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Stream Analysis and Protection For Urban Area Case Study: Tembagapura, Papua

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Abstract

The problem with an urban area, which close to river that has steep slopes and fluctuated intensity of rainfall, is that flood might occur during rainy season while in the dry season the area is lack of sufficient water supply. This condition and situation normally can be solved by constructing a dam to control the discharge and manage the expected quantity of water. However, the geological condition of the area has also contributed to the flood with large amounts of debris (and sometimes boulders) which carried onto downstream area and caused damage to residential infrastructures. This study is conducted to find suitable approaches to decrease flood velocity which implicates in reducing the peak flood discharge and momentum to transport debris and boulder, as well as give assurance of safe water passage. The analysis is done by iteration in reducing river-bed slope to get stable regime, at the same time protect the residential area from excess debris and normalize the river at selected sections and critical banks. The result suggested installation of series of check dams to trap debris material and use it to build mild bed slope, along with providing sufficient channel capacity to convey at least 50-year flood return period, with additional consideration of using dolos and gabion to stable the riverbanks.
Keywords: *Flood Control, Urban Area, Stream Protection, Debris Transport*

Abstrak

Permasalahan pada daerah perkotaan yang dekat dengan sungai yang memiliki kemiringan lereng yang curam dan intensitas curah hujan yang fluktuatif, banjir dapat terjadi pada musim hujan sedangkan pada musim kemarau daerah tersebut kekurangan pasokan air. Kondisi dan situasi ini biasanya dapat diatasi dengan membangun bendungan untuk mengontrol debit dan mengatur kuantitas air yang diharapkan. Namun, kondisi geologis daerah tersebut juga berkontribusi terhadap banjir dengan sejumlah besar puing-puing (dan kadang-kadang bongkahan batu) yang terbawa ke daerah hilir dan merusak infrastruktur pemukiman. Studi ini dilakukan untuk menemukan pendekatan yang sesuai untuk mengurangi kecepatan banjir yang berimplikasi pada pengurangan debit puncak banjir dan momentum untuk mengangkut puing-puing dan batuan, serta memberikan jaminan aliran air yang aman. Analisis dilakukan dengan iterasi dalam mengurangi kemiringan dasar sungai untuk mendapatkan rezim yang stabil, pada saat yang sama melindungi kawasan pemukiman dari puing-puing berlebih dan menormalkan sungai pada ruas-ruas terpilih dan bantaran kritis. Hasilnya menyarankan pemasangan serangkaian bendungan untuk menjebak material puing-puing dan menggunakannya untuk membangun kemiringan dasar yang ringan, bersama dengan menyediakan kapasitas saluran yang cukup untuk mengalirkan setidaknya periode ulang banjir 50 tahun, dengan pertimbangan tambahan menggunakan dolos dan bronjong untuk menstabilkan tepi sungai.
Kata Kunci: *Pengendalian Banjir, Kawasan Perkotaan, Perlindungan Aliran, Transportasi Puing-Puing*

INTRODUCTION

To have a sustainable and safe urban area, the local government needs to aware of any possible threat that might occur in the region. Many fast-growing world populations are living in urban areas, and this is only expected to grow more in the coming decades (USAID, 2001). Most of the urban areas are exposed to natural hazards, such as flooding, storms and land-subsidence depend on their location. Urban areas also have a varying degree of vulnerability; depending on the level of development, the coping capacity and the effectiveness of risk reduction strategies that have been implemented. Beside flood, in the area which surrounding by steep slopes and has fluctuated intensity of rainfall, the threat could come in the form of debris flow. The debris flows can be triggered by intense rainfall, by dam-break or by land-sliding that may or may not be associated with intense rain. In order to prevent debris flows reaching property and people, a debris basin, such Sabo dam, may be constructed. Debris basins are designed to protect soil and water resources or to prevent downstream damage. Such constructions are considered to be a last resort because they are expensive to construct and require commitment to annual maintenance (FWS, 2013).

This study gives an example of stream and urban area protection calculation where flood with debris flow often occur in rainy season, together with a strategy to manage safe water passage and obtain sufficient fresh water as city water supply during the dry season.

Study Area

The study area is the Tembagapura Town which located in Mimika Regency, Papua Province, Indonesia (see figure 1). The town is situated on a high land area by the height between 2000 and 2400 meters above sea level, surrounded by hills and has two main rivers with many streams in the upstream part.

