International Journal on Advanced Science Engineering Information Technology

Vol.8 (2018) No. 6
ISSN: 2088-5334

Investigation of Pangkalan Floods: Possible Reasons and Future Directions

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***Abstract*— Two flood events in Pangkalan, Lima Puluh Kota Regency on 3 March and 29 December 2017 have triggered some questions whether a dam downstream the catchment is solely responsible, or they were caused by other factors. In fact, several other major floods have been recorded after dam commission in 1998. Yet, the catchment have undergone rapid land use conversion into commercial plantation such as palm and Uncaria gambir Roxb (gambir) since mid-1990's. To understand the flood, three contributing factors i.e. flood inundation by the dam and river tributaries, land use changes, and rainfall data were discussed and analysed, and some field works were conducted along the main river and flooded areas. Flood inundation was estimated using Digital Elevation Models (DEM) of 30 m in resolution and modeled using QGIS. Land use changes from year 1994 were analysed from Landsat and EVI (Enhanced Vegetation Index) time series. Rainfall data were collected and analysed using nearby station from year 1980. Flood inundation analysis showed that dam spillway at an elevation of 80 m is unlikely the main reason, since maximum flood elevation occurred at 92 m. Rather, the flood was likely induced by a constriction due to rock in the river at midstream catchment, since flood inundation model using this scenario exhibited similarities to the impacted areas. Furthermore, land conversion from forest to palm plantation and gambir was thought to increase runoff and also contributed to the floods. Yet, this manuscript needs to be followed by a model with reliable data such as river topography and high resolution DEM and automatic water level recorder (AWLR).**

***Keywords*— flood; inundation; EVI; Landsat; land use.**

I. INTRODUCTION

Two flood events in Pangkalan District, Lima Puluh Kota Regency in a single year has caused considerable loss of properties and widespread social impacts. The first one on 3rd March 2017 affected at least 50 sq.km. The second flood was on 29th December 2017 affected a smaller area in the upstream, but its effect on transportation is comparable. In fact, in the last two decades, at least four big floods have been recorded. Some believe that the presence of a hydropower dam downstream the river is responsible for the disaster [1] since flood frequency has increased since the dam was built in 1996. In 1998, two big floods struck the same area, emerging a lot of debates and decline in the presence of the dam. However, recently, illegal logging in the upstream catchment and rapid land conversion from forest to palm plantation in the last two decades was thought as a contributing factor. This study aimed to provide insight into possible causes and future directions of the floods for further study and mitigation purposes.

Flood is as an event that channel capacity is exceeded [2]. Regarding the discharge increase, there are some reasons for this occurrence, such as land use changes [3], and climate changes [4]–[6]. At the local scale, poor channel maintenance and management may cause channel blockage and contraction. Dam construction may cause a reduction in channel capacity when deposited sediment is not removed [7]. In transboundary of Bulgaria, Turkey, and Greece, the presence of dams has caused some floods upstream to the dam [8].

However, flood processes are very complex since it is driven by an intertwined association between climate, land use, geology, and anthropology (human intervention). Soil with high initial moisture and shallow base rock would enable less infiltration than deep soil with the same rainfall intensity. Likewise, multi-layer forest canopy produces higher interception than single-layer canopy or palm plantation. Provided similar soil type and rainfall intensity, the former would generate delayed peak flow than the later.

Recently, rainfall-runoff modeling has been central to flood prediction and mitigation. This is aimed to disentangle various variables and enable future estimation for immediate mitigation strategies. Hence, presenting related variables such as precipitation, land use changes, topography, and human activities in the studied catchment is necessary. Remote sensing data offers unparalleled advantages due to spatial and temporal coverage with now easy access to websites. In some areas and datasets, data availability is limited, and pixel size limits accuracy for the high precision model, particularly at small catchments. Therefore, validation is needed using field works and other methods.

