Initial investigation of hydraulics engineering for flood mitigation: A case study in Krueng Aceh Sub-watershed

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Abstract. Problem of flooding in the Krueng Aceh Sub-watershed occurs almost every year, thus, the study is conducted. This article aims at the initial study of flood mitigation investigations in the Krueng Aceh Sub-watershed, which consists of an analysis of existing channel hydraulics and an ideal design plan at the study site for hydrological analysis of the Sub-watershed. In addition to the analysis of channel hydraulics, analysis of the safety factors of existing channel cliffs and plans is also carried out. In addition to flood mitigation in the form of redesigning existing canals, this article proposes the construction of an earth-embankment dam. In the analysis of this existing channel, discharge is obtained by 1098.857 m³/s. When compared with the design flood discharge for a period of 100 years, the channel discharge capacity cannot accommodate flood discharge. With the redesign of the channel, the storage capacity can accommodate the flood discharge with a safety factor of 2.804, greater than the existing channel of 2.711. Earth-embankment dam is proposed with a safety factor of 3.497. Further studies need to be done flood routing to find out how much the contribution of the dam reservoir to the reduction of flooding in the study area.

1. Introduction
Flood disaster becomes a threat for every region worldwide [1-3]. Both developed and developing countries tried to figure out the proper mitigation according to special characteristics in the region. Many ways are investigated, including structural and non-structural ways of flood disaster mitigation [4–8]. Both methods have each benefits to tackle flooding in certain regions. Structural ways [8] provide flood reduction in huge amount of discharge because of its structural characteristics and non-structural ways seem effective in urban areas. Due to the research area location, a structural way prospects better choice to reduce the flooding. In Indonesia, a structural way is still more popular for flood adaptation and social resilience towards the disaster [9]. Since every region has a different treatment for the mitigation, this research aims to investigate the initial phase of flood disaster adaptation in Aceh province.

The Krueng Aceh Sub-watershed has a flat, wavy, hilly, and mountainous physiography that is generally located in Aceh Besar District. The area with a flat topography (0-8% steep slope) is 46,487.29 ha (23.50%) of the total area of the Krueng Aceh Sub-watershed. Furthermore, the wavy area (8-15% steep slope) is 26,421.16 ha (13.35%), hilly (15-25% steep slope) is 9,338.96 ha (5%) and slightly mountainous (25-40% steep slope) is 2,368.86 ha (1.20%), and the rest is mountainous areas (> 40% steep slope) covering an area of 113,236.06 ha (57.23%). The Krueng Aceh Sub-watershed consists of several Sub-watersheds, namely the Krueng Seulimeun Sub-watershed, the Krueng Keumireu Sub-watershed, the Krueng Inong Sub-watershed, and the Krueng Jreub Sub-watershed, and the downstream part of Krueng Aceh. All water flows from the Sub-watershed are concentrated into the main river, namely the Krueng Aceh River, which empties into the downstream of the watershed (Lampulo-Banda Aceh). To anticipate flooding in Banda Aceh City, the Krueng Aceh river water flow is also heading to Alue Naga, Banda Aceh City. Thus the flow of the Krueng Aceh River in the downstream of its...
watershed is divided into these two areas. Based on data for the last ten years, from 2000 to 2009, the climate in the Krueng Aceh Sub-watershed is classified as wet Sub-watershed with a value of 0.3077, and the average annual rainfall is of 1225.9 mm with an average of 145 rainy days. According to climatology station in Krueng Aceh Sub-watershed, from 2000 to 2009, the highest amount of rainfall occurred in 2009, 1,772 mm/year, while the lowest was in 2008 with the amount of rainfall of 1,207.4 mm/year. By these condition, Krueng Aceh Sub-watershed faces flood disasters in frequent events with few mitigation efforts.

In this study, the research aims to design and to investigate flood mitigation by conducting hydraulics engineering. The stages involve using rainfall analysis methods, the estimating of flood discharge, and the using of several software, including HEC-RAS, Geo-studio, and others, to determine the mitigation planning in the study area.

