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Flood Risk Analysis of Residential Areas at Downstream of the Elmali Dam

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Abstract

One of the natural disasters that hurts humankind is the flood. This disaster consists of climate change, geotechnical and topographic features in the region. Floods are usually influenced by the interaction of catchment-specific characteristics, such as meteorology, topography, geology and lately climate change. In addition, human activities increase flood risks. The most important causes of flood disasters in the world are uncontrolled urbanization activities and interventions in river beds near floodplains. Researchers have scientifically proven a sharp global increase in the economic risk associated with floods though flood-related fatalities might be decreasing. The study area is located on the downstream side of the Elmali Dam built on the Goksu Creek in Beykoz District of Istanbul Province. In this study, the flood risk maps for floods that will be formed in Goksu Creek on the downstream side in the various discharge of the Elmali Dam spillway are prepared by modeling with 2D DHI MIKE 21 FM software. MIKE 21 Flow Model is a modeling system for 2D free surface flows. Also, the regions exposed to floods, the magnitude and risks of floods that will occur were evaluated with different scenarios. There were 4 scenarios in the study. As a result of the scenarios, the regions on the downstream side of the Elmali Dam are classified in terms of flood risk. The areas at risk are shown as flood maps. In the downstream area, the relation between flood flow and its area is observed linearly.

Key words: Flood, Risk analysis, Numerical model, MIKE 21.

1. Introduction

In Turkey and many countries, one of the major natural disasters which adversely affect their social and economic life such as people's life and property losses, is flood. Climatological-meteorological and geological-geomorphological features, vegetation and humanitarian interventions are among the main factors of the flood. The most important causes of flood disasters in the world are uncontrolled urbanization activities near to flood regions and interventions in river beds.

A deterministic approach is used by Mao et al. to calculate the hydraulic elements of the dam fracture. In addition, MIKE-21 dam breaking model is used to generate the hydraulic elements and generated hydraulic elements are integrated with a digital elevation model of the site downstream of the dam to map the possible affected areas. Simulation data and study results

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can provide a socio-economic framework for downstream areas and a basis for emergency management of the dam reservoir [1].

The subject of dam flooding potential caused a prolonged flooding was considered by Diman & Tahir. Although floods are less likely to occur from dams, understanding the dam flood routing map can preserve the lives and property of downstream residents [2].

Dat et al. use a 1D and 2D model of MIKE FLOOD to simulate downstream flood of Tra Khuc-Song Ve River basin, including the breakdown of the DakDrinh. The establishment of DakDrinh flood map shows flood areas and depth of its downstream. Results obtained by Dat et al., make it possible for managers to create preventable plans and provide information to reduce disasters in vulnerable areas in the event of failure [3].

Mohd Sidek et al used the Clear Day scenario and Probable Maximum Flood scenario for dam break modeling. Flood area, flood duration and maximum flood depth in the downstream are obtained by the Mike Flood model. This result will lead to the identification of the affected location or villages located at downstream of the Susu Dam [4].

Although there is a decrease in flooding that occurs as a result of an increase in dam, ponds and stream rehabilitation works in Turkey, according to DSI data, from 860 floods occurred in the last 40 years, 660 deaths and 799,758 hectares of agricultural land have exposed to flood. Thus, the annual damage that has been caused in Turkey's economy is about 150 million Turkish Lira [5].

The biggest reason for the losses caused by the floods in Turkey occurs as a result of settlements closing the stream bed. In this case, it will inevitably overflow from its narrowed bed due to the increase in the flow rate resulting from heavy rain, and flood the settlement in front of it to reach the sea [6].

In another study, the risks of flooding that may arise from the Havran dam were taken into account. Risk analysis was carried out according to the flood return period of streams, flood scenarios that will occur with dam overflow and possible dam destruction. As a result, losses based on dam scenarios were found more destructive than other flood scenarios [7].