II. Material and Method

A. Study area

The study was conducted at District of Pangkalan, Limapuluh Kota Regency, and West Sumatra Province. The catchment Mahat is situated at 0°2'38.4"- 0°6'50.4" S and 100°37'57.72"- 100°51'10.8" E, covering an area of 3,287 sq. Km (Fig. 1). The catchment has a maximum elevation of 5011 m to a minimum of 28 m. The outlet of the catchment is at Koto Panjang dam, a dam built for electricity from 1993 to 1996. The mainstream of the catchment is Mahat River, with many tributaries from Bukit Barisan mountain range (Figure 2). One of its essential tributaries is River Mangilang, covering an area of 87 sq. km. In the year 2017, two big floods occurred at Mangilang creek. At the Mahat River, there is a contraction due to bed rock expanded to the center of the river.

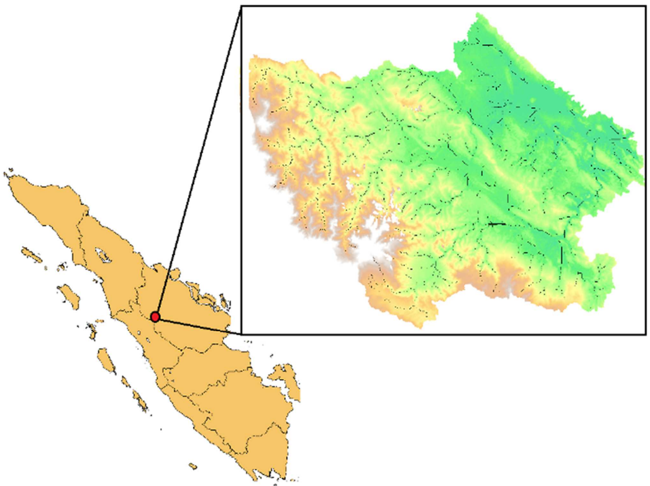

Fig. 1 Mahat Catchment.

B. Terrain Analysis

Terrain analysis was conducted using 30m DEM provided by ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model). Fieldwork was performed on April 6th, 2017, for verification of elevation with high precision GPS. Stream networks were acquired from the Provincial Office for Regional Planning (Bappeda) of West Sumatra Province.

C. Land use

Land use changes were analyzed using two methods. The first one is using MODIS (MODerate resolution Imaging Spectroradiometer) EVI (Enhanced Vegetation Index), MOD13Q1. This dataset consists of 4,800 rows and 4,800 columns of 250 m pixel resolution for every 16 days, available at https://earth explorer.usgs.gov/ from 2000 to now. The EVI is defined as:

$$EVI = \frac{G(\rho_{NIR} - \rho_{Red})}{\rho_{NIR} + C_1\rho_{Red} - C_2\rho_{Blue} + L}$$

Where ρ_{Blue}, ρ_{Red}, and ρ_{NIR} are the reflectance in the blue, red, and near-infrared (NIR) bands, respectively, G is the gain factor (=2.5), and *L* is for the canopy background adjustment (=1). C_1 and C_2 are correction coefficients for aerosols in the red band using the blue band (C_1 = 6 and C_2 = 7.5) [9], [10]. MODIS has 36 bands with wavelengths ranging from 0.4 to 14.4 µm. MODIS EVI has been used to identify plant response to water availability in Korea [11], to map paddy farms in North-Eastern China [12], and to study greenness phenology in Tanzania [13]

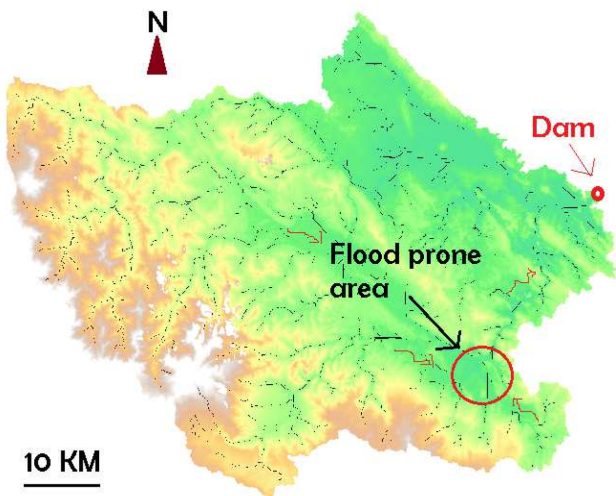

Fig. 2 Mahat catchment with flow directions from its main tributaries.

