Flood prediction, its risk and mitigation for the Babura River with GIS

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Abstract. This paper describes the flood prediction along the Babura River, the catchment of which is within the comparatively larger watershed of the Deli River which crosses the centre part of Medan City. The flood plain and ensuing inundation area were simulated using HEC-RAS based on the available data of rainfall, catchment, and river cross-sections. The results were shown in a GIS format in which the city map of Medan and other infrastructure layers were stacked for spatial analysis. From the resulting GIS, it can be seen that 13 sub-districts were likely affected by the flood, and then the risk calculation of the flood damage could be estimated. In the spirit of flood mitigation thoughts, 6 locations of evacuation centres were identified and 15 evacuation routes were recommended to reach the centres. It is hoped that the flood prediction and its risk estimation in this study will inspire the preparedness of the stakeholders for the probable threat of flood disaster.

1. Introduction

Societal responses to floods traditionally relied on efforts to limit flood hazards through structural protections such as dams and dikes, but this is considered not effective enough in flood mitigation processes [1]. Flood hazards and losses can be prevented and minimized by providing people with accurate information about the risk of flooding through flood inundation maps [2]. Flood inundation maps are also used as the foundation for urban planners and the government to manage land use for city mitigation planning.

Medan City as one of the biggest metropolitan cities in Indonesia is frequently faced with flood problems. One of the areas potentially affected by flood in Medan City is the Babura sub-watershed, which is situated within the upper part of the larger Deli watershed. The main stream that flows in the Babura sub watershed is the Babura River which is a tributary that feed into the Deli River [7]. As a first step to flood mitigation, this study describes the flood prediction and its risk along the Babura River.

As shown in previous studies [2,3,4,5], Geographic Information Systems (GIS) has been used in visualizing flooded areas and analysing flood-prone spaces to produce a flood damage estimation map depicting likely flood risk condition. The GIS must be used together with a hydraulic model to estimate flood profiles which are among others dependent upon the given return periods [2]. One of the most popular programs that models the hydraulics of water flow is the Hydrologic Engineering Centres River Analysis System (HEC-RAS) developed by the United States Army Corps of Engineers (USACE).

HEC-RAS is a free software with a friendly graphical user interface that is often used for flood studies [6].

GIS is applied in this study to show the resulting flood map developed using HEC-RAS based on the available data of rainfall, catchment, and river cross-sections. Stacked with the city map and other infrastructure map layers, the GIS is used to identify floods prone sub-districts and estimate the damage caused by certain return period floods in the Babura sub-watershed. Also, in the spirit of flood mitigation thoughts, the possible locations of evacuation centres are identified and the evacuation routes are selected to reach the centres.

2. Method

This study is located along the Babura River which is a tributary of the Deli River. The Babura sub-watershed stretches from Sibolangit in Deli Serdang County to Medan City with an area of 98 km^2 and 36 km in length (BPDAS Wampu Sei Ular, 2012). The geographical positions lay between 3° 25' 12" to 3° 35' 27" northern latitudes and 98° 32' 37" to 98° 40' 20" eastern longitudes. The location of this study can be seen in Figure 1.

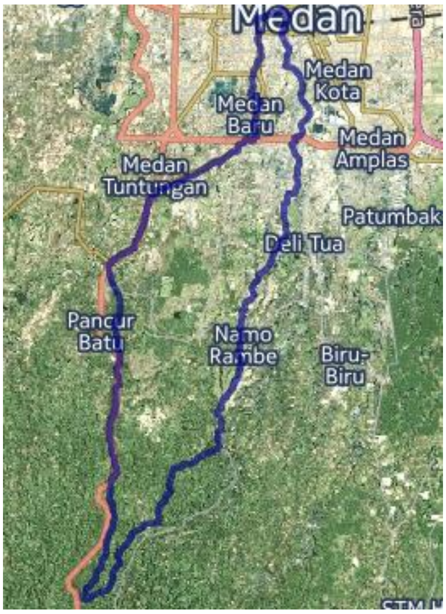


Figure 1. The Babura sub-watershed

2.1. The Available Data

The data used in this study are the available data obtained from the relevant institutions as follows:

- Maximum daily and monthly rainfall data in the period of 2006 to 2015 from Sampali Climatology Station, Medan.
- Population data of Medan City from BPS-Statistics of Medan City in 2016.
- The digital map of the Babura sub-watershed from Watershed Management Agency-BPDAS Sei Wampu Ular.
- Administration and land use digital map of Medan City from Regional Development Planning Agency-BAPPEDA Medan City.
- Digital Elevation Model (DEM) SRTM with 30 m resolution from http://earthexplorer.usgs.gov.
- Long and cross section profiles of the Babura River from River Basin Organization-BWSS-II.

