well as all over the world, Turkey exposures to floods more frequently as a result of climate change. The study area, Mert River is located in Samsun city north of Turkey and also frequently exposed to floods and flood management studies in the region are carried out in progress by local administrations. The aim of this study is to compare different hydraulic modeling methods on Mert River, mainly related to floodplain modeling. Therefore, different hydraulic models have been applied to the Mert River. Two types of 2D models are examined in this paper, these are respectively MIKE 21 and FLO-2D. In this study a comparison of the simulation results of models are performed. By these comparisons, the benefits and limitations of the models in flood forecasting are trying to show. The analysis of the results shows that there is a consistency between different 2D models and that the reliability of the results strongly depends on the sufficiency of the available data.

Keywords: Flood modeling, MIKE 21, FLO-2D.

INTRODUCTION

Flood disasters are the most important natural disaster succeeding the earthquakes. extreme precipitation, heavy populated areas, industrialization, unplanned urbanization along the river banks, debris fan, intense deposits on the river bed, rapid urbanization are the main causes of the floods. Also, it is expected that climate change will exasperate and accelerate the hydrological cycle. Thus, magnitude and frequency of future floods can increase (Kvocka et al., 2015). However, unplanned urbanization and failures in disaster management are main factors that turn floods into disasters. In order to minimize flood damage, analysis of the floods with various frequencies and determination of the inundated areas be carried out. Floods are not completely preventable, but if the flood-prone areas are known in advance, most of the damage can be reduced. Therefore, in order to reduce the loss of life and property in floods, it is necessary to estimate the water levels of river cross-sections for expected floods in urbanized areas (Sahoo and Sreeja, 2015). Also, the estimation of the flood inundation locations is very essential for development of insurance maps of risk assessments and effective management plans for reducing future flood risk.

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Flood inundation mapping and identifying the flood risk zones are primary steps for formulating any flood management strategy (Patel et al., 2017). Understanding the effects of flood inundation in terms of area, depth and time is mandatory for efficient flood risk management. 1D modeling approaches could be useful mainly for artificial channels however it has limitations for overflow analysis (Srinivas et al., 2009). In situations such as overflowing of water from the channels, 1D models become meaningless. Then it becomes a 2D phenomenon and the use of a 2D model is more suitable. Also, model type selection in flood modeling depends on many aspects. These aspects are mainly the catchment area and both spatial and temporal data availability.

In this study, Mert river floods are modeled by using 2D numerical models. There are many studies in the literature comparing various flood models. Hunter et al. (2008) described benchmark testing of six two dimensional (2D) hydraulic models (DIVAST, DIVASTTVD, TUFLOW, JFLOW, TRENT and LISFLOOD-FP) in terms of their ability to simulate surface flows in a densely urbanized area in their study. Banks et al. (2014) presented a review of currently available flood damage assessment tools and their abilities. Crispino et al. (2015) discussed a comprehensive comparison between 1D and 2D modelling of floods in meandering channels, to guide practitioners in the confident choice of a tradeoff between complexity and accuracy.

Tools that model flood inundation and perform damage assessment have historically been directed at planning for disaster response or developing flood insurance rate maps (Flo-2D Software, 2012; FEMA, 2008, Banks et al., 2014).

The comparison of 2D hydraulic models for simulating flash floods over the Mert River is the aim of this study. For this purpose, the dynamic behavior of Mert River in Turkey was modelled by using numerical analysis of advanced modelling tools; MIKE 21 FM and FLO-2D. Hydraulic modelling consists in simulating the river flows. The two-dimensional modelling includes a significant improvement in calculating hydraulic variables and also the delineation of flood zones.

CASE STUDY AREA AND DATA USED

Mert River (41.279 latitude and longitude: 36.352 coordinates) located in the district of Samsun Canik and Ilkadim and to the Middle Black Sea was selected. Figure 1 shows the study area. The Mert River has an important place in terms of drinking and irrigation water provided to Samsun through its history. This river has a total of six bridges, including a 5-divided road bridge and a pedestrian bridge. The first, second and third bridges of the Mert River are located on the coast of the Black Sea and are used for intercity road transportation. The fourth and fifth bridges are built on the Mert River and are used for road transport between Canik and Ilkadım districts (Demir, 2015). Mert river has a 740 km^2 precipitation area. 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. Flow discharges for different return period floods are obtained from State Hydraulic Works Samsun Office and given in Table 1. Manning roughness coefficients are obtained with field surveys. Values of 0.022, 0.026, 0.045, 0.030 were used for concrete, bush-wooded and woodland for river banks respectively and 0.03 for the river bed (Chow, 1959). 1/1000 scale topographic map which improved with field surveys has digitized and used in this study as a base map.