The second method employs Landsat datasets from 1994 to 2017. Landsat images have been employed to identify land use changes in Ghana [14], in India [15], and to detect land use changes in urban areas [16]. These two methods have both advantages and disadvantages. MODIS EVI is fairly coarse that cannot detect small changes, but it is powerful at large spatial scale. Detecting changes in small-scale farms are very hard.

On the other hand, Landsat offers better resolution and longer temporal scale, but at the tropical forest such as the study catchment, cloud cover is a big challenge. In this study, both methods are complementary to each other. Due to cloud presence, only images with cloud cover less than 10% were processed and presented.

D. Rainfall

Daily rainfall data were collected from a nearby station at Tanjung Pati, 25 km south of the catchment. Data were available from 1978 to 2017. Data were presented in daily maximum every year.

III. Results and Discussion

A. Flood Inundation

Terrain and stream network analysis shows that Mahat catchment comprises many sub-catchments, the biggest one being sub-catchment 3 (Figure 3). Sub-catchment 1, namely Mangilang, and sub-catchment 2, namely Upstream Mahat, meet at a junction just a few meters nearby national road. At this area, river width is between 45-60 meters and depth between 5-7 meters from the bed to the bank. Sub-catchment 3 flows directly downstream of Mahat River before entering the impoundment of the dam. About 650 meters downstream of the junction, there is a big rock, locally known as "Paisok Rock." The rock extends from the river bed up to 14 meters, and as wide as 20 meters from the river bank to the center of the river. In normal flow condition, the rock remains 2 meters above water level (Fig. 4). The junction between Upstream Mahat and the Mangilang River is just upstream a sharp bend with sediment deposit covering almost two-thirds of river width. River slope from Upstream Mahat and Paisok Rock is 0.004, and regular water level at Paisok Rock is at 83 m.above MSL.

Further downstream, spillway level at the dam is 80 m above MSL. In 2017 floods, the most affected area is at Mangilang sub-catchment (sub-catchment 1) and some area downstream sub-catchment 2. Information from local people advised that flood inundation reached a few hundred meters downstream the Paisok Rock.

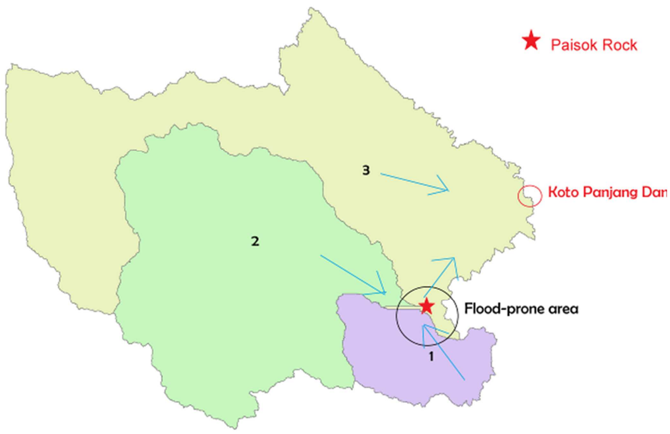

Fig. 3 Sub-catchments in the Mahat Catchment.