The main softwares used in this study to process the above data are HEC-RAS version 5.0.1, ArcGIS version 10.2, and Google Earth Pro Version 7.1.7.2600.

2.2. The Data Processing

The first computation process taken in this study was to analyse the rainfall that occurred over the Babura sub-watershed with Thiessen polygon method. From the calculation of average rainfall with the Thiessen polygon method, we can determine the possibility of recurrence of maximum rainfall to determine the design flood discharge. After the design rainfall depth was obtained, the Koolmogrov-Smirnov goodness fit of test was conducted to evaluate the accuracy of the fitting of a distribution [9]. If the test is accepted then the design rainfall can be used to calculate the design flood discharge.

In determining the design flood discharge, we first need to know the runoff coefficient of the Babura sub-watershed calculated using weighted average formula [10]. Then the flood discharge was calculated by the Nakayasu synthetic hydrograph method with the main following parameters: watershed area (A) = 98 km^2, main River Length (L) = 36 km, R_0 = 1 mm, and α = 2.

The flood discharge obtained was inputted together with the river profile data to HEC-RAS to determine the potential flood. The resulting output from HEC-RAS would be used in GIS framework to predict the inundation area using ArcGIS. In the GIS, layers of watershed, Medan City administrative and infrastructures, and DEM were essentially useful in spatial analysis for flood prediction and its impact. Then the flood risk was evaluated by the number of flood affected people in each of the identified inundation areas and the total cost of damage caused by floods according to certain return periods.

Next we could identify the evacuation centres and routes. The selection of the evacuation centres was based on several considerations as follows [11]:

1. The minimum distance of evacuation centres is about 750-1500 meters perpendicular to the river.
2. The selected evacuation centres are open and dry area.
3. The evacuation centres are not in the vicinities of any dense residential areas.
4. The spatial distribution of the evacuation centres are selected with consideration of the flood affected areas.

Having selected the location of the evacuation centres, we could identify the evacuation routes with the following conditions.

1. The evacuation route is designed away from the flood plain and the stream.
2. The evacuation path is not restricted to any rivers or bridges.
3. For densely populated residential areas the evacuation path is a block system in such away that the periodic movement of each block is not mixed each other to avoid congestion.
4. The selected route could be a national road, a provincial road, or a district road.

3. Results and Discussions

3.1. Analysis of Average Rainfall

The analysis of the average rainfall over the watershed by the Thiessen polygon method is based on the catchment area of each rain gauge station which can be obtained by spatial analysis with GIS. The average daily maximum rainfall over the Babura sub-watershed ranges from 83 mm to 136 mm. From the calculation with Gumbel distribution, the rainfall depths of the 10, 25, 50, and 100 years return periods are 139 mm, 153 mm, 170 mm, and 182 mm respectively. The rainfall design is accepted according to the test using the Kolmogrov-Smirnov Test.

3.2. Flood Discharge Analysis

In determining the design flood discharge, we first needed to know the runoff coefficient of the Babura sub-watershed. The runoff coefficient was calculated based on the land use layer in the GIS developed. Within the range of the runoff coefficients from 0.1 to 0.9 dependent of the land use type, it is found that weighted average runoff coefficient C was 0.3. Then we determined the design flood discharges Q of different return periods (10, 25, 50, and 100 years) using the Nakayasu synthetic unit hydrograph shown in Figure 2.