Abdollahzadehmoradi et al have numerically determined the flood risk of the downstream area of Samsun Mert River. Analyses were carried out according to various flood peak flows and according to risk situations, 8 different scenarios were performed with MIKE 11 software. As a result, it was observed that the streambed posed a risk in the 1000-year flood period. Thus, it was estimated that there would be a water depth of 1m from the upper level of the stream [8].
In this study, the study area is located on the downstream of Elmali Dam on Goksu Stream in Beykoz District of Istanbul Province. In this study, the flood risk maps for floods that will be formed in Goksu Creek on the downstream side in various discharge of the Elmali Dam spillway are prepared by modeling with 2D DHI MIKE 21 FM software. As a result of various simulations, risk areas on the downstream side of the Elmali Dam were identified.

2. The Study Area

Figure 1 shows the study area, which is located in Istanbul province, Beykoz district, Goksu Stream.

Figure 1. Study area

Flood risk analyses were made on the downstream side of the Elmali Dam. Elmali 2 Dam in 1955 and Elmali 1 Dam in 1907 have been started to operate. Elmali 1 Dam is located in Bogazici, 3.3 km southeast of Anadoluhisari and 1.2 km downstream of Elmali 2 Dam (Figure 2).

Figure 2. Plan of dam locations

The height of Elmali 1 Dam is 22 m from the foundation and its type is masonry. Type of Elmali 2 Dam is a buttress dam and height from the foundation is 49 m. The total drainage area of both dams is 81.5 km^2. The normal water levels of the Elmali 1 and Elmali 2 Dams are 32.40 m and 67.50 m, respectively [9, 10, 11]. The images and plans of Elmali 1 and Elmali 2 Dams are shown in figures 3 and 4.

(a) (b)

Figure 3. Images of dams (a) Elmali 1 (b) Elmali 2

There are 3 spillways in Elmali 1 Dam, each of which is 3.75 m wide and at elevation of +31.00. In addition, there are 11 sliding spillways with a width of 4.30 m and a height of 2 m at the elevation of 29.00. Thus, Elmali 1 Dam has 14 spillways in total. The maximum flow capacity of the spillway is 540 m^3/s [9].

(a)

(b)

