Flood Routing Model Using Integration of Delft3D and GIS (Case Study: Tanggul Watershed, Jember)

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Abstract. Flood disaster is one of the most common disasters in Jember District. One that is often affected is in 10% of the area of Jember District, namely the Tanggul watershed with an area of 345,875 km2. The condition of Tanggul River, with a length of 23.50 km, which tends to narrow and meander can reduce flow especially when the river discharge is enlarged due to rain. If rainfall is above 100 mm on the upstream part of the watershed, then the downstream of the Tanggul River with a length of ± 10.19 km that passes through Paseban Village, Kraton Village, and Kencong Village are often unable to withstand the discharge which will overflow the surrounding area. The history of flood occurences in the Tanggul watershed in the last 25 years had occurred 27 times, including 9 times which resulting in breakdown of the embankment. According to records from the Lumajang Public Works Office, the latest flood event in Tanggul River was occurred on December 22, 2018 with water elevation reaches 3.5 m and a discharge of 749,153 m^3. This resulted in a broken embankment with a length of 60 m and a height of 7.2 m from the riverbed. Mitigation efforts such as flood routing to get an overview and information on overtopping points is needed to be done in order to minimize losses. This research aims to simulate flood using integration of the main programs DELFT3D and GIS. The flood routing model is obtained by utilizing a spatial model of analysis in Geographic Information Systems (GIS) to determine critical embankment or overtopping points and hydraulic flow simulation with DELFT3D program. The modeling results are visually compared with the coordinates of the flood events in the field that prepared by the Lumajang Public Works Office. Based on the 1000-year return period, the overtopping point occurs at ± 12.8 km from the downstream, namely Kencong District and ± 11.8 km from the downstream, namely Paseban District. In the end, this model can be used as a framework for the Tanggul watershed flood routing model to look for the effectiveness of various non-technical flood control alternatives such as land conservation and technical such as river normalization.

INTRODUCTION

The phenomenon of floods often strikes Indonesian territory. In 2008, Indonesia was included in the top 10 countries in the world that frequently experienced natural disasters in the last 10 years (2006 - 2015). Countries in the order of the first three are occupied by China, United States and India, and Indonesia came in fourth. Based on data statistic that released by the Center for Research on the Epidemiology of Disasters (CRED) in 2016, the most common disaster that occurred in Indonesia, was hydrological disaster related to floods and followed by geophysical disasters which were related to earthquakes. Furthermore, results of the analysis of these data indicate that the flood disaster occurred in Indonesia is the most frequent occurring disasters are around 80% of all disasters [1].

Flood disaster is one of the most common disasters in Jember Regency. An area that is often affected is Tanggul watershed with an area of 345,875 km^2, which is equivalent to 10% area of Jember Regency. The condition of the

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Tanggul River with a length of 23.50 km tends to narrow and meander. This condition would inhibit the flow. Especially when the river discharge enlarges due to rain. If there is a high rainfall above 100 mm in the upstream reaches of the watershed, the Tanggul River downstream with a length of ± 10.19 km that passes through Paseban Village, Kraton Village, and Kencong Village are often unable to withstand the discharge from the rainfall until it overflows and inundate surrounding area where flooding occurs.

Based on reports from Lumajang Department of Public Work, the occurrence of floods in Tanggul watershed in the last 25 years had occurred 27 times which 9 times of them resulted in broken embankment as shown in figure 1. The most recent incident occurred on December 22, 2018, the embankment was broken along 60 m with a height of 7.2 m which caused the river current to turn quickly into the rice fields and residential areas. It was recorded that the water level reached 3.5 m with a discharge of 749,153 m3. The 595 houses in three villages namely Kecong, Kraton and Paseban villages were flooded and 345 rice fields were flooded [2]. These conditions make the Tanggul watershed as an area that has a high level of flood vulnerability.

