The Study Of Riverbed Change And Bed-load Transport In The Middle Segment Of The Batang Kuranji River

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Abstract. Batang Kuranji is one of the biggest river in Padang City with catchment area of 202.7 km². In the middle segment of this river have degraded significantly, especially in the downstream side of Gunung Nago Dam after the big flash flood in 2012. This also supported by the steep river slope of 0.017 and the activity of excavation of sand and gravel downstream of Gunung Nago Dam. Based on this, the authors are interested in examining the study of riverbed change and bed-load transport in the middle segment of the Batang Kuranji River, to determine the amount of sediment and changes in riverbed elevations that occur and analyse the location of proper building to reduce water damage. In conducting this research, researchers collected primary data, namely direct sampling in the field and secondary data from various relevant literature sources. In this study seven methods of calculating bed-load transport were used, including Meyer Peter Muller, Einstein, Einstein-Brown, Kalinske, Frijlink, Engelund and Hansens, and Van Rijn. Based on the results, there was a change in riverbed elevation, in the period of 2011 to 2013 there was a scour volume of 902,527 m³ greater than the sediment volume of 193,435 m³ where the sediment occurred was only 21.43% with the deepest scour 10.52 m. Kalinske sediment transport method has the closest value to manual calculation. The comparison between Kalinske method and manual calculation respectively; 0.056 m³/day and 0.187 m³/day in S12 sample; 0.312 m³/day and 0.554 m³/day in S23 sample; and 0.020 m³/day and 0.081 m³/day in S33.

1. Introduction

1.1 Background
The construction of Gunung Nago Dam (1985-1987) in Batang Kuranji, Padang City was a government effort to exploit the potential of water that can irrigate rice fields of ± 2,800 hectares. Dam structures indirectly affect the river topography where there will be additional river basins (aggradation) at the upstream and decrease in riverbed (degradation) in the downstream. Based on the experience, many dams damaged by local scouring that occur right downstream even though they are equipped with gabions or masonry due to scouring. The occurrence of scouring at the downstream of the weir is also due to the mining of sand and gravel excavation at the downstream of the weir. It causes the slope of the riverbed to be steeper. The steep slope of the river bed will change the flow velocity even greater. The effect of increasing this speed will result in scouring on the riverbed which will slowly move upstream to the foot of the dam [1].
The West Sumatra Provincial Management of Water Resources (PSDA) office as the relevant agency has conducted the Check dam Batang Kuranji Detail Engineering Design (DED) in 2011, found that there were several locations have potential for river degradation [2]. However, before the physical activities of the river had carried out, they experienced flash floods, which had changed the shape of the basic geometry of the Batang Kuranji River as seen in Figure 1 [3], which threatened the infrastructure around the Batang Kuranji stream, especially in the Gunung Nago Dam.

![Figure 1. Comparison of river geometry after the flood (a) 24 July 2012 and (b) 12 September 2012 in the downstream side of Gunung Nago DAM (photos facing upstream, documentation of BWSS V)](image)

Based on this, the authors were interested in examining the study of riverbed change and bed-load transport in the middle segment of the Batang Kuranji River.

1.2 Research Objectives
The primary objective of this study was to determine the amount of bed-load transport that occurred in the middle segment of the Batang Kuranji River before the construction of sediment control structures. In addition, the research also aimed to:

- Determine changes in riverbed elevation in the middle segment of Batang Kuranji after the big flood in 2012.
- Obtain the most viable method that closely resembles the results of bed-load transport in the middle segment of the Batang Batang Kuranji River.

1.3 Research Location
This research was conducted in the middle segment of Batang Batang Kuranji River, Padang City, at the downstream of Gunung Nago Dam until the Checkdam of bypass bridge with ± 4.5 km length. The majority of the area is administratively located within the Kuranji District. The work location is illustrated in Figure 2.

![Figure 2. Research Location](image)
2. Literature Review

2.1. Sedimentation
Sedimentation is the process of deposition of material transported by upstream flow due to erosion. Rivers carry sediment in each stream. Sediments can be in various locations in the flow, depending on the balance between the upward speed of the particle (tensile force and lift force) and the speed of particle deposition [4].

There are three kinds of sediment transport movements, namely:

- **Bed load transport**
  Bed-load is a rough particle that moves along the river bed as a whole. Bed-load is indicated by the movement of large particles on the river bed, where the movement can shift, roll or jump, but never escape from the bottom of the river.

- **Wash load transport**
  Wash load is the transport of fine particles which can be in the form of silks and dust, which are carried by the river flow. These particles will be carried away to the sea, or they can settle in a quiet stream or in stagnant water.