Mert river flooding occurred on 3 July 2012. This is preferred because it is a high level of loss of life and property. Mert river was chosen as the study area because of the flood disasters that happened in the past. In 4.7.2012, an extreme flood disaster occurred in Mert river (Figure 2). With this event, especially the industrial zone took a severe economic damage and 10 people lost their lives as a result of the inundated basements. Discharge of flood was measured 570 m^3/s by State Hydraulic Works in 04.07.2012. Flood models are calibrated with 2012 flood event discharge value and watermarks at the study area.

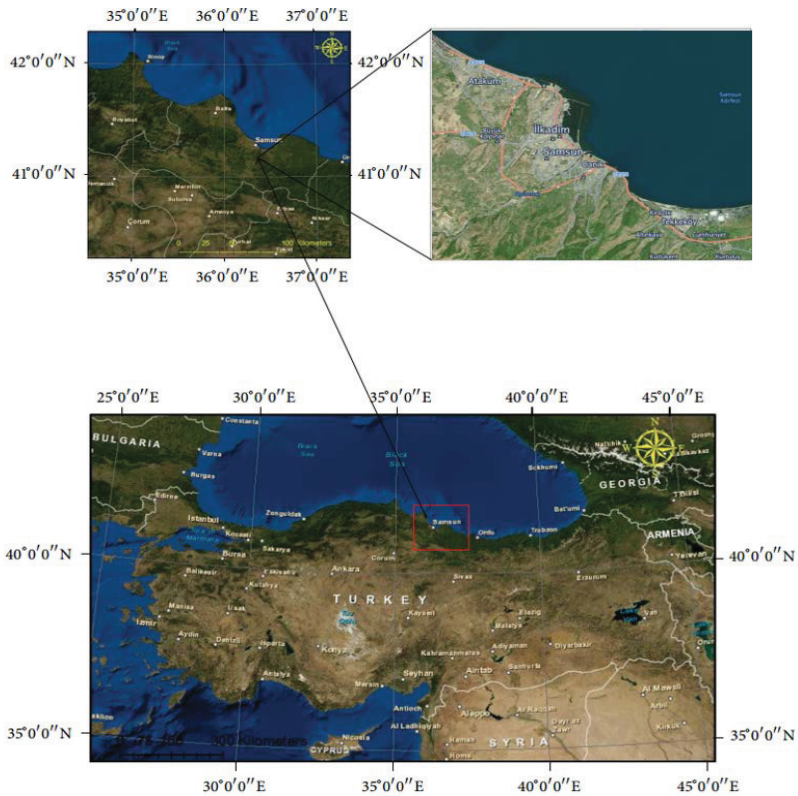

Figure 1. Study area, Google-Earth Images

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

Return Periods	5	10	25	50	100	500	1000	10000
Discharge (m^3/s)	440.2	522.3	719.4	863.9	1029.1	1453.3	1722.4	2660.0

Figure 2. 2012 Mert river flood

FLOOD MODELING

Two-dimensional flood inundation models have become an integral part of flood risk assessment in both urban and rural areas, providing a means of converting catchment discharge into inundation extent, depth and in some cases flow velocity. These models vary in complexity from solutions of the two-dimensional shallow water equations to storage cell models based on Manning's equation (Neal et al., 2010).

MIKE 21 FM

MIKE 21 Flow Model FM is a two-dimensional modeling system which based on a flexible mesh approach. Model is suitable for free surface flows. MIKE 21 has a basic computational component Hydrodynamic Module. 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, 2016; Ulke et al., 2017). In base of MIKE 21 HD, continuity equation write as follows;

$$\frac{\partial s}{\partial t}+\frac{\partial}{\partial x}Uh+\frac{\partial}{\partial x}Vh=F_s \tag{1}$$

$$\frac{\partial s}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}+g\partial_x s+\frac{g}{C^2 d}U\sqrt{U^2+V^2}+\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial U}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial U}{\partial y}\right)=F_s \tag{2}$$

$$\frac{\partial s}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+\frac{\partial s}{\partial x}+\frac{g}{C^2 d}V\sqrt{U^2+V^2}+\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial V}{\partial y}\right)=F_s V_s \tag{3}$$