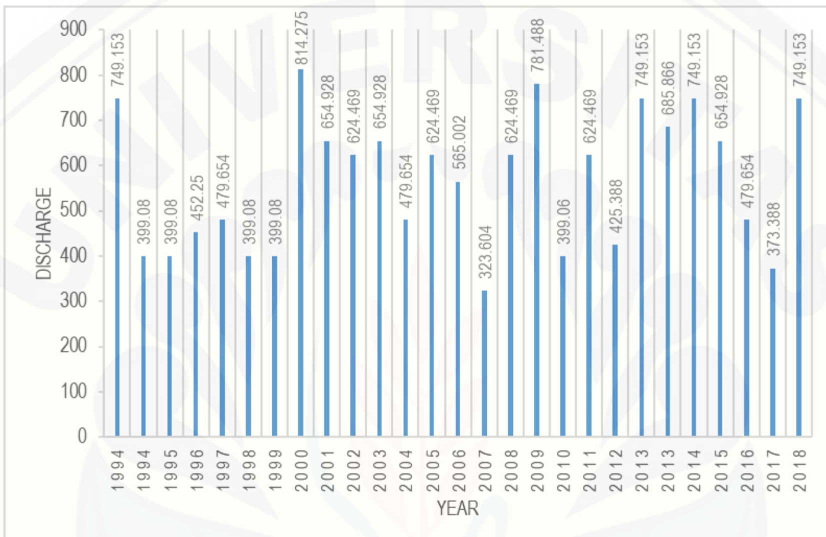


Figure 1. Flood event in the Tanggul River (Lumajang Department of Public Work, 2018)

The figure above shows that the impact of flood discharge in the Tanggul River still occurs every year where the flood discharge of the Tanggul River is also increasingly critical. Mitigation efforts such as flood routing and information on overtopping points need to be done to get an overview and minimize losses.

Flood Routing has an impact on the amount of discharge and the time of peak discharge, the depth and level of flooding, as well as environmental factors such as erosion on river banks and everything related to sediment [3]. This is a technique for determining flood hydrographs by utilizing flood flow data in one or more upstream sections. Hydrological analysis such as flood estimates, technical mitigation, early warning systems, water building designs always include flood routing [4].

In this research, simulation of the flood routing model uses DELFT3D software. Delft3D-FLOW software simulates hydrodynamic flow, sediment dynamics, and morphological processes in shallow water environments. Delft3D-FLOW solves the two-dimensional (average depth) or model three-dimensional processes based on simulating tidal dynamics [5]. Sediment transport and sedimentation are calculated simultaneously with hydrodynamics, creating direct feedback between hydro and morphodynamics [6]. Delft3D-FLOW matches the flooding and drying algorithm. The grid cells are activated when the water level exceeds the flood threshold, while the grid is deactivated when the local water level drops below half this threshold [6]. The Delft3D model has been validated against various experiments with excellent results [7]. These models have also been applied to simulate sediment transport and morphological changes near Calang (Aceh Barat) due to the tsunami [8]. Delft3D can be run in both Cartesian and Spherical coordinates [9]. Such flexibility can be suitable for domains that will stretch from the coastline to about one kilometer towards the sea [10].

METHOD

This research was conducted in the Tanggul watershed in Jember Regency, East Java. Geographically, the Tanggul watershed with an area of 345,875 km^2 is located at 8º 05 ’55" LS - 113º 30' 00 "East. Administratively it passes through 7 Subdistricts namely Sumber Baru, Tanggul, Semboro, Jombang, Umbulsari, Kencong, and Gumukmas Sub-districts in the downstream as shown in figure 2.