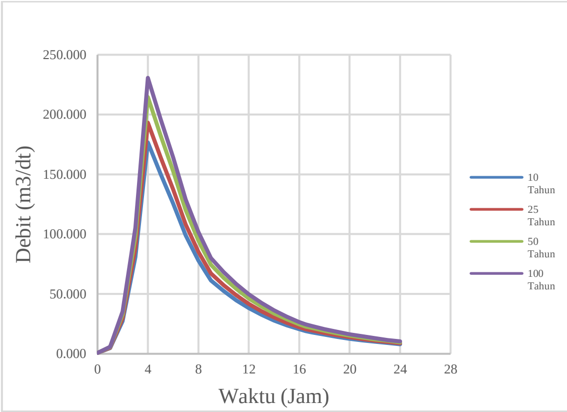
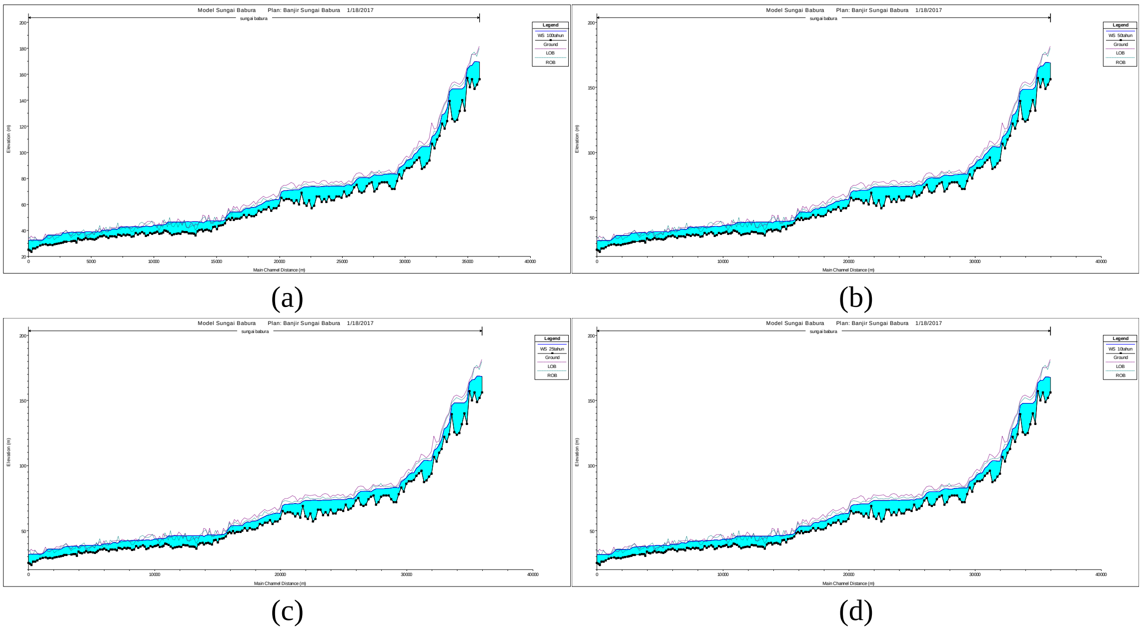


Figure 2. Nakayasu synthetic unit hydrograph of the Babura sub-watershed

3.3. Flood Potential Analysis Using HEC-RAS

Based on the input of river geometry and design flood discharges, HEC-RAS would self-assess the river cross-sectional capacity and subsequently show the water level in the crosswise and long wise. Figure 3 shows the long profile of water level of the Babura River for discharges of 100 year return period (Q_{100}), 50 year return period (Q_{50}), 25 year return period (Q_{50}), 10 year return period (Q_{10}).



(a) (b) (c) (d)

Figure 3. Long profile of the Babura River (a) Q_{100} years; (b) Q_{50} years; (c) Q_{25} years; (d) Q_{10} years

From Figure 3 it can be seen that along the Babura River, overflow that causes flooding occurs at a distance of 5 km to 15 km from the downstream outlet. While in the upstream portion no overflow occurs. Thus no concerns for flooding shall be given to the upstream areas of the Babura sub-watershed.

3.4. Flood Inundation using GIS

Output from HEC-RAS can be used to model the inundated area using ArcGIS. To do that, data from HEC-RAS were imported into ArcGIS with the help of extensions HEC-GeoRAS. The result of GIS showing the inundated area is shown in Figure 4.