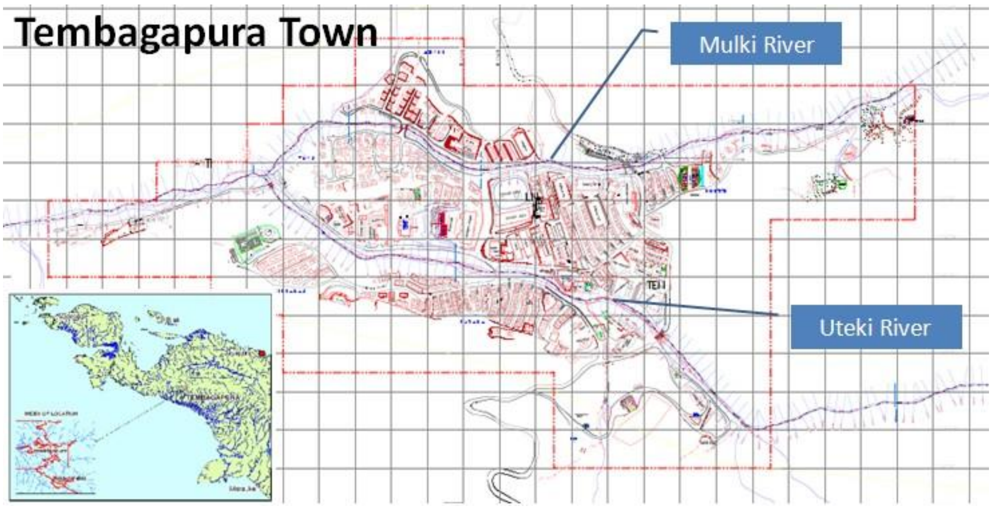


Figure 1. Tembagapura Town Site Area

Hydrological condition

From the rainfall records, Tembagapura has maximum monthly rainfall about 550 mm during September to October, while reached only about 330 mm in June. The range of number of rainy days is between 11 to 30 days throughout the month. The Intensity- Duration-Frequency (IDF) curve from 2021 record is shown in figure 2.

Catchments in Tembagapura are divided into two sub-catchments which surface water flow directly through two rivers, namely Mulki River and Uteki River. Mulki sub- catchment has area about 3.82 km2 and Uteki sub-catchment has about 7.46 km2. Both rivers flow towards western part of the region and merged in downstream area as Banti River (figure 3). Those rivers have a high discharge only in the rainy season while in the dry season they have a small discharge so that they cannot fulfill fresh water needs for Tembagapura town.

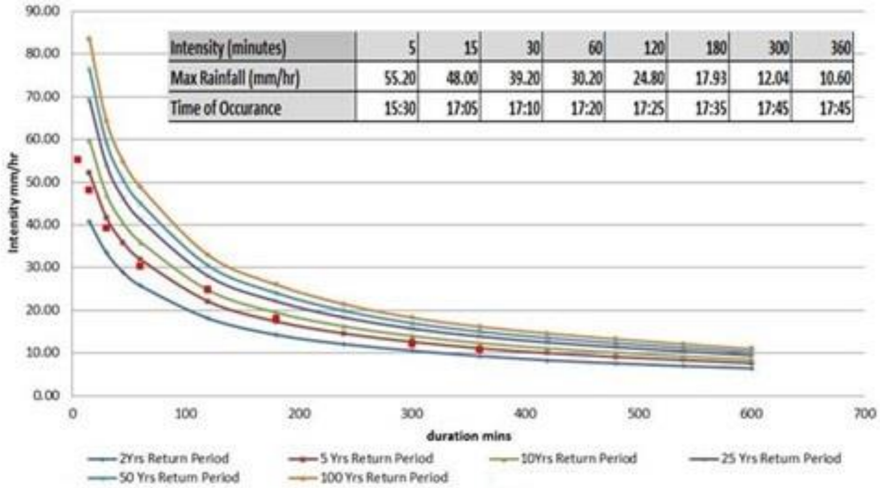


Figure 2. IDF-Curve of Tembagapura (2021 records)