- **Suspended load transport**
  Suspended load is a bed material that floats in the flow and consists mainly of fine sand grains which are always floating above the river bed, because they are always driven by flow turbulence. Suspended load itself generally depends on the speed of falling or better known as a fall velocity.

In reality, in one unit of time the movement of sediment transport that can be observed is bed-load transport and suspended load transport.

The shear stress in the riverbed has contributed in sedimentation process. Due to the shear stress, the bed-load transport in curve channel of outer bank have more became unstable of the riverbed and give much more contribution for the sedimentation in river [5].

2.2. Sediment Transport
Various equations for estimating basic sediment loads have been widely developed, although the application for investigation in the field still needs further study. Some estimation formulas are generally developed from investigations in small-scale laboratories. Its application is also limited to the similarity of hydraulic conditions and sediment material as the original conditions of the equation are developed. Generally used the Meyer-Peter (MPM) equation and the Einstein equation [6].

The methods that can be used in the calculation of sediment transport are as follows:

1. Meyer, Petter dan Muller
Meyer, Petter and Muller’s equation is written as follows:

\[
q_s = 8 \rho_s D_{m}^{2} \sqrt{g \Delta} \left[ \frac{R_i}{D_m} - 0.047 \right]^{\frac{1}{2}}
\]

where:
\( q_s \) = the amount of sediment transport (kg/dtk.m)
\( \Delta \) = \( \frac{\rho_s - \rho_w}{\rho_w} \)
\( \rho_s \) = sediment density (kg/m³),
\( \rho_w \) = water density (kg/m³)
\( D_m \) = particle size representing basic material / \( D_{50} \)
\( R_i \) = hydraulic radius (m)
\( i \) = slope of the river bed

2. \( \mu \) = ripple factor = \( \left[ \frac{C_e}{C} \right]^{\frac{1}{2}} \) Einstein
Einstein defined the bed-load equation as an equation that connects the motion of basic materials with local flow. The equation illustrates the balance of exchange of river bottom grains between the bed layer and its base (sediment balanced with scour). Therefore, Einstein's equation is written as follows:

If the flow intensity parameter:

$$\psi = \frac{\rho_s - \rho}{\rho} \frac{D}{i R_h}$$

(2)

and the intensity of bed-load transport as:

$$\phi = \frac{q_s}{\rho_s} \left( \frac{1}{\rho_s - \rho D} \right)$$

(3)

where;

- $D_{35}$ = particle size where 35 percent of the basic ingredients are finer (m)
- $\Phi$ = intensity of bed-load transport
- $R'_h$ = The hydraulic radius is related to the grain (m)
- $C' = \frac{\mu}{\rho}$
- $\bar{U} = \text{Average speed of river water flow (m/s)}$
- $C' = \text{Roughness factor due to grain diameter} = 18 \log \left( \frac{12 \sqrt{R}}{D_{90}} \right)$
- $D_{50}$ = particle size where 50 percent of the basic ingredients are finer (m)

3. Einstein-Brown

The Einstein-Brown formula is written in the following form:

$$q_s = \sqrt{g \Delta D_{50}} \cdot 60. \rho_s \cdot \left[ \mu \frac{R_i}{\Delta D_{50}} \right]$$

(4)

where;

- $D_{50}$ = particle size where 50 percent of the basic ingredients are finer

4. Kalinske
The Kalinske formula [7] is written in the following form:

\[
\frac{q_v}{u_s d \rho_s} = \text{fct}_k \left[ \frac{(\tau_o)_{cr}}{\tau_o} \right]
\]

(5)

where:
- \(fct_k\) given in Figure 5
- \((\tau_o)_{cr}\) = the magnitude of the grating force at the start of the movement is given in Figure 4
- \(\tau_o\) = water shear force
- \(U_o\) = sliding speed
- \(= \sqrt{g \mu R_i}\)

![Figure 4. Critical Shear Stress as Function of Grain Diameter](source_image)

![Figure 5. Kalinske's Bed-load Equation](source_image)

5. Frijlink
Frijlink proposes a formula by taking into account the influence of the riverbed configuration specifically as follows:

\[ \frac{q_s}{\rho_s \cdot D_m \sqrt{g \cdot \mu \cdot R \cdot i}} = 5.0 \cdot e^{-0.27 \frac{\Delta D}{\mu \cdot R \cdot i}} \]  

(6)

6. Engelund Hansens

The Engelund Hansens equation for wide rivers can be written with:

\[ q_i = \sqrt{8 \cdot \Delta D_{50}^3 \cdot 0.0504 \cdot \rho_s \cdot \left( \frac{R_i}{\Delta D_{50}} \right)^{0.5} \cdot \frac{C^2}{g}} \]  