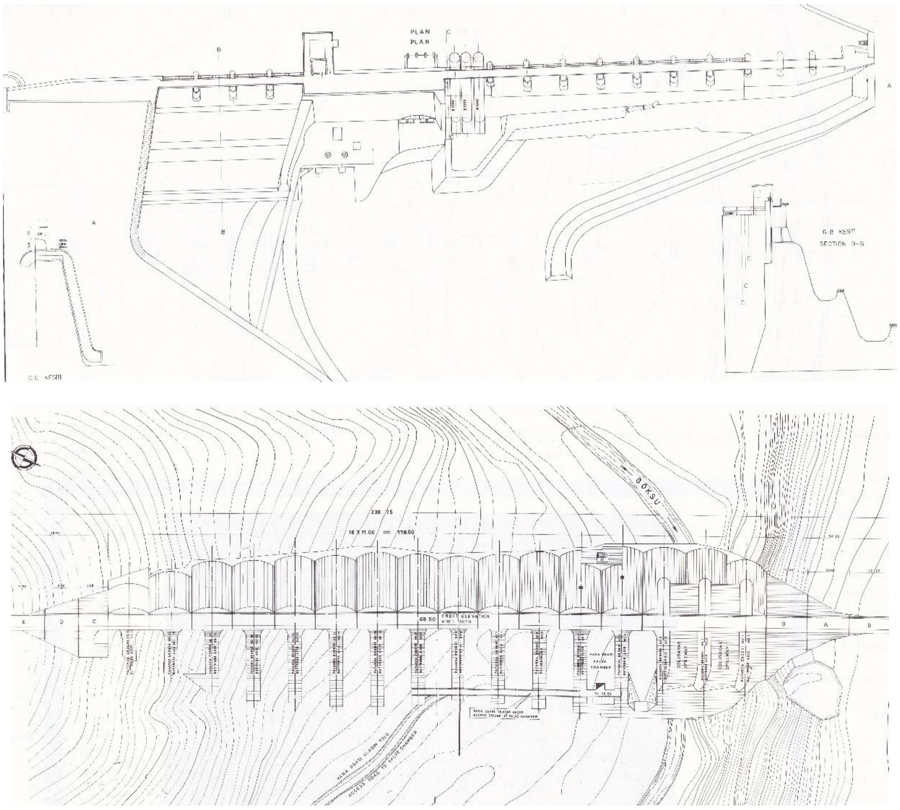

Figure 4. Plan images of dams (a) Elmali 1 (b) Elmali 2

3. Simulation Setup and Methods

In this study, the MIKE 21 FM numerical model based on the 2D Flexible Mesh approach, which is developed by the Danish Hydraulic Institute (DHI), was used as a hydrodynamic model. This model simulates the water level variations and flows velocities in response to a variety of forcing functions in a flood plain [12]. The model also includes continuity, momentum, temperature, salinity and density equations based on the numerical solution of two and three-dimensional Navier-Stokes equations with Boussinesq and hydrostatic pressure assumptions. The two-dimensional mesh consists of triangular or rectangular elements [13].

MIKE 21 Flow Model is one of the best software developed for numerical modeling of oceanographic conditions, coastal areas, river and water resources simulation. This model simulates two-dimensional flow, by using bathymetry, meteorological, tidal changes and other hydrographic conditions. Equations below represent the time-dependent, non-linear equations of continuity and conservation of momentum that solved by this model (h=η+d):

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial y}=hS \tag{1.1}$$

$$\frac{\partial h\bar{u}}{\partial t}+\frac{\partial h\bar{u}^2}{\partial x}+\frac{\partial h\overline{vu}}{\partial y}=f\bar{v}h-gh\frac{\partial \eta}{\partial x}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial x}-\frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial x}+\frac{\tau_{sx}}{\rho_0}-\frac{\tau_{bx}}{\rho_0}-\frac{1}{\rho_0}\left(\frac{\partial s_{xx}}{\partial x}+\frac{\partial s_{xy}}{\partial y}\right)+\frac{\partial}{\partial x}\left(hT_{xx}\right)+\frac{\partial}{\partial y}\left(hT_{xy}\right)+hu_sS \tag{1.2}$$

$$\frac{\partial h\bar{v}}{\partial t}+\frac{\partial h\bar{v}^2}{\partial y}+\frac{\partial h\overline{uv}}{\partial x}=f\bar{u}h-gh\frac{\partial \eta}{\partial y}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial y}-\frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial y}+\frac{\tau_{sy}}{\rho_0}-\frac{\tau_{by}}{\rho_0}-\frac{1}{\rho_0}\left(\frac{\partial s_{yx}}{\partial x}+\frac{\partial s_{yy}}{\partial y}\right)+\frac{\partial}{\partial x}\left(hT_{xy}\right)+\frac{\partial}{\partial y}\left(hT_{yy}\right)+hv_sS \tag{1.3}$$

where t is time, x and y are spaces in cartesian coordinate system (m), η is water level variations (m), d is time-varying water depth (m), u is velocity component of x-direction (m/s), v is velocity component of y-direction (m/s), $f=2\Omega\sin\varphi$ is Coriolis parameter (Ω (s^{-1}) is angular turnover, φ geographic latitude), g is the acceleration due to gravity (m/s^2), ρ_w is the density of water, S_{xx}, S_{xy}, S_{yx} ve S_{yy} are radiation stress tensor component, P_a is atmospheric pressure ($kg/m/s^2$) , ρ_0 is reference specific mass of water, S point source discharge, u_s and v_s velocity (m/s) , T_{ij} viscous, parameter including turbulence friction factors and differential transport, (τ_{sx}, τ_{sy}) ve (τ_{sx}, τ_{sy}) x and y component of surface wind and floor friction stress, T temperature and S salinity [13].