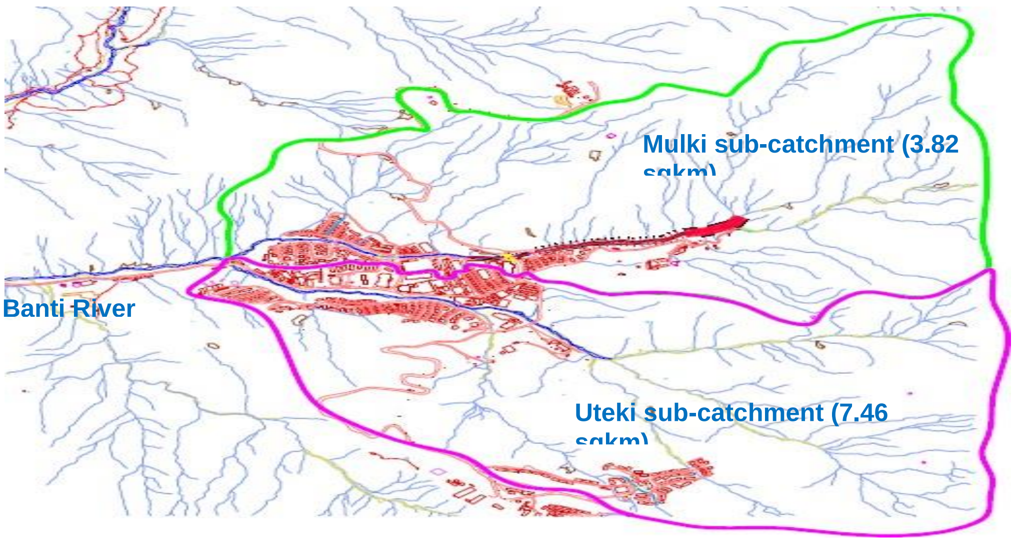


Figure 3. Two main catchment areas of Tembagapura

Geological condition

The geological condition of Tembagapura town site consists of predominantly moderate to complete weathering, red and green mudstone and siltstone inter-bedded with fresh to moderate weathering, red, green and white sandstone and minor conglomerate. These rocks are classified as a part of the Tipuma Formation and Kopai Formation (figure 4) which have metamorphosed.

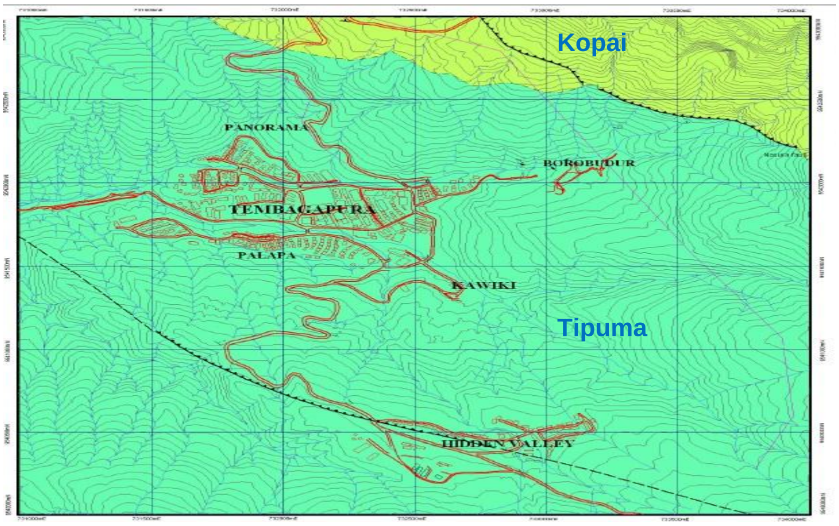


Figure 4. Geological map of Tembagapura site

The Tipuma and Kopai Formations are defined by Visser and Hermes (1962) and have been described in detail by geology investigation. The interpretation of aerial photograph and direct mapping has succeeded in categorizing the slope range and its characteristics as well as the distribution of landslides. The correlation among distribution of landslide and slope range is also shown in table 1 below. It has been identified that the landslides often occur at the slope range between 30% and more than 70%.

Table 1. Slope range and its characteristic

No	Slope Range	Town site (Tembagapura)		Characteristic Terrain Condition	Southern Slope		Northern Slope		Eastern Slope		Tembagapura Slope	
		Area (km²)	Percentage (%)		Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%
1	7 – 15 % (4º – 8º)	0,492	5,455	Sloping	-	-	-	-	-	-	0,38	51,35
2	15 – 30 % (8º – 16º)	0,703	7,795	Moderately Steep	0,03	0,79	-	-	-	-	0,32	43,24
3	30 – 70 % (16º – 35º)	1,882	20,867	Steep	0,87	22,96	0,34	12,83	0,29	26,85	-	-
4	> 70% (> 35º)	5,942	65,883	Very Steep	2,92	76,25	2,31	87,17	0,79	73,15	0,04	5,41
	Total	**9,019**	**100**		**3,79**	**100**	**2,65**	**100**	**1,08**	**100**	**0,74**	**100**

METHOD

As mentioned earlier that the objective of the study is to find suitable approaches to decrease flood velocity and anticipating the transport debris in the area, as well as give assurance of safe water passage. There are 3 main goals of the analysis with different approach for each purpose. Figure 5 describes the methodology used in the analysis.