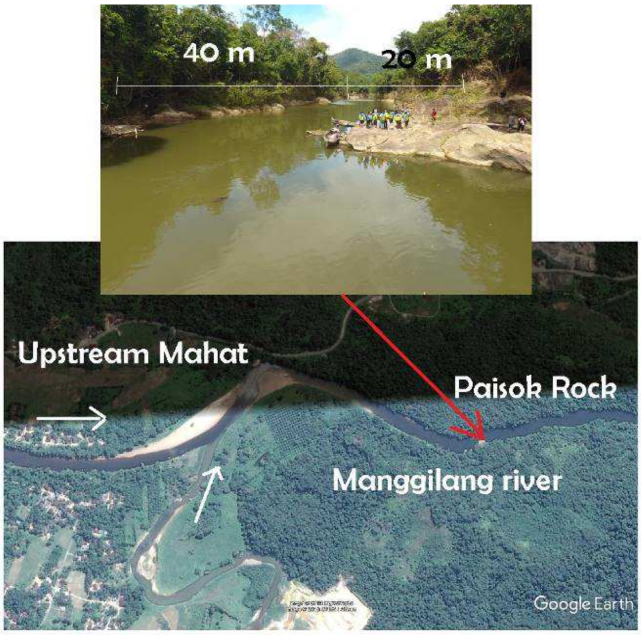

Fig. 4 Paisok Rock downstream junction of Mangilang River and Upstream Mahat River.

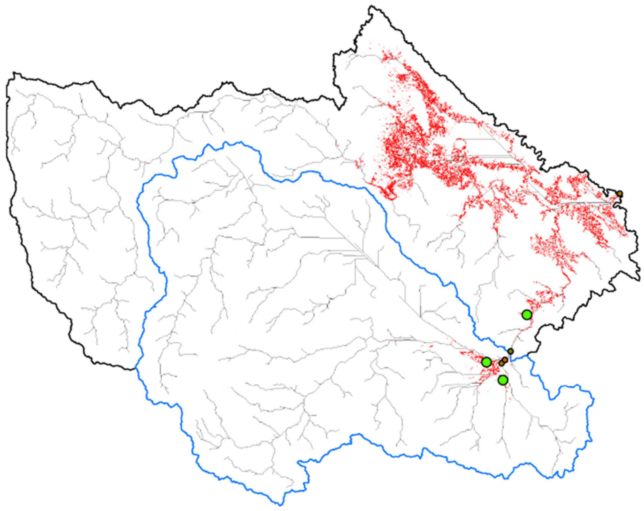

Fig. 5 Scenario 1: dam as bottle neck.

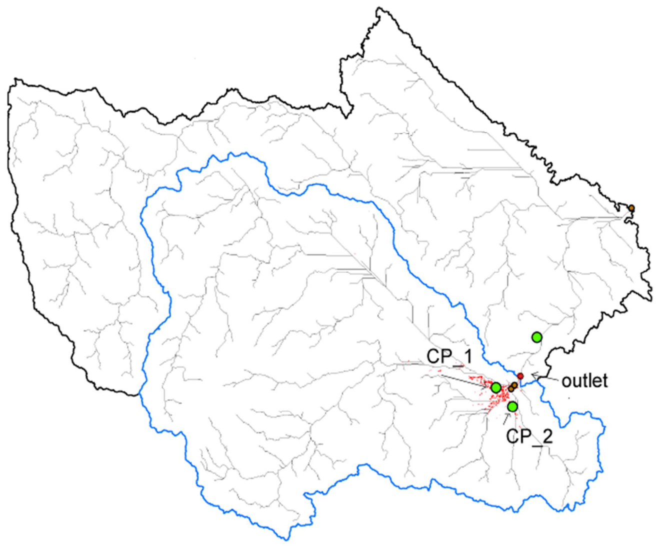

Fig. 6 Scenario 2: outlet as a bottleneck

Fig. 7 CP_1 at Pangkalan Mosque.

Fig. 8. CP_2.

Flood inundation maps of two scenarios are revealed in Fig. 5 and 6. Scenario 1 assumes that runoff from the entire catchment flows directly to the dam. Fieldwork confirmed that maximum water level at 3rd March 2017 was 92 m. Flood inundation reached north-east of the catchment at sub-catchment 3 and a small part at catchment 1 and 2. Scenario 2 assumed that outlet (Fig. 6) act as a bottleneck, so that runoff upstream the outlet would be concentrated from this point upward. Similar to scenario 1, scenario 2 was set to 92m as maximum flood level. Flood inundation covered downstream sub-catchment 1 and 2 at which CP_1 and CP_2 were observed.

Theoretically, scenario 1 would not occur for some reasons. First, hydropower dam operates at an average storage level of 80 m. above this point, an operator opens the gate and flow excess spills downstream to Kampar River. In this map (Fig. 5), water height must be 12 m above the spillway to enable this inundation, far beyond dam capacity. Second, there was no report on flood occurrence in areas that are far from storage and wetlands around the river.