In equations1.1, 1.2 and 1.3, depth average velocity and T_{ij} values are calculated with the following equations:

$$h\bar{u}=\int_{-d}^{\eta}udz, \qquad h\bar{v}=\int_{-d}^{\eta}vdz \qquad T_{xx}=2A\frac{\partial \bar{u}}{\partial x} \qquad T_{xy}=A\left(\frac{\partial \bar{u}}{\partial y}+\frac{\partial \bar{v}}{\partial x}\right) \qquad T_{yy}=2A\frac{\partial \bar{v}}{\partial y}$$

The mesh used in the study area is shown in Figure 5. As can be seen in Figure 5, a triangular and rectangular calculation meshes are used to include all the buildings in the study area. The number of mesh elements is 32766. As the boundary conditions, the flow values shown in Table 1 were used respectively, on the upstream (Output of the Elmali-1 Dam) for 60 minutes. Since the stream is poured into the sea (Bosporus), the seawater level value is accepted as zero. Simulated flood maps obtained the maximum depth of water at each node of the mesh.

In this study, floods caused by the Elmali 1 Dam were investigated and risky areas were identified. The percentage of the maximum overflow discharge from the spillway of the dam was used in flood risk analysis. Flood risk maps for various scenarios were created with MIKE 21 FM. There were 4 scenarios for Goksu creek and the results of the scenarios are shown in Figures 10, 11, 12 and 13. Also in Figure 14, Figures 10, 11, 12 and 13 are shown as a unified map.

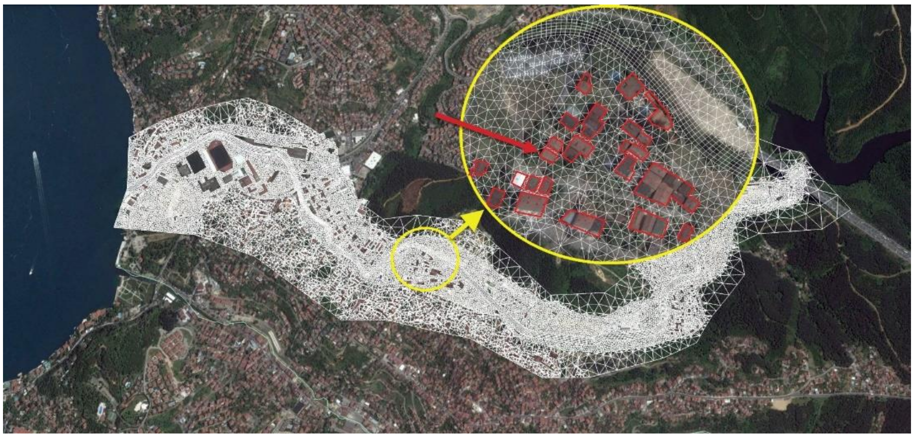

Figure 5. Implemented mesh in the study area

In the first scenario, the flood map is created when 25% of the maximum capacity of the spillway is discharged. Then, flood maps consisting of 50%, 75% and 100% of the maximum capacity of the spillway were obtained. Spillway discharge and duration are given in Table 1. The maximum capacity of the spillway (Q_{max}) is 540 m^3/s. In all scenarios, the effect of the buildings in the Goksu stream is also reflected in the models. Thus, the effect of urbanization on flood progression is also included in the model. The buildings are shown in Figure 5 in red color.

Table 1. Flood scenarios

Scenario No.	The percentage of spillway discharge capacity	Discharge capacity of spillway (m^3/s)	Discharge duration (min)
1	%25	135	60
2	%50	270	60
3	%75	405	60
4	%100	540	60

Flood areas are classified according to 3 critical depths, 0.6, 1.0 and 3.5 m. The basis for the selection of critical depths is described as follows: In general, the height of schools and public buildings is 0.6 m from the ground. If the flood depth is more than 1.0 m, there is a possibility of loss of life. In addition, great damage is expected in agricultural production. The minimum height of sills for shelters and also for one-story buildings is usually 3.5 m. The classification of hazards according to the flood depth is given in Table 2 [14].