2. Methods

2.1. Average maximum rainfall
This method estimates the area represented by each station, the rainfall intensity, and the number of a station in the sub-watershed. Polygons are created by connecting the lines of the shortest diagonal weight of the rain station used. The average rainfall calculation is done by taking into account the area of influence of each station. This method can be used if there are at least three rain stations under review, and the coordinates of the rain stations are known. The calculation step of this method begins by creating a polygon for each rain station. After the polygon was formed, the Thiessen coefficient was calculated. For more details, here are the steps for calculating regional rainfall with the Thiessen method [10]: 1) determine the rain station being reviewed; 2) find the maximum daily rainfall from each rain station; 3) plot the rain station according to the coordinates of the rain station onto the map; 4) draw a Thiessen Polygon; 5) calculate the area that represents each station; and 6) calculate the rain for the area using the following formula:

$$\bar{p} = \frac{A_1x_1 + A_2x_2 + \ldots + ANx_n}{A_1 + A_2 + \ldots + A_n} \quad (1)$$

where,

- $\bar{p}$ = average rainfall intensity in the sub-watershed
- $x_1, x_2, \ldots, x_n$ = rainfall intensity in the station 1, 2, ..., n
- $A_1, A_2, \ldots, A_n$ = area of the station from polygon analysis

2.2. Flood return period
The rainfall data was processed to obtain the flood discharge by employing Nayakasu synthetic hydrograph unit (SHU) [11]. In the calculation of the synthetic Nakayasu SHU, it is necessary to calculate the distribution of rainfall and effective rainfall. Rainfall distribution uses the Mononobe formula, and effective rainfall is obtained using the Curve Number method. The formula for determining the peak discharge value for the Nakayasu synthetic hydrograph unit is as Equation 2:

$$Q_p = \frac{AR_0}{3.6(0.3T_p + T_{0.3})} \quad (2)$$

where,

- $Q_p$ = peak flood discharge (m³/s)
- $R_0$ = rain unit (mm)
- $T_p$ = interval from the start of rain to the peak of the flood (hours)
\[ T_{0.3} = \text{the time taken by the decrease in discharge, from peak to 30\% of the peak discharge} \]
\[ A = \text{area of flow to an outlet (km}^2\text{)} \]

### 3. Result and Discussion

#### 3.1. Rainfall Analysis

The location of the research is the Krueng Aceh Sub-watershed, which is located in the city of Banda Aceh. The map of the Krueng Aceh Sub-watershed can be seen in the following figure.

After plotting the location of the rain station, then proceed with making a Thiessen polygon, as depicted in Figure 2, with the following steps: 1) Connect each rain station point with a line, 2) Each connected line is taken its midpoint, 3) From the midpoint, perpendicular lines are drawn so that they intersect one another, and 4) The intersecting lines are the division of the rain area.

![Figure 1. Study area of Krueng Aceh Sub-watershed [12]](image1)

![Figure 2. Thiessen polygon of the sub-watershed](image2)
The rainfall intensity data was collected by using secondary data from three rainfall stations, as depicted in Table 1. The average maximum rainfall intensity was obtained by using the Equation 1 and thiessen polygon result, which could be observed in Table 1.

| Year | Iskandar Muda station | Mata’ie station | Blang Bintang station | Average maximum rainfall intensity |
|------|-----------------------|-----------------|------------------------|-----------------------------------|
| 2009 | 25.22                 | 88.48           | 8.52                   | 40.74                             |
| 2010 | 54.00                 | 80.67           | 9.37                   | 48.02                             |
| 2011 | 22.67                 | 61.15           | 7.39                   | 30.40                             |
| 2012 | 17.32                 | 57.90           | 7.57                   | 27.60                             |
| 2013 | 10.95                 | 71.56           | 5.68                   | 29.40                             |
| 2014 | 23.69                 | 51.40           | 8.14                   | 27.74                             |
| 2015 | 24.20                 | 53.35           | 17.23                  | 31.59                             |
| 2016 | 32.86                 | 70.91           | 10.23                  | 38.00                             |
| 2017 | 28.28                 | 72.86           | 10.79                  | 37.31                             |
| 2018 | 47.64                 | 93.03           | 7.57                   | 49.41                             |