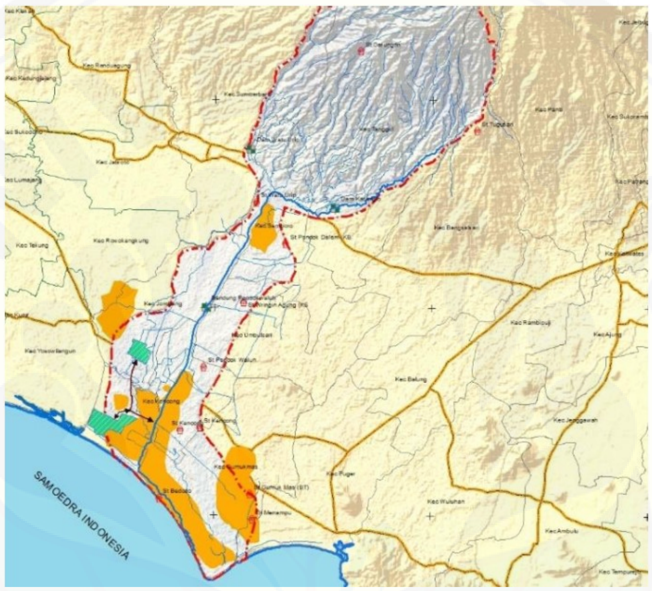


Figure 2. Research Location.

The river embankment generated from Digital Elevation Model (DEM) data has a flow direction that is not in accordance with the actual river. This happens because the DEM data estimates the river flow based on lower elevations. In addition, the river embankment is also included in a small river with a river width between 10 - 20 meters so that by using DEM which generally has a resolution of 30 x 30 m, the river flow is not spatially visible. DEM data that have low accuracy such as ASTER DEM, do not allow it to be used in modeling hydrological models [11]. High accuracy DEM data (LiDAR DEM, DEM planimetric survey, and aerial photo DEM) will give more accurate results and lower error rates compared to low accuracy DEM data [12]. So that in this research river flow is estimated by depicting river geometry based on contours and following the actual river flow. Because the contours / samples that can be read by Deflt3D use the *.xyz format, the terrain *.tin that was previously built from a combination of vector data and raster data must be converted to *.xyz format as shown in figure 3.

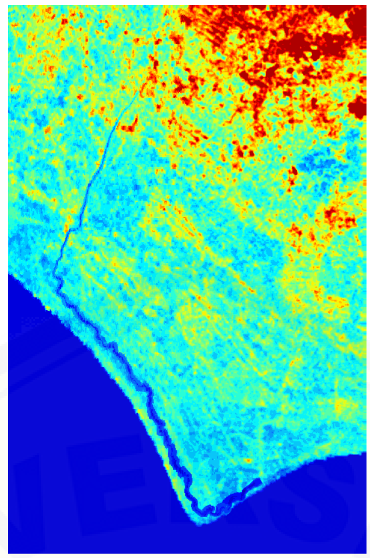


Figure 3. Terrain or Contour or Sample in *.xyz format

The data is interpolated with the QUICKIN Delft3D program into a 50m x 50m (*.grd) grid. The depth of the simulation area on Delft3D QUICKIN. Positive depth values (+) are used as sea depth information, while negative values (-) are used as land elevation information. The interpolation results are saved in *.dep format as shown in figure 4.