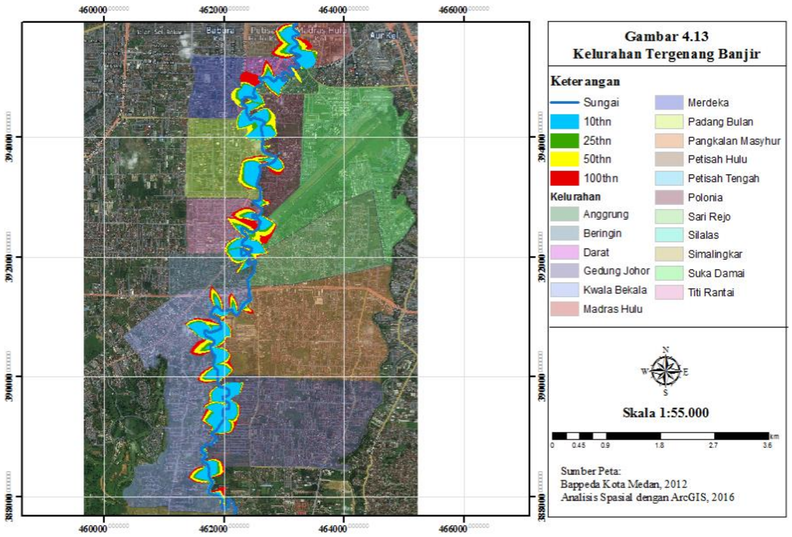


Figure 4. Inundated area

Note in Figure 4 it that Q_{100} has the largest inundated area of 2.34 km^2, whereas the smallest inundation results from Q_{10} with an area of 1.57 km^2. This indicates that large flood discharges would not result in linearly wider inundation.

To find out which sub-districts are flooded, the layer of inundation area is overlaid with the layer of administrative of Medan City as shown in Figure 5. Then the inundated area in each sub-district is tabulated in Table 1.

Table 1. Predicted inundation with Q_{100}, Q_{50}, Q_{25}, and Q_{10}

District	Sub-district	Area (km^2)	Inundated Area (km^2)			
			Q_{100}	Q_{50}	Q_{25}	Q_{10}
Medan Petisah	Petisah Tengah	1.403	0.0073	0.0066	0.0057	0.0049
Medan Baru	Darat	0.394	0.1476	0.1336	0.1159	0.0989
	Merdeka	0.905	0.0266	0.0241	0.0209	0.0178
	Padang Bulan	1.705	0.2399	0.2171	0.1884	0.1608
	Petisah Hulu	0.684	0.1255	0.1136	0.0986	0.0841
	Titi Rantai	1.003	0.1349	0.1221	0.1059	0.0904
Medan Polonia	Anggrung	0.336	0.0802	0.0726	0.0630	0.0537
	Polonia	1.345	0.2417	0.2187	0.1898	0.1620
	Sari Rejo	2.046	0.0136	0.0123	0.0107	0.0091
	Madras Hulu	0.784	0.126	0.1140	0.0990	0.0844
	Suka Damai	4.253	0.2059	0.1863	0.1617	0.1380
Medan Selayang	Beringin	0.804	0.0513	0.0464	0.0403	0.0344
Medan Johor	Kwala Bekala	4.171	0.4636	0.4195	0.3641	0.3106
	Pangkalan Masyhur	4.493	0.229	0.2072	0.1798	0.1534
	Gedung Johor	3.753	0.2496	0.2258	0.1960	0.1673
Total			2.3427	2.1197	1.8398	1.5698

From Table 1 it can be seen that there are 13 affected sub-districts, and the largest inundated area of 0.31 km^2 – 0.46 km^2 for all year return discharges is situated in Kwala Bekala. Whereas the smallest inundated area of 0.02 km^2 – 0.03 km^2 for all year return discharges is in Merdeka.

3.5. Flood Risk Estimation

In this study, the estimated risk due to floods was calculated based on the inundation area and the number of residents and houses damaged in a sub-district. The value of the risk of flood loss is calculated with reference to the explanation by the Ministry of National Development Planning, Republic of Indonesia on the assessment of damage and losses after the flood disaster in Jabodetabek which occurred early February 2007,

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In the estimation, the cost of loss, representing the flood risk, was calculated using the following classification: missing, major damage, and minor damage as described in the explanation by the Ministry. The type of classification could be identified based on the damage zone on which the houses was located. The determination of the zone was based on the depth of flood as shown in Figure 5. The results of estimated flood risk for each return period are described in Table 2 suggesting that the total loss may range from 35 billion rupiah for Q_{10} up to 53 billion rupiah for Q_{100}.