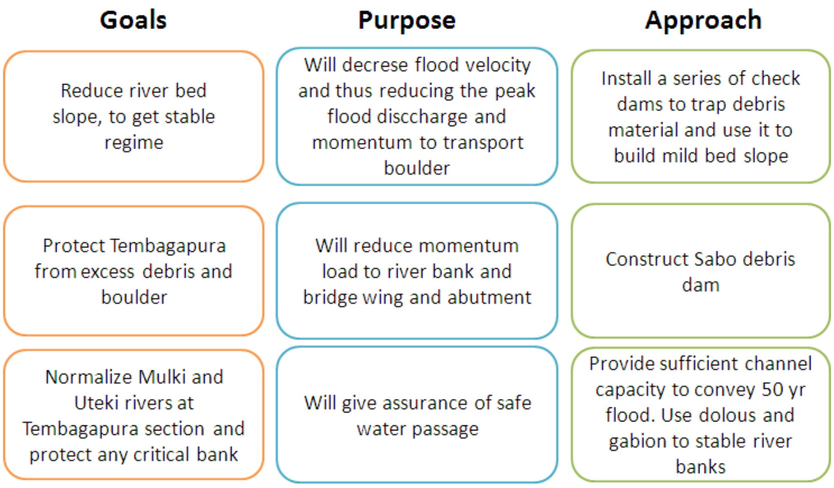


Figure 5. Methodology of the study

For the first purpose, the analysis is done by iteration in reducing river-bed slope to get stable regime; this will decrease the flood (water) velocity and lower the peak discharge. Where this can also reduce the momentum to transport boulder brought down the stream during flooding.

The second purpose has strong relation to the first one since the reduced momentum will protect the residential (urban) area from excess debris and boulder. The possible approach would be constructing a debris dam or known as Sabo dam.

The third purpose will give assurance of safe water passage by normalize those rivers at selected sections and protect any critical banks. To do so, an estimation of 50 years return period of design flood has been set.

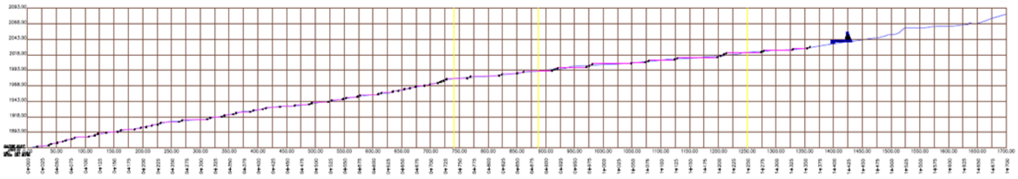
RESULTS AND DISCUSSION

Reducing bed slope for stable regime

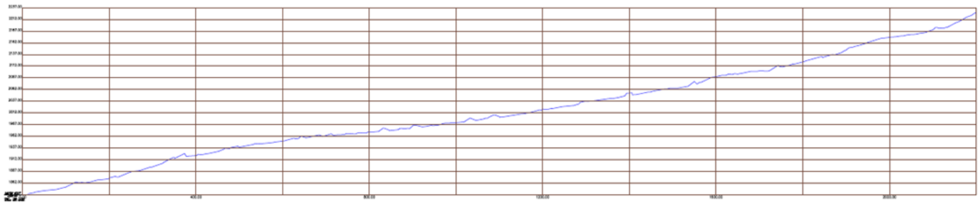
The two rivers, Mulki and Uteki, have similar regime and stream characteristics, but the slope in the Mulki catchment has steeper slope than the Uteki catchment. Figure 6 shows the cross-section of each river, where both rivers have slope average more than 20%.