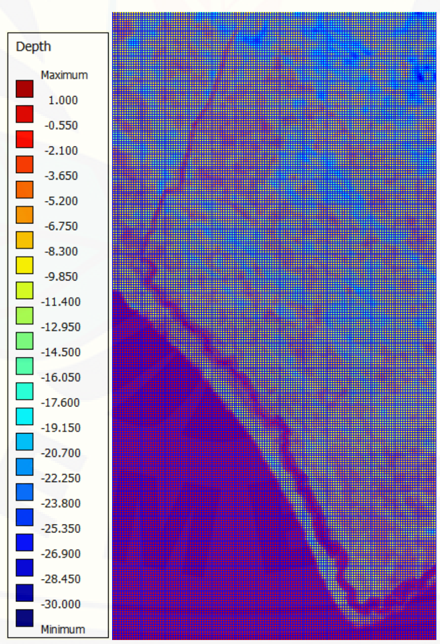


Figure 4. Terrain or Contour or Sample with 50x50 grid in *.dep format

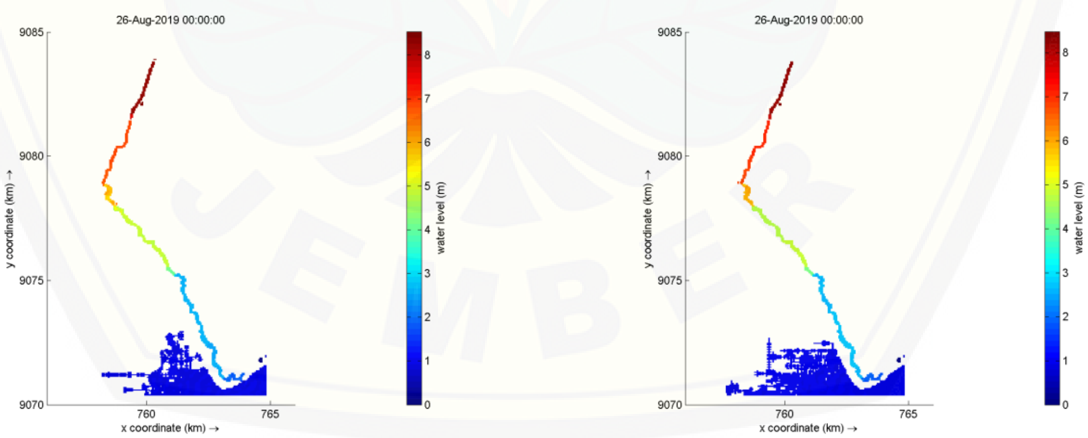
Furthermore, depth data in *.dep format is used as bathymetry input in Delft3D-FLOW. Then make bathymetry and flow model. Bathymetry arrangements include setting the boundary of the plain, setting the grid, and setting the depth. The flow model settings are using input data from 25, 50, 100, 200, 500 and 1000-years return period discharge results. The re-discharge on the upstream boundary conditions uses the result of hydrological analysis based on rainfall for 24 years (1994-2018) analyzed with the Gumbel frequency distribution of the Chi-Square and Smirnov-Kolmogorov conformity test results to find out the truth of the frequency hypothesis as shown in table 1 [13]. The design discharge obtained then becomes the Nakayashu synthetic unit hydrograph. Validation is done by comparing the results of the model with the results of observations at certain points during flood events.

Table 1. Maximum annual discharge

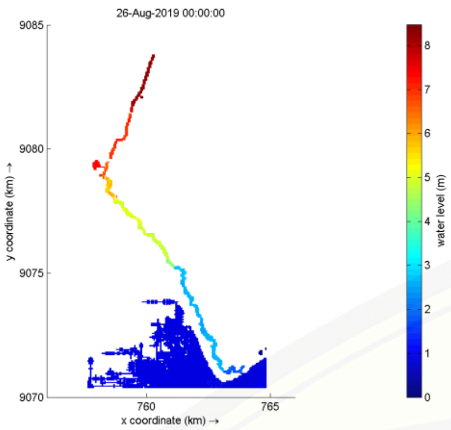
Tr	**Discharge (m^3/s)**
20	407.204
25	468.488
50	541.632
100	622.732
200	702.732
500	812.448
1000	934.098

RESULT AND DISCUSSION

The flood routing model produced by Delft3D is in the form of two dimensions or spatial visualization. This visualization was developed from a combination of vector and raster data which was then interpreted into a flood distribution by Delft3D as the final stage of the flood route modeling process.



(a) (b)



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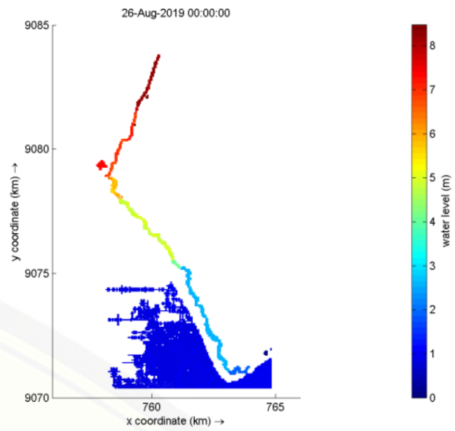