Scenario 2 is likely to occur after the estimation of flood level at CP_1 and CP_2, and reports from local people. Documentation from Pangkalan Mosque (Fig. 7) and a small prayer house (Fig. 8) at the affected areas, coupled with field measurement, confirmed these findings. However, there must be a detail hydraulic modeling at the outlet to estimate hydraulic conditions at the outlet during the flood.

The biggest challenge in modeling this flood is the availability of topographic data in the river and the catchment. The available numerical model for flood prediction such as HEC-RAS and MIKE, coupled with a hydrologic model such as HEC-HMS in the past has been able to estimate flood inundation with various precision between regions [17]–[20]. At Mahat catchment, however, topographic data is rare, and current data only comprises ground elevation at several points. Survey and measurement of the river bed and cross sections are highly needed for an accurate model.

B. Land Use

Land use changes from 1994 to 2018 were analyzed using Landsat datasets with a spatial resolution of 30 x 30 m. However, due to poor cloud cover at some parts of the catchment, only the Mangilang sub-catchment were processed. Land cover was classified into five classes, i.e., forest, barren or sparsely vegetated, farms, shrublands, and water. The upper catchment is mostly covered by heterogeneous forest, particularly along Bukit Barisan mountain range. In the north-east part of Kampar catchment, conversion from forest to palm plantation began in the early 1990s. This can be confirmed using Google earth.

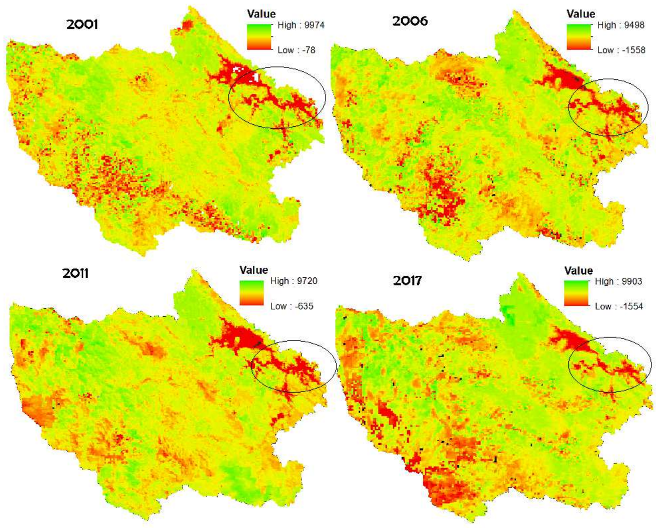

Fig.9 Enhanced Vegetation Index (EVI) from 2001 to 2017. The circled area is dammed impoundment and wetlands.

Paddy farms inhabit a small part of the catchment due to its hilly terrain and water scarcity in the upper part of the hills. Therefore, *Uncaria gambir* Roxb (locally known as *gambir*) is a popular commodity since it can live in hilly terrain and does not need irrigation. This plant is a shrub-like tree, with a height of 1-1.5 m, harvested by cutting its leaves and twigs. Due to increasing demands and stable price, more lands were converted into Gambir's farms at the individual scale. Landsat identified Gambir as shrub lands (Fig. 11). However, Landsat fails to distinguish between palm plantation and forest. Time series from 1994 to 2008 exhibited unusual trends in that total area of forest increased from 1999 to 2004 (Fig. 10). In the same period, Google

Earth showed that in this area, forest declined and converted into palm plantation.