(7)

7. Van Rijn

The form of the Van Rijn equation [8] is as follows:

\[ q_b = \frac{0.053 \cdot T^{2.5} (\Delta g)^{0.5} \cdot D_{50}^{2/3}}{D_*^{1/3}} \]  

where;

- \( q_b \) = the amount of sediment transport \( (m^3/s) \)
- \( T \) = transport stage parameter

\[ T = \frac{(U_*)^2 - (U_{cr})^2}{(U_{cr})^2} \]  

(9)

- \( U_* \) = shear speed against granules
- \( U_{cr} \) = critical sliding speed according to Shield \( (m/s) \)
- \( \overline{U} \) = average speed of river water flow \( (m/s) \)
- \( C' \) = chazy coefficient

\[ C' = 18 \log \left( \frac{12 \cdot R}{3D_{50}} \right) \]

To simplify the calculation, the steps are as follows;

1. Calculate the particle parameters with the equation;

\[ D_* = D_{50} \left( \frac{4 \cdot g}{v^2} \right)^{1/3} \]  

(10)

- \( D_* \) = particle parameters
- \( D_{50} \) = particle size \( (m) \)
- \( \Delta \) = \( \frac{\rho_s - \rho_w}{\rho_w} \)
- \( v \) = kinematic viscosity coefficient \( (1.10^6 \ m^2/det) \)

2. Van Rijn provides an equation for calculating critical shear velocity based on the Shield diagram shown in figure 6.

3. Calculating the value of \( C' \)

4. Calculate transport stage parameters

5. Determine the amount of sediment transport.
3. Research Methodology

3.1. Data Collection
Data collection in the form of secondary data was obtained directly from several relevant government agencies and primary data from the research location. Some of the data:
- Topographic map/measurement map in 2004, 2011 and 2013 at the research location.
- River discharge data at BWSS V and PSDA Office.
- Data on physical properties of soil in the form of direct sampling in the field.

3.2. Data Processing
From the data that has been obtained, it will be processed with the following steps:
1. Equate the elevation reference in the longitudinal pieces of each measurement data.
2. Make a cross section with a calibrated elevation.
3. Comparing changes in the cross-sectional shape of the river before and after the year to calculate the magnitude of the changes that occur.
4. Calculating sediment transport with an empirical formula.
5. Comparing the results of calculations based on changes in geometry with empirical calculations.
6. Selecting the method of calculating the amount of sediment that is close to the results of geometry calculations.
7. Conclusions.

4. Results and Discussion

4.1. Changes to River Base Elevations
The topographic data obtained was calibrated for the benchmark of the measurement data elevation reference. Gunung Nago Dam Lighthouse was used as a reference for basic elevation benchmark because it has not changed, in which there is a difference of 5.78 meters between the results of measurements in 2011 and 2013. The results of the 2013 measurement were used as guidelines so that the elevation obtained in 2011 was reduced by 5.78 meters. From the results obtained there was a change in the elevation of the riverbed of ±2 km starting from Gunung Nago check dam to the lower reaches. A large elevation change occurred ±270 m below the Gunung Nago check dam, which had eroded as deep as 10 m in the period of 2011 to 2013 as shown in Figure 7. This is due to the steep
slope of the riverbed of 0.018, the activity of sand and gravel excavation in the downstream and the occurrence of flash floods on July 24 and September 12, 2012.

Figure 7. Chart of Riverbed Elevation Change

The cross section in 2013 had compared with the cross section in 2011 by overlaying the situation maps as demonstrated in Figure 8.

Figure 8. Overlay of the Topographic Measurements in 2011 and 2013
From the comparison, there was a change in the river channel on stake no. 74 until stake no. 67, which also shown through the Google Earth Map recorded on December 9, 2011 and January 31, 2014 in Figure 9.

![Aerial Photos of Batang Batang Kuranji River in 2011 and 2014](image)

**Figure 9.** Aerial Photos of Batang Batang Kuranji River in 2011 and 2014

From Figure 10 above there was a shift in the river section from the right to the left of the flow starting at stake 74 which is in the upstream where on the left was scouring, and the right part of the sediment appears and vice versa on stakes 67 in the downstream. Figure 11 indicated there has been a maximum scour as deep as 10.52 m at the foot of the gabion pair on the stake 74.

Using Figure 10 as a reference to find out the comparison of estimated scouring volume and sedimentation. The volume of scouring and sediment that occurs in the first stakes and then averaged with the stakes afterwards, then multiplied by the distance between stakes. Moreover, this study can
only calculate from the available topographic maps with a river length of 4,421.5 m resulted scour values of 902,527 m$^3$ and deposits of 193,435 m$^3$, where deposits occur only 21.43%.