Table 2. Flood risk type

Flood hazard No.	Depth of flooding, d, (m)	Type of flood hazard
H_1	$0.0<d<0.6$	Low
H_2	$0.6<d<1.0$	Medium
H_3	$1.0<d<3.5$	High
H_4	$3.5<d$	Extreme

In the first scenario, the flood map that will occur in the downstream of the dam is presented in Figure 6 when 25% of the maximum capacity of the spillway discharged. In Figure 6, the impact of urbanization on the flood direction and residential areas exposed to the flood are clearly understood. Also, the depth of the water reaches up to 4 m in some parts of the middle part of the stream bed. Flood is spread more in the region where the stream connects to the sea, creating large-scale risky areas. Here, the depth of water has increased up to 1.2 m in residential areas.

If there is agricultural land where the stream is connected to the sea, it is expected that this land will be damaged in case of a possible flood.

As a result of the second scenario, at points 1, 2, 3 and 4 shown in Figure 7, the flood stream bed was spread more to the surrounding land. In Scenario 2, the depth of the water in the surrounding land was more than 1 m, and in the event of a flood, there is a possibility of a loss of life and property. At point 4, flood water depth reaches up to 3 m.

Considering the most recent scenario (Figure 9) and the most hazardous situation, there is no obvious difference in the lower parts of the stream (towards the sea) with Scenario 3, and only a slight increase in the flood depth has occurred. Considering the results of scenario 4 and 3 in the upper areas of the stream (Output of dam), the flood was spread more to the surrounding area in scenario 4 and the facility areas at the output of the dam were completely submerged (point 5).

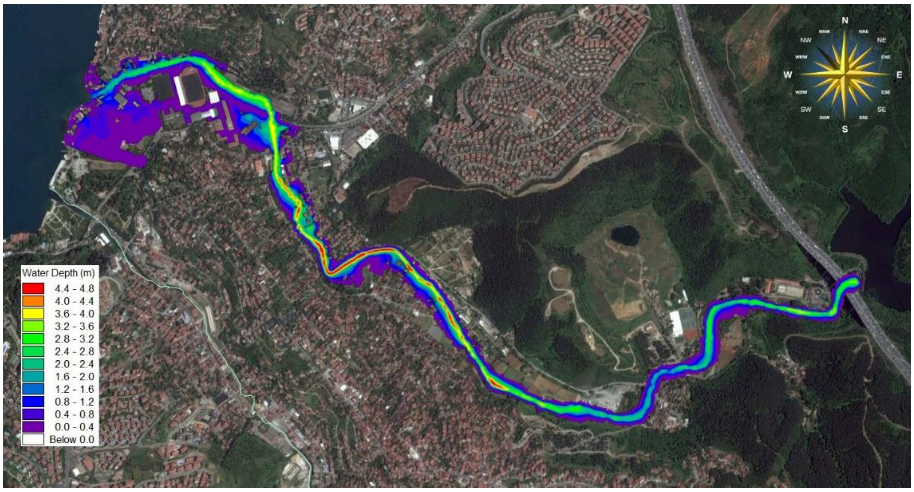

Figure 6. Flood risk map of the first scenario ($0.25Q_{max}$)