The slope is stabilized using check dams along the cross-section’s iteration has been done to obtained proper distance and space. Check dams are constructed across the gully bed to stop channel and lateral erosion. By reducing the original gradient of the gully channel, check dams diminish the velocity of water flow and the erosive power of run-off (FAO, 1986). Run-off during peak flow is conveyed safely by check dams. Temporary check dams, which have a lifespan of three to eight years, collect and hold soil and moisture in the bottom of the gully.

To obtain satisfactory results from structural measures, a series of check dams should be constructed for each portion of the gully bed. Because they are less likely to fall, low check dams are more desirable than high ones. Check dams may also be combined with retaining walls parallel to the gully axis in order to prevent the scouring and undermining of the gully banks.



(a)



(b)

Figure 6. (a) Uteki cross-section, (b) Mulki cross-section

Stabilized watershed slopes are the best assurance for the continued functioning of gully control structures. Therefore, attention must always be given to keeping the gully catchment well vegetated. If this fails, the structural gully control measures will fail as well. Figure 7 shows the typical check dams constructed along the channel.

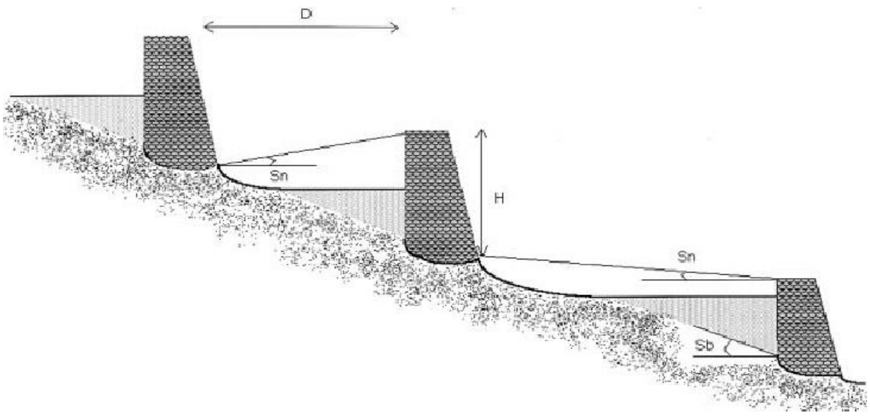


Figure 7. Check dam dimensions in longitudinal section: height (H), horizontal distance between two dams (D), slope gradient of gully bottom (S b), slope gradient of line connecting spillway and foot of upstream check dam (S n).

Between the dams on the left, S n has a negative value (reverse slope) (Source: Nyssen, J; 2006)

Protection Against Debris Flow And Boulders

To protect the area against debris flow and boulders, after the regime has been stabled, a Sabo dam will be constructed to capture and hold the debris and boulders. Based on the natural function of Sabo dam, the height of the main dam will bring a result for the stabilization of the river's slope in this specific area where the dam is planned to be built. There will be possibilities where the height obtain from the design will be higher than the existing cliff. Therefore, if it does happen, the height of the main dam will reflect with the height of cliff. Follows are some calculation examples to obtain proper dimension of proposed dam (Li, B.; 2015). The design debit of debris rate (Q) is affected by the sediment ratio concentration (α) and the design debit (Qp) (Fajarwati, Y., et.al; 2020).

Geometric properties of the river:

a. Baseflow elevation on the downstream of the Sabo Dam River : 2044.5 m

b. Elevation of the cliff : 2054.2 m

The slope is determined with this equation below:

$$I_s = \left(\frac{80{,}9d}{g.10^2}\right)^{\frac{10}{7}} \left(\frac{B}{nQd}\right)^{\frac{6}{7}}$$

Where:

Is = slope of the river

d = the river bed debris' diameter (m) g = acceleration due to gravity (m/s) b = the width of the river (m)

n = Manning coefficient

Qd = Discharge of the river (m3/s)

Then using equation (1): $I_s = \left(\frac{80{,}9x0.04}{9{,}8x10^2}\right)^{\frac{10}{7}} \left(\frac{10}{0{,}033x80x0.04}\right)^{\frac{6}{7}} = \mathbf{0.00089 = 0.089}$

Considering the height of the cliff's right side is +2054.24 m, the height of the dam is determined with this equation below:

The height difference of the cliff and the riverbed = 2054.24-2044.5 = 9.74 m

The dam height must be below from the cliff's height where the dam height is determined to be 6.34 m.