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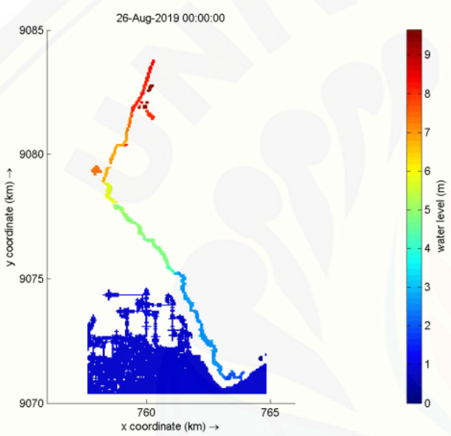

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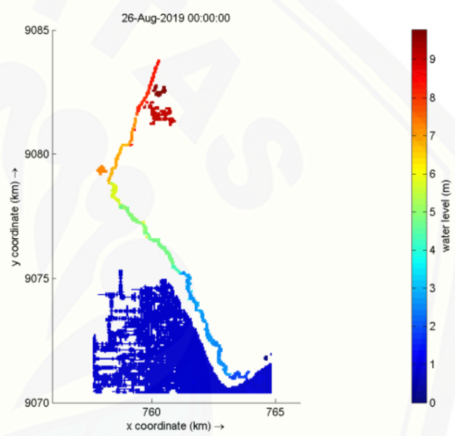
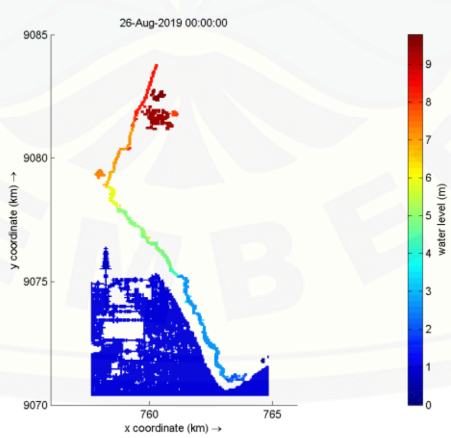


(f)



(g)

Figure 5. Simulation result with re-discharge. (a) Q20. (b) Q25. (c) Q50. (d) Q100. (e) Q200. (f) Q500. (g) Q1000.

Figure 5 shows the simulation results based on various discharge times according to the results of the hydrological analysis in table 1. The modeling results are visually compared with the coordinates of the flood events in the field that prepared by the Lumajang Public Works Office. When using the 20 and 50 -year return period discharges with flows of 407,204 m^3 and 468,488 m^3 respectively, the results of the model have not shown any indication of runoff. Whereas runoff began when using 50 and 100 -year return period discharges with 541,632 m^3 and 622,732 m^3 discharges, with runoff points occurring at ± 11.8 km from the downstream, namely Paseban Regency. Then based on the 200 to 1000 -year return period discharges with flows of 702,732 m^3, 812,448 m^3 and 934,098 m^3 respectively, the runoff point occurs at ± 12.8 km from downstream, namely Kencong Regency and ± 11.8 km from downstream, namely Paseban Regency.

CONCLUSION

Based on the results of the simulation, the occurrence of flooding begins at 100 to 1000-years return period discharge. The overtopping points occur at ± 12.8 km from downstream, namely Kencong Regency and ± 11.8 km from downstream, namely Paseban Regency. When viewed in the distribution area, the area affected by flooding occurs in residential areas because most of the area is dominated by settlements. Efforts to anticipate floods that are structural and appropriate in residential areas by establishing embankments which must be sufficiently safe and stable and will withstand during the occurrence of flood. In addition, the normalization of river basins, relocation of illegal settlements around rivers, and the construction of flood canals are also needed to lower the elevation of river flood water levels and reduce the area and height of inundation. In the end, this model can be used as a framework for the Tanggul watershed flood routing model to look for the effectiveness of various non-technical and technical. This research is expected to continue to a higher stage by adding other factors such as the influence of climate change and the amount of impact

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