In Equations 1-2 and 3 definitions are; s: height, h: water level, U and V are the notations of the depth averaged velocity components of Cartesian, C: the Chezy component, Kxx and Kyy: the eddy viscosity, F: source term, and Vs and Us: the velocity components at the source. The program has a toolbox for flood damage assessment that integrates with ArcGIS, which can calculate damage per unit area in any specified currency. However, the user must supply specific depth–damage estimates for various land uses (Banks et al., 2014). Training is available for both urban and river applications of MIKE powered by DHI softwares. Each course costing €1,050 (DHI, 2018). MIKE Flood license fees begin at $18,500 (Banks et al., 2014).

FLO-2D

FLO-2D is one of the package programs produced and developed by O'Brien for 2D hydraulic models. FLO-2D is widely used in flood models made in recent years. The program models the flow of water depending on time (O’Brien, 2006). FLO-2D, a commercial software, is a program that simulates the flow of sludge and rubble with finite difference methods based on second-order rheological conditions. FLO-2D is a finite volume model, including Herschel-Bulkley (HB) rheology, which represents a viscous fluid. This rheological model can model the rubble flow of muddy type with sufficient clay content (Hsu et al., 2010). FLO-2D is a dynamic flood-displacing model that can simulate river and surface flows. The model solves the full dynamic wave momentum and continuity equations (Equation 4-8) for square grid elements using the finite difference method. Thus, the two-dimensional propagation of the flood wave in the grid elements system is calculated (Elci et al., 2017).

$$\frac{\partial U}{\partial t}+\frac{\partial F}{\partial x}+\frac{\partial G}{\partial y}=S \tag{4}$$

$$U=\begin{bmatrix} h \\ h_u \\ h_y \end{bmatrix} \tag{5}$$

$$F=\begin{bmatrix} h \\ h_{uu} \\ h_{uv} \end{bmatrix} \tag{6}$$

$$G=\begin{bmatrix} h \\ h_{uv} \\ h_{vv} \end{bmatrix} \tag{7}$$

$$S=\begin{bmatrix} 0 \\ -gh\dfrac{\partial Z}{\partial x}-g\dfrac{n^2u\sqrt{u^2+v^2}}{h^{\frac{1}{3}}} \\ -gh\dfrac{\partial Z}{\partial y}-g\dfrac{n^2v\sqrt{u^2+v^2}}{h^{\frac{1}{3}}} \end{bmatrix} \tag{8}$$

In Equations 4-8 definitions are; h: flow depth; u: velocity x direction; v: velocity y direction; g: acceleration; Z: water surface elevation, n: Manning roughness coefficient. (Tayfur, 2017; Ying et al., 2009). The single-user license price of the program is at \$3495. Also, RiverFlo-2D is capable for hydrodynamic modeling of river and can be purchased for \$3950. FLO-2D has online courses which has a cost that ranging from \$50 to \$200. Course prices depends on to the course duration, location, and course type. (Banks et al., 2014).

RESULTS

The results of both MIKE 21 and FLO-2D models are given side by side in Figure 3-5 for Q100, Q500 and Q1000 respectively.