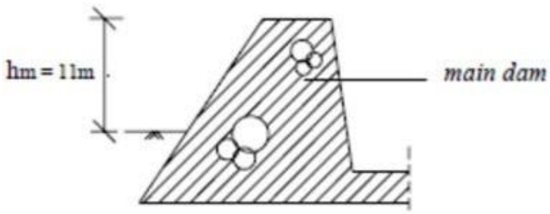


Figure 8. Sketch of the height of Uteki main dam

Main dam's width design:

This equation below is used to determine the width of the main dam

$$B_1 = 0{,}7\ B \qquad (2)$$

Where:

B = the width of the riverbed (m) = 10 m

B_1 = the width of the spillway (m)

From the equation (2), the width of the spillway is determined to be 7 m

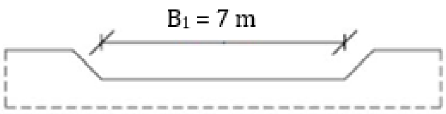


Figure 9. Sketch of the width of Uteki main dam

Spillway height design:

Flow rate which passes through the spillway is quantified by this equation below:

$$Q_d = \left(\frac{2}{15}\right) C_d (2g)^{\frac{1}{2}} (3B_1 + 2B_2) h_w^{\frac{3}{2}} \quad (3)$$

Where:

Qd = Discharge of the river

Cd = Discharge coefficient (0.6 – 0.66)

g = Acceleration due to gravity = 9.8 m/s2 B1 = the width of the spillway (m) = 7 m

B2 = the width of the upper spillway (m) = (B1 + 2m.hw)

M = spillway slope

hw = water level (m)

After the equation being executed, there is only one variable undefined which can be determine by using trial and error test. The result shows that B2 is 12.6 m.

Free board design:

The function of the free board is to avoid water to be over-spilled into side of the river. Free board is determined based on the flow-rate of the river. From the calculation, and based on the design rainfall, the free board height is obtained about 0.6 m.

Thickness of main dam spillway:

The thickness of the spillway must reflect from the stability and the probability of impact caused by the debris. The thickness is determined to be 4 m.

Depth of dam sub-structure:

This equation below is used to determine the depth of the dam structure

H_p=(1/3 up to 1/4) ($h_w + h_m$) (4)

Where:

h_w = water level above spillway

h_m = effective height of the main dam

Therefore from the equation (4) it could have two different value of H_p which is:

1). H_p = (1/3) ($h_w + h_m$); where H_p = 3.047 m

2). H_p = (1/4) ($h_w + h_m$); where H_p = 2.285 m

From the results can be obtained that Hp value is in range between 2.285 - 3.047 m, where in this design the average value of Hp is 2.5 m.

Slope of the main dam design:

The slope of the main dam is designed for avoiding an intense impact from upstream's debris because it might cause bigger damage into the dam and ignite an abrasion problem in downstream of the dam. Other than that, the slope will give a big influence on the stability of the main dam.

Downstream slope of the dam is based on the material and the critical velocity that passing through the spillway and free falling on the apron floor. The downstream slope is determined with ratio of 1:0.2.

Apron design:

We obtain that the length of the apron is 18.97 m therefore we could even the number and use 21 m as the length of the design.

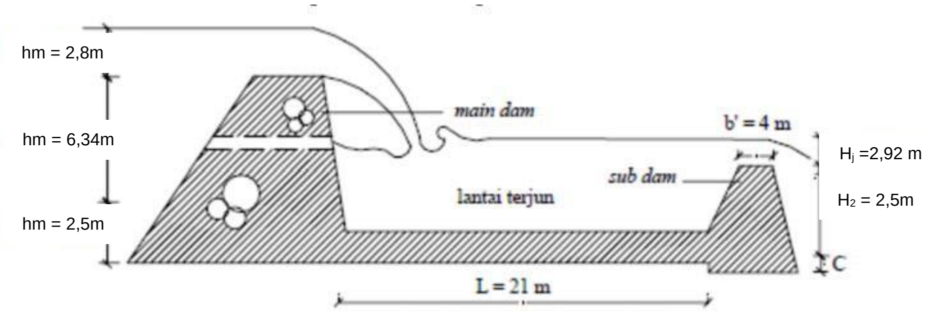


Figure 10. Uteki Dam and Apron Sketch

From overall calculation that has been conducted, the design of Sabo dams of Mulki River and Uteki River are typical. Below are proposed designs for Sabo dam in each river.