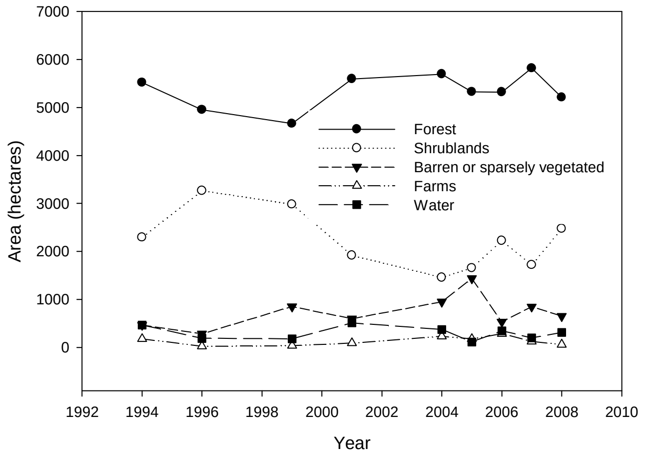

Fig. 10 Land use changes from 1994 to 2008 at Managing sub-catchment.

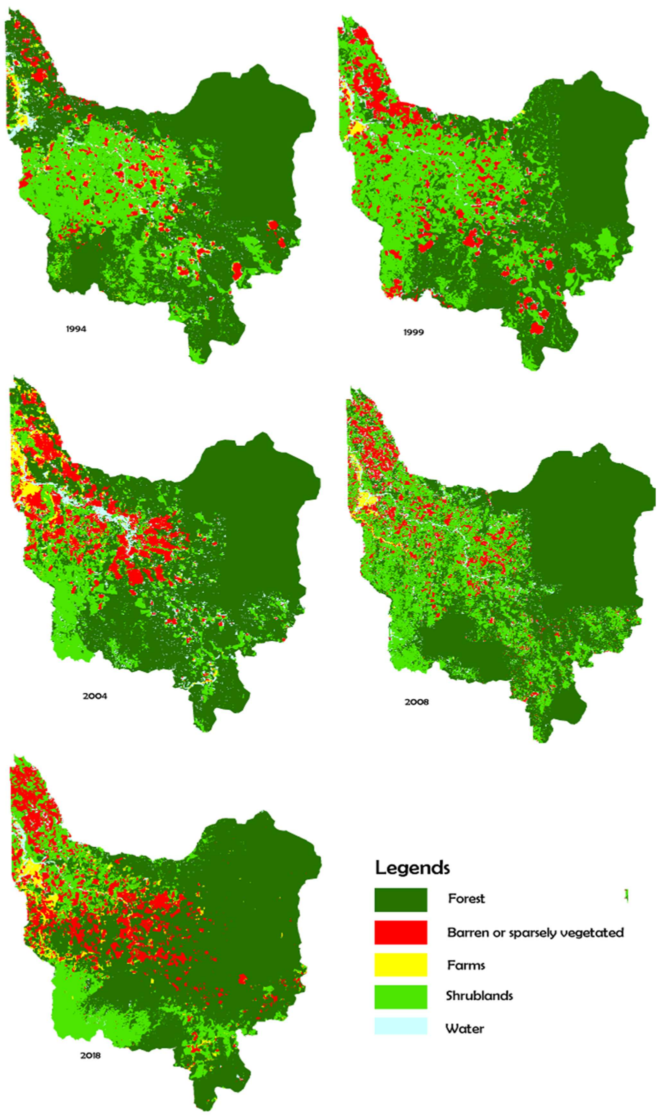

Fig. 11. Landsat land cover classification at Mangilang sub-catchment.

Unlike Landsat data, the EVI (enhanced vegetation index) are fairly cloud-free, thanks to its algorithm and bigger pixel size. However, EVI is only available from 2000 to now. Fig. 9 shows that changes were mostly observed in the upper and middle catchment. However, since EVI data only comprise 2001-2017, land use changes before 2001 were not presented. Considering that fundamental changes occurred in the early 1990s, there needs a mean to trace the data back to 1990s using AVHRR NDVI (Average Very High-Resolution Radiometer-Normalized Difference Vegetation Index), an index similar to that of the EVI [11].

C. Rainfall

Rainfall data since 1980 reveals that maximum daily rainfall at Pangkalan reached 211 mm on 5th October 1980 (Fig. 12). The second highest recorded was 145 mm on 22nd January 2010. On the day of the flood on 3rd March 2017 daily rainfall reached 50 mm, but this has been preceded by rainfall on two consecutive days on the first and the second of March. However, due to unavailability of rainfall intensity, it was difficult to estimate hourly rainfall and duration.