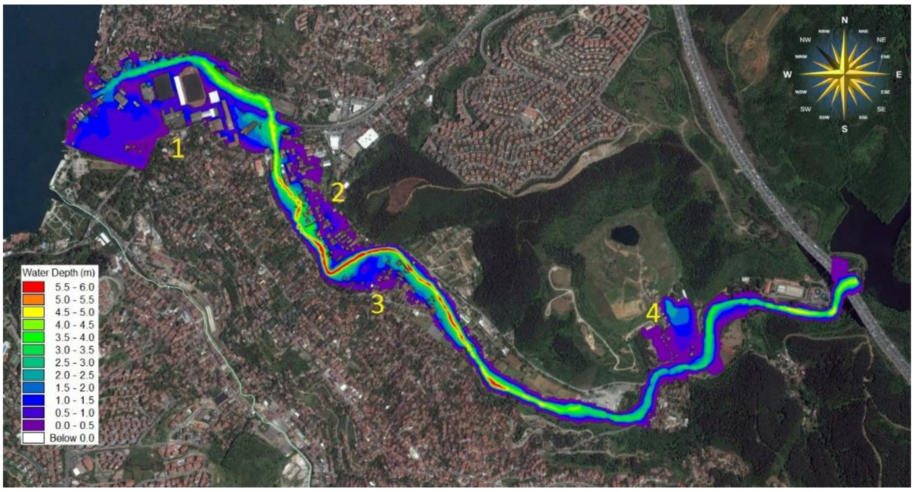

Figure 7. Flood risk map of the second scenario ($0.50Q_{max}$)

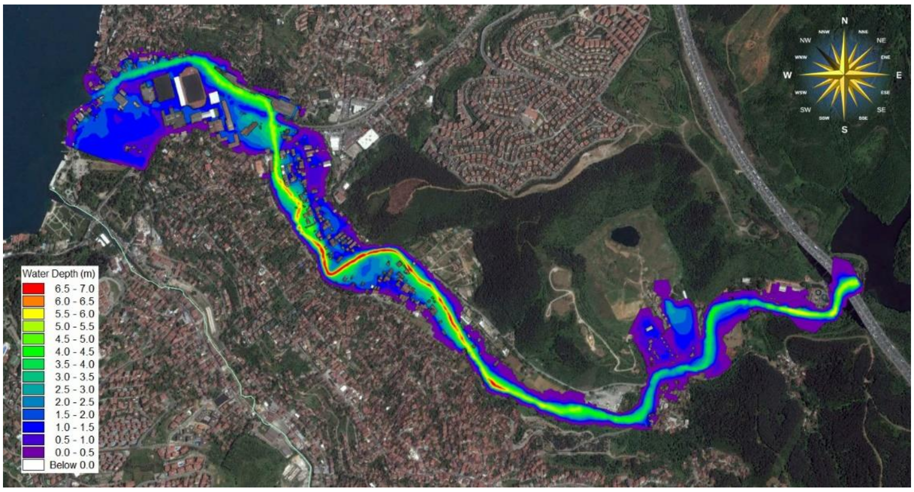

Figure 8. Flood risk map of the third scenario ($0.75Q_{max}$)

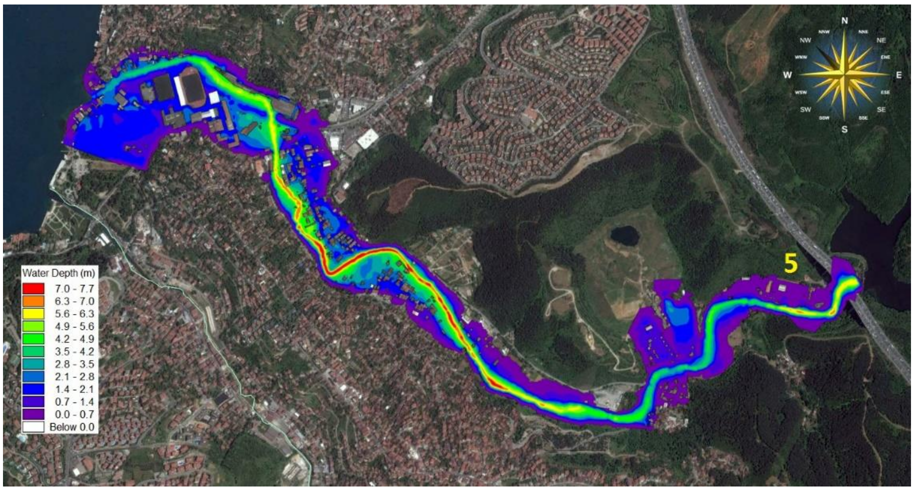

Figure 9. Flood risk map of the fourth scenario (Q_{max})

Finally, Figure 10 shows the flood map of the four Scenarios. In this map, red, orange, yellow and green areas are maps obtained from scenarios 1, 2, 3 and 4, respectively, and show the areas exposed to flooding. In the first scenario, the area exposed to floods is 0.453 km^2. In the event of a possible flood, the buildings in this area are urban areas that are always at risk and can be damaged.