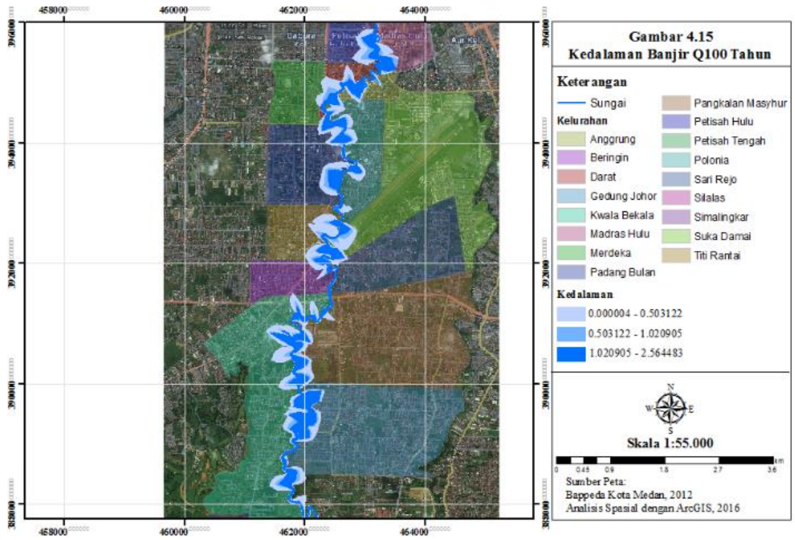

Figure 5. Damage zones based on the flood depth

Table 2. Estimated cost of flood risk

Kecamatan	Kelurahan	Estimated Cost			
		Q_{100}	Q_{50}	Q_{25}	Q_{10}
Medan Petisah	Petisah Tengah	Rp 204,491,326	Rp 185,028,430	Rp 160,590,712	Rp 137,025,771
Medan Baru	Darat	Rp 2,153,863,249	Rp 1,948,864,741	Rp 1,691,467,511	Rp 1,443,263,039
	Merdeka	Rp 367,559,823	Rp 332,576,537	Rp 288,651,334	Rp 246,294,888
	Padang Bulan	Rp 5,415,018,282	Rp 4,899,632,419	Rp 4,252,511,156	Rp 3,628,501,367
	Petisah Hulu	Rp 2,671,197,829	Rp 2,416,960,904	Rp 2,097,739,652	Rp 1,789,919,160
	Titi Rantai	Rp 2,996,997,607	Rp 2,711,751,996	Rp 2,353,596,072	Rp 2,008,231,431
Medan Polonia	Anggrung	Rp 1,703,793,438	Rp 1,541,631,279	Rp 1,338,019,601	Rp 1,141,679,768
	Polonia	Rp 9,596,275,896	Rp 8,682,929,961	Rp 7,536,127,891	Rp 6,430,283,037
	Sari Rejo	Rp 615,087,622	Rp 556,545,352	Rp 483,039,362	Rp 412,158,586
	Madras Hulu	Rp 1,603,903,967	Rp 1,451,249,001	Rp 1,259,574,605	Rp 1,074,745,723
	Suka Damai	Rp 717,216,607	Rp 648,953,994	Rp 563,243,089	Rp 480,593,288
Medan Selayang	Beringin	Rp 1,512,227,015	Rp 1,368,297,598	Rp 1,187,579,047	Rp 1,013,314,730
Medan Johor	Kwala Bekala	Rp 11,615,386,061	Rp 10,509,867,029	Rp 9,121,771,384	Rp 7,783,250,583
	Pangkalan Masyhur	Rp 5,886,226,643	Rp 5,325,992,523	Rp 4,622,559,549	Rp 3,944,249,180
	Gedung Johor	Rp 5,575,224,667	Rp 5,044,590,821	Rp 4,378,324,109	Rp 3,735,852,636
Total		Rp 52,634,470,030	Rp 47,624,872,584	Rp 41,334,795,073	Rp 35,269,363,187

3.6. Evacuation Centres and Evacuation Paths

Referring to the guidelines described in the section 2.2, we selected 6 evacuation centres and their associated evacuation paths using the GIS layers including the inundation, road infrastructures, and administrative. The results shown in Figure 6 can be delineated as follows:

- Open field next to Medan Fair Plaza at Jl. Gatot Subroto was the evacuation centre for Kelurahan Petisah Hulu.
- Gajah Mada Park at Jl. Gajah Mada was the evacuation centre for Petisah Hulu sub-distrct, Merdeka village, and Land village.