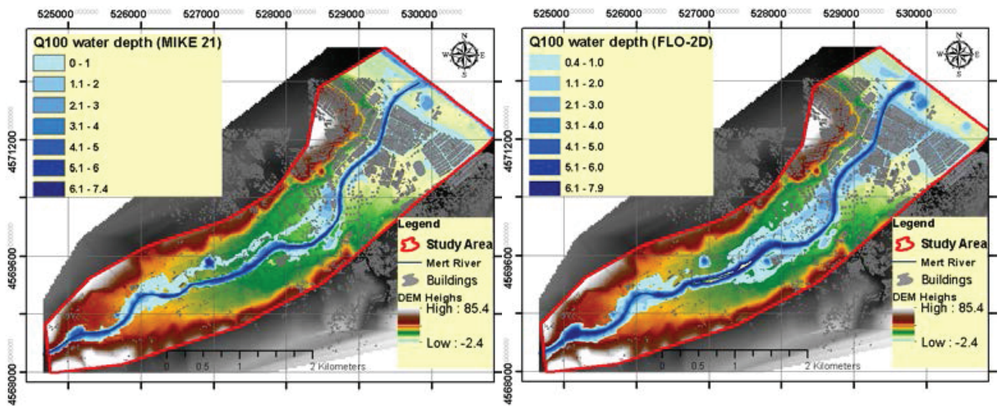

Figure 3. Water depth results for Q100 for MIKE 21 and FLO-2D

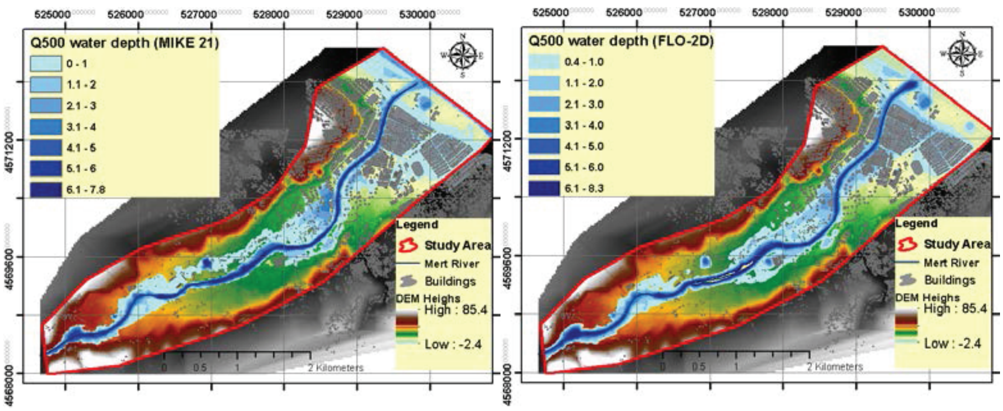

Figure 4. Water depth results for Q500 for MIKE 21 and FLO-2D

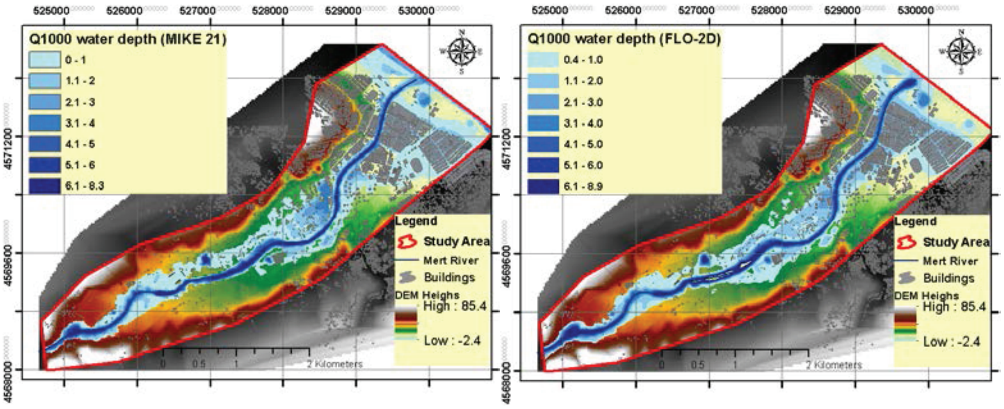

Figure 5. Water depth results for Q1000 for MIKE 21 and FLO-2D

The water depths and DEM (digital elevation model) are in meters. According to the results, the propagation areas are similar. There is a small difference between MIKE 21 and FLO-2D water depth results. Authors have used same boundary conditions in modeling phase which were flood hydrographs, base map, bed resistance, study area boundaries and initial conditions. In Figure 6 flood propagation areas of MIKE 21 and FLO-2D results are shown with superpositioning respectively. Information on flood exposed areas is given on the Table 2.