The maximum rainfall intensity data was computed to obtain the design flood by employing the Nakayasu method, then the maximum design flood discharge for the 5, 10, 25, 50, 100, 500, 1000 years return period were obtained. The maximum design flood discharge data will be used for hydraulic analysis of the channel, as shown in Table 2. The data still needs calibration to validate the result, meanwhile AWLR (Automatic Water Level Recorder) data is limited in the study area to collect.

| Return period | 5       | 10      | 25      | 50      | 100     | 500     | 1000    |
|---------------|---------|---------|---------|---------|---------|---------|---------|
| Flood discharge (m$^3$/s) | 1410.027 | 1699.412 | 2069.784 | 2419.644 | 2762.944 | 3479.966 | 3806.259 |

The existing hydraulics capacity was conducted and resulted 1098.857 m$^3$/s water volume which could be accommodate by the channel. When compared with the design flood discharge for the 100-year period, the discharge storage channel cannot accommodate the flood discharge because, the flood volume is greater than the hydraulics channel capacity.

| Properties   | Dimension |
|--------------|-----------|
| Upper width  | 75 m      |
| Base width   | 51 m      |
| Height       | 11 m      |
| Slope        | 0.000718  |
| Flow velocity| 4.775 m/s |

Because of this condition, a new design channel is proposed in this research. In this design channel analysis, the discharge storage channel is 3308.754 m$^3$/s, which is 119.75% of the 100-year flood return discharge. When compared with the design flood discharge for a 100-year period, the discharge storage channel can accommodate the flood discharge because, the discharge storage channel is greater than the maximum discharge for a 100-year return period. The detail design is figured out as following Table 3.

3.2. **HEC-RAS and Geo-studio modelling**

The new design of the channel was modelled by using HEC-RAS [13-15] software to visualize the water level of the channel with 100-year discharge return period, as depicted in Figure 3.
Figure 3. HEC-RAS model of the new design channel in the (a)-(c) upper stream part, (d)-(f) middle stream part, and (g)-(i) downstream part of the channel

Moreover, the slope stability of the riverbank was observed by using Geo-Studio software [16, 17]. The existing channel gives the slope stability value of 2.711 and the new proposed design channel provides greater value with 2.804. Figure 4 and Figure 5 are the result of slope stability analysis for existing and new channel conditions, respectively.

Figure 4. Slope stability analysis of the existing channel

Figure 5. Slope stability analysis of the proposed design channel
In flood mitigation, structural ways are connected with physical structures of water infrastructure, such as river channel and river dam. Hence, HEC-RAS as river modelling supporting tool and GeoStudio as slope stability modelling supporting tool for dam or channel could be called as structural mitigation software.

3.3. Earth-embankment dam: initial analysis
This research also provides initial investigation of the possibility of earth-embankment dam [18], [19] to be constructed in the study area. With the secondary data of rainfall intensity, climate data, and flood volume estimation, the dam design is depicted in Figure 6, with the dam dimensions are:

- a. Height of dam = 99.38 m
- b. Height of water = 85 m
- c. Width of crest = 22.92 m
- d. Width of core base = 205 m
- e. Upstream slope = 1:3.5
- f. Downstream slope = 1:3.2

After safety factor and flow nets analysis, the dam gives the value of 3.497 which indicates safe category of hydraulics structure, as depicted in Figure 7 and Figure 8. To reach the flood reduction analysis, future research needs water level data and reservoir analysis. Hence, flood volume reduction level could be visualized.

![Figure 6. Proposed design of earth-embankment dam](image)

![Figure 7. Safety factor analysis of proposed earth-embankment dam design](image)
Figure 8. Flow nets analysis with steady flow condition

4. Conclusion
Since this initial investigation for flood mitigation in the study area, the existing channel could not accommodate the 100-year discharge return period. Hence, the proposed design of the channel in this research confirms that the future flood volume could be accommodated. In addition, the new design channel provides higher safety factor of river bank. To conclude, the rehabilitation of river channel through hydraulics engineering seems to obtain successful path for flood mitigation in the study area. Meanwhile, data validation and more primary data are needed to obtain more comprehensive result of the study in the future. The condition also applies to the data quality and availability for earth-embankment dam analysis.

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