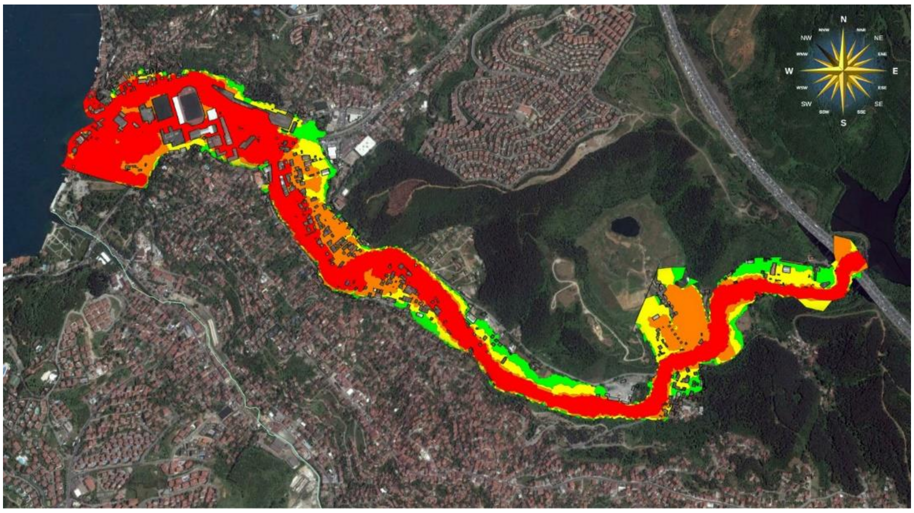

Figure 10. Unified map of four scenarios' result

The results of the second scenario are shown with orange and the area exposed to flood is 0.605 km^2. In this scenario, the maximum water depth created by the flood is 6 m. The areas of floods in the third (yellow) and fourth (green) scenarios are 0.732 km^2 and 0.820 km^2, respectively.

4. Conclusions and Recommendations

In this study, the floods that may occur in the Goksu stream originating from the operation of the spillway of the Elmali dam were investigated. In other words, the flood, which can occur in accordance with the operational plan of the spillway of the Elmali dam, has been investigated with a numerical model. In this study, 4 scenarios are taken into consideration. Thus, flood maps, formed by 25%, 50%, 75% and 100% of the maximum discharge capacity of the spillway, were obtained and risky areas were determined.
Areas exposed to flooding are divided into three critical depths, 0.6, 1.0 and 3.5 m. These ranges are classified into 4 groups as 0-0.6 m depth low risk zone, 0.6-1.0 m depth medium risk zone, 1.0-3.5 m depth high risk zone, and regions with more than 3.5m depth are extreme risk zone. In the First Scenario, the flood is spreading more frequently in the region where the stream is connected to the sea and constitutes high risky areas. If there are agricultural lands where the stream is connected to the sea, possible floods are expected to cause great damage to this land. In the second scenario, the flood streambed is spreading more to the surrounding land and in the event of a flood, there is a high probability of loss of life and property.

In the Third Scenario, there is a 25% discharge flow increase compared to the previous scenario and the flood flow is taken as 405 m^3/s. The most hazardous region of this scenario is point 3 and is located in overly risky areas according to the flood risk type. When the last scenario with the third scenario are compared, it is seen that there is no significant difference in the flood area (towards the sea) in the downstream areas of the stream. In addition, in the upper areas of the creek (point 5 in figure 9), the areas exposed to flooding in Scenario 4, cover more land than scenario 3, and it is likely that the flood may affect dam facilities. In Figure 10, the regions where the four scenarios are exposed are shown in various colors. In this figure, red, orange, yellow and green areas are flood maps obtained from scenarios 1, 2, 3 and 4, respectively.