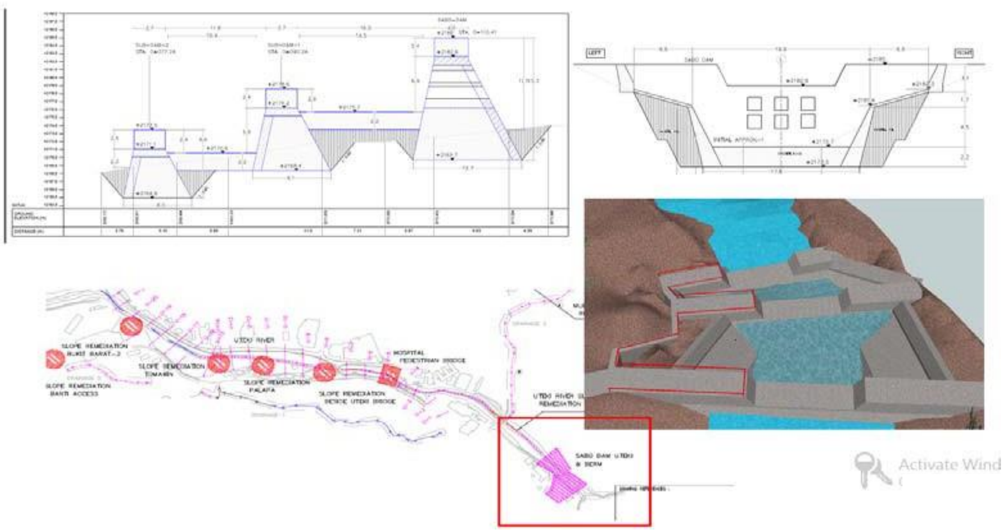


Figure 11. Proposed Sabo dam for Uteki River

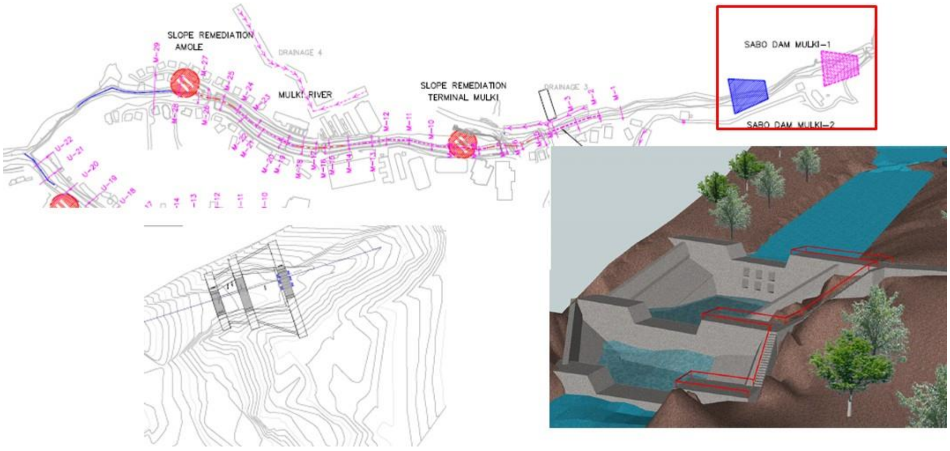


Figure 12. Proposed Sabo dam for Mulki River

River Normalization

Normalization of both rivers could be done by removing sediment deposited along the stream, place dolos/coarse materials at the toe of the riverbank and the fix eroded areas above to protect surrounding infrastructures (road, bridge, and barracks). It is also necessary to remove large boulders in the upstream part which might triggered to be swept away when the peak discharge occurs.

Normalization can be done using existing natural rocks arranged according to the regime (figure 13 a) and in more flat areas, it can be proposed using the vertical gabions along the river side or embankment as shown in figure 13 b.

(a) (b)

Figure 13. (a) Normalization using natural rocks, (b) Normalization using vertical gabions (source: https://estuarymetal.com/normalization-vs-naturalization)

CONCLUSION

This study has shown approaches to decrease flood velocity which implicates in reducing the peak flood discharge, reduce the momentum of debris transport, and design normalization of rivers to give assurance of safe water passage.

Reducing riverbed slope to get stable regime will have impact to the protection the residential/urban area from excess debris and boulders. Installation of series of check dams to trap debris material and use it to build mild bed slope, along with providing sufficient channel capacity to convey at least 50-year flood return period, with additional consideration of using dolos and gabion to stable the riverbanks.It is also suggested to normalize the river at selected sections and critical banks.

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