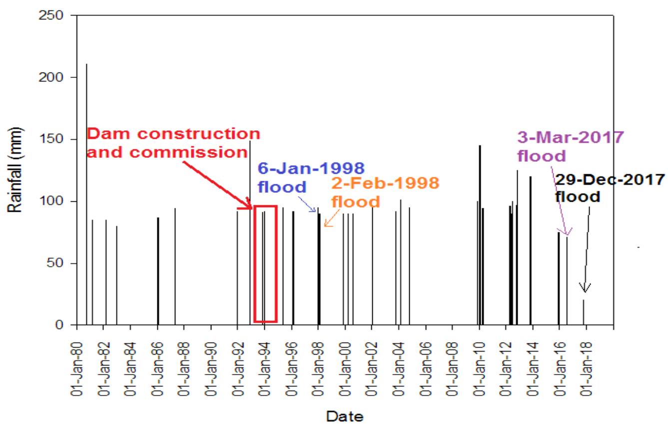

Fig. 12. Maximum Daily Rainfall at Tanjung Pati Station.

Rainfall record exhibits some critical information on the occurrence of floods in Pangkalan. Before dam construction and commission from 1993 to 1996, a rainfall of twice higher than that of the 1998 rainfall that caused the first big flood after dam commissioning has been recorded in this area. Although the intensity is unknown, this magnitude is classified as very high and rare compared to the rest of West Sumatra [21]. No flood was reported this year. On the other hand, two high rainfall of 95 and 90 mm on 6th January and 2nd February, respectively, has resulted in floods on these days.

Likewise, in 2017 floods, two rainfall similar to that of the 1998 flood also caused floods but at a different scale. On 3rd March 2017, rainfall on three consecutive days on 1st, 2nd, and 3rd of March with daily rainfall of 19, 2.2, and 50.3 mm, respectively, caused a flood in sub-catchments 1 and 2. On 29th December 2017, the flood covered mostly in sub-catchment 1 with sub-catchment 2 nearly unaffected. On this date, the recorded rainfall was 19.2 mm or less than one-third of the 3rd March event. Although this rain is much less, the topographic conditions of the area and the river morphology are the main reasons for the flood. Sub-catchment 1 is steeper with fan-like catchment. Steep and short tributaries direct to the mainstream. The mainstream is narrow and winding. Field observation after the flood suggested that downstream the congested river, flood effect was negligible and therefore sub-catchment 2 was unaffected.

IV. Conclusions

Three factors, *i.e.* dam impoundment, land use changes, and rainfall have been discussed as possible cause of Pangkalan floods, particularly the two floods in 2017. Our initial model shows that dam is not solely responsible for the 2017 floods. There are other factors such as river morphology that affect hydraulic conditions of the flow. River constrictions downstream the flooded areas may also be a dominant factor during peak flow. Land use changes may be a dominant factor since the conversion to commercial plantation without considering land, and water conservation will result in quicker catchment response to rainfall. Palm and Gambir plantation create unhealthy catchments due to poor infiltration and high runoff.

High daily rainfall would also be responsible for the flood events. However, lacking rainfall intensity data is the main obstruction for the accurate hydrologic model. The absence of automatic water level recorded in the upper and middle catchment further exacerbates hydrologic and hydraulic modeling.

However, due to the inherently complex nature of hydrology-hydraulic processes in flood occurrence, a study in this area needs to be supported by sufficient data for modeling as well as verification purposes. In order to comprehensively understand the problem, some efforts must be made to ensure that the data are available for modeling purposes. The use of remote sensing data such as EVI, rainfall, and Landsat must be complementary to ground-measured data. Hence, reliable data is the key to the success of understanding the floods for better mitigation and preparedness and to reduce loss and victims.

This manuscript is not meant to find a definite answer to the problem comprehensively, but it gives an insight into contributing factors for further study.

Acknowledgments

This research is partly funded by a research grant from the Ministry of Research and Higher Education, Republic of Indonesia, 2017-2018.

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