Dams are important structures for flood control. Although floods are less likely to occur from dams, determination of the dam flood map can protect the lives and properties of downstream residents. In the study, hazardous areas exposed to flood were determined in the case of various discharge flows from the spillway of the Elmali 1 Dam. In addition, some suggestions have been made to reduce flood damages. Thus, it is important that the dam reservoir is emptied in a controlled manner when floods can occur. One of the preventions that has been taken in this direction is the controlled structuring of urbanization in risky areas and urbanization activities should not be allowed in H_2, H_3 and H_4 situations. In the current urbanization situation, by using high-tech communication devices, inhabitants should be informed about the immediate evacuation quickly. Another precaution during the flood that can be taken is to quickly discharge any obstacles that reduce the discharge capacity of the creek, for example, existing boats at the port of the sea.

References

[1] Mao, J.; Wang, S.; Ni, J.; Xi, C.; Wang, J., (2017), Management System for Dam-Break Hazard Mapping in a Complex Basin Environment, *ISPRS Int. J. Geo-Inf.*, *6*, 162.

[2] Diman, C. P., & Tahir, W. (2012). Dam flooding caused a prolonged flooding. *International Journal of Civil & Environmental Engineering*, *12*(6), *71-75*.
[3] Dat, T. T., Tri, D. Q., Truong, D. D., & Hoa, N. N. (2018), Application of Mike Flood Model in Inundation Simulation with the Dam-break Scenarios: a Case Study of DakDrinh Reservoir in Vietnam. *Inter. J. Earth. Sci. Eng.(SCOPUS, Q4)*.
[4] Mohd Sidek, L., MOHD SHAH, MOHD. RASHID., Yalit, R., PONRAJ, MOHANADOSS., & Basri, H. (2017). Hydrodynamic Numerical Modelling Of Dam Failure and Impacts Assessment of Susu Dam With Mike, *E-proceedings of the 37 th IAHR World Congress*, Kuala Lumpur.
[5] DSİ, (2013), “Water resources development working group report” *forestry and water council*, 12 March. (In Turkish)
[6] Özcan O., Musaoglu N., Seker D.Z., Tanik A. (2008), Determination of flood risk in Sakarya sub basin using remotely sensed data and GIS, *Fresenius Environmental Bulletin*, *17(11b)*, *1964-1971*.
[7] Özdemir, H., (2007). Flood risk analysis according to various scenarios: The Case of Havran creek. *Proceedings book of TMMOB disaster symposium*, Balikesir, Turkey. (In Turkish)
[8] Abdollahzadehmoradi, Y., Erdik, T., Mahnamhar, F., Özger, M., Altunkaynak, A., (2013). “Determination of the flooding risk in the slum areas of ÇAY district, İLKADIM County of SAMSUN province.” *Flood and Landslide Symposium*, Trabzon, Turkey. (In Turkish)
[9] Ağıralioğlu, N., Altunkaynak, A., Özger, M., (2015), “Elmali - I and II dams engineering studies technical report” İSKİ. (In Turkish)
[10] Ural, O.M. and Ungan, Ü., (1967) Large Dams in Turkey, DSİ.
[11] Orhon, M., Esendal, S., Kazak M.A., (1991), Dams in Turkey, DSİ general directorate.
[12] Kadama, P. and Sen, D., (2012). Flood inundation simulation in Ajoy River using MIKE-FLOOD, *ISH Journal of Hydraulic Engineering, Vol. 18, No. 2, June 2012, 129–141*.
[13] DHI, 2010. MIKE 21 & MIKE 3 Flow Model FM. Hydrodynamic and Transport Module Scientific Documentation, Release 2010, (D.H.I). *Danish Hydraulic Institute*.
[14] Tingsanchali, T., ve Karim, M.F. (2005), “Flood Hazard and Risk Analysis in the Southwest Region of Bangladesh”, *Hydrological Processes, 19, 2055-2069*.