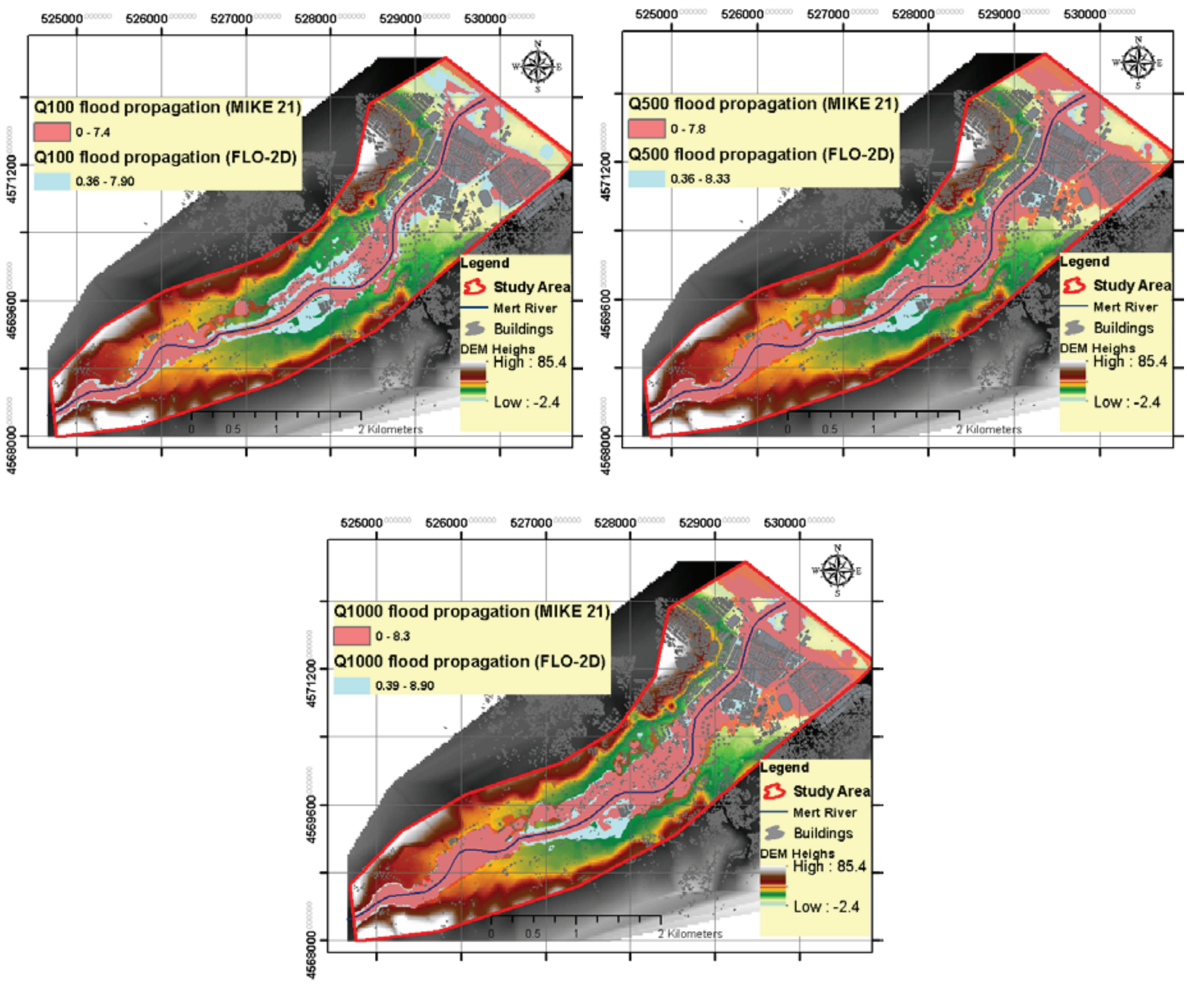

Figure 6. Flood propagation comparisons of MIKE 21 and FLO-2D results

Table 2. Flood propagation areas (km^2)

	Q100	Q500	Q1000
MIKE 21	2.75	3.10	3.50
FLO-2D	2.81	3.26	3.67

The FLO-2D propagation areas of Q100, Q500 and Q1000 discharges are 2.1%, 5.2%, and 4.8% higher than that of MIKE 21, respectively. At water depths, there is about a 0.5 m difference between the two model results.

CONCLUSION

Numerous models have been developed for numerical analysis of floods. A major part of them is the computer software which is widely used in literature. In this study Mert river which were exposed to floods frequently was selected as study area. Q100, Q500 and Q1000 discharges are modeled by two different flood model; MIKE 21 and FLO-2D. According to the results it is expected that future floods will suffer great damage to the study area. The obtained results are sufficient for this study however results have some differences. According to the authors, these differences may originate from the different mesh approaches of the selected models. Studies on this subject are underway. This paper is a part of a study which is developing by authors with more specific manner.

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