- Ahmad Yani Park at Jl. Jendral Sudirman was the evacuation centre for Madras Hulu and Kelurahan Anggrung sub-districts.
- The vacant lot of Polonia Airport parking lot at Jl. Polonia was the evacuation centre for Polonia, Suka Damai, and Anggrung subdistricts.
- Private Elementary School at Jl. Ngumban Surbakti was the evacuation centre for Kelurahan Padang Bulan, Kelurahan Titi Rantai, and Kelurahan Beringin.
- The complex of Asrama Haji at Jl. A.H. Nasution was the evacuation centre for Kelurahan Pangkalan Masyhur, Kelurahan Kwala Bekala, and Kelurahan Gedung Johor.

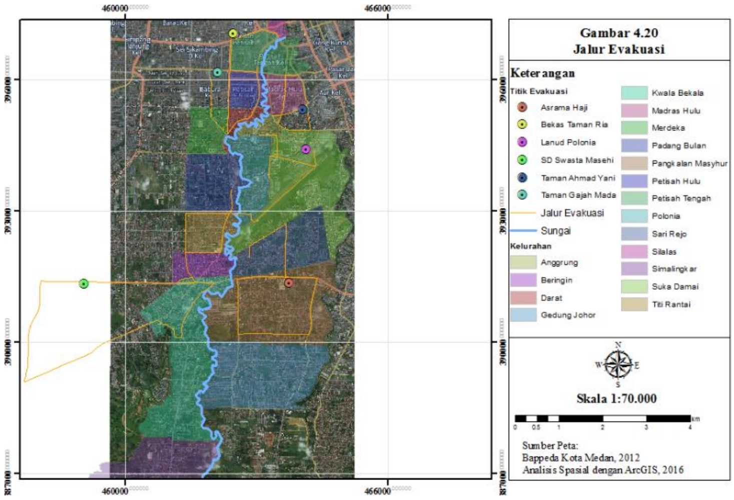

Figure 6. Evacuation centres and paths

Having selected 6 evacuation centres, we were able to recommend 15 evacuation paths to reach the centres as shown in Figure 6. Two evacuation paths are given below as examples to reach 2 evacuation centres for Petisah Hulu sub-district:

>Jl. S. Parman - Jl. Sultan Hasanuddin – Jl. Gajah Mada - Jl. S. Parman Street – Jl. Gatot Subroto

>Jl. S. Parman - Jl. Hayam Wuruk – Jl. Iskandar Muda – Jl. Gajah Mada

4. Concluding Remarks

We were able to demonstrate the applicability of GIS to help visualize flood prediction and spatially analyse the flood related problems along the Babura River. From the flood prediction, it is estimated that the total inundated area extends from 1.70 km^2 for Q_{10} to 2.34 km^2 for Q_{100}. The inundation would likely occur in 5 districts involving 13 sub-districts: Kelurahan Darat, Merdeka, Padang Bulan, Petisah Hulu, Titi Rantai, Anggrung, Polonia, Madras Hulu, Suka Damai, Beringin, Kwala Bekala, Pangkalan Masyhur, dan Gedung Johor. The total flood risk may range from 35 billion rupiah for Q_{10} up to 53 billion rupiah for Q_{100}. Six suitable evacuation centres were suggested: Asrama Haji, open field next to Plaza Medan Fair at Jl. Gatot Subroto, Polonia Airport, Ahmad Yani Park, Gajah Mada Park, and Private Elementary School at Jl. Ngumban Surbakti. The recommended evacuation routes to these evacuation centres consist of 15 alternative paths. In the spirit of mitigation efforts, it is hoped that the flood prediction and its risk estimation in this study will inspire the preparedness of the stakeholders for the probable threat of flood disaster, especially within the Babura sub-watershed.

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