**Figure 11.** Photo Drone of BWS V Construction Stone Gabion Stake 74 on April 10, 2015

From the calculation of scour and sediment calculations above, if it is assumed that the eroded material was not carried downstream of check dam which is under the bypass bridge. It was possible to calculate the volume of excavation of sand and gravel (excavation C) which had transported out in the middle segment of Batang Kuranji River.  

Volume Excavation C = scour volume - sediment volume  
= 902,527.69 – 193,435.09 m$^3$  
= 709,092.59 m$^3$

In order to find out the average volume of daily-excavated sand and gravel, the volume divided by the time interval between measurements June 15, 2011, March 4, 2013, i.e. 628 days.

Average volume excavation C / day = 709,092.59 m$^3$ / 628 days  
= 1,129.12 m$^3$/day

4.2. *Calculation of Bed-load Transport*

After samples had been retrieve from three locations, as shown in Figure 12, the field data and laboratory test results were obtained.
Figure 12. Location of Sediment Samples and Flow Measurements

The sample code 1 is at 0 to 1/3 of the width of the river, sample 2 is at 1/3 to 2/3 of the width of the river and sample 3 is on 2/3 to the width of the river from the right of the river can be illustrated in Figure 13.

Figure 13. Illustration of Location of Sediment Samples and Flow Measurements in the cross section

From field data and laboratory test results based on sediment transport methods that have been described in the previous chapter, data processing was carried out to obtain basic sediment transport such as Table 1.

From Table 1 and Figure 14 it can be inferred that samples in the MPM and Van Rijn methods, which values cannot be defined (#NUM!) were due to their negative order of the magnitude values during the calculation process. At the first location in the S12 sample, the method for calculating Kalinske sediment transport is 0.056 m$^3$/day, which is closest to the manual calculation of 0.187 m$^3$/day. In the second location, the Kalinske calculation method in the S23 sample is 0.312 m$^3$/day approaching the manual calculation, which is 0.554 m$^3$/day. Moreover, at the third location in the S33 sample the calculation method for Kalinske sediment transport is 0.020 m$^3$/day, which is closest to the calculation value manually 0.081 m$^3$/day.

Table 1. Recapitulation of Daily Sediment Transport Calculation

| No | Sample | MPM m$^3$/day | Einstein m$^3$/day | Einstein-Brown m$^3$/day | Kalinske m$^3$/day | Frijlink m$^3$/day | Engelund Hansens m$^3$/day | Van Rijn m$^3$/day | Manual Volume m$^3$/day |
|----|--------|----------------|-------------------|--------------------------|-------------------|----------------|--------------------------|--------------------|-----------------------|
| 1  | S11    | #NUM!         | 67.320            | 13.700                  | 0.025             | 4.581          | 0.471                    | 54.917             | 0.187                 |
| 2  | S12    | 67.583        | 104.654           | 46.916                  | 0.056             | 67.394         | 1.239                    | 64.978             | 0.187                 |
| 3  | S13    | 82.412        | 117.487           | 55.506                  | 0.049             | 82.282         | 1.416                    | 53.125             | 0.187                 |
| 4  | S21    | #NUM!         | 8.046             | 9.788                   | 0.033             | 3.622          | 38.873                   | #NUM!              | 0.554                 |
| 5  | S22    | #NUM!         | 5.023             | 6.915                   | 0.002             | 0.950          | 30.007                   | #NUM!              | 0.554                 |
| 6  | S23    | 15.626        | 39.312            | 17.903                  | 0.312             | 18.359         | 60.527                   | #NUM!              | 0.554                 |
| 7  | S31    | 87.258        | 147.450           | 154.083                 | 0.006             | 92.253         | 60.649                   | #NUM!              | 0.081                 |
| 8  | S32    | #NUM!         | 5.141             | 8.514                   | 0.461             | 2.125          | 6.035                    | #NUM!              | 0.081                 |
| 9  | S33    | 74.846        | 114.762           | 161.061                 | 0.020             | 73.602         | 82.582                   | 163.986            | 0.081                 |
5. Conclusions.

From the results of research carried out in the middle segment of Batang Kuranji River, we can conclude:

1. The downstream side of the Check dam Gunung Nago has eroded significantly within 2 km length. A large elevation change occurred at 270 m under Gunung Nago Check dam, which had eroded as deep as 10.5 m. This is due to the steep slope of the riverbed of 0.018, the activity of sand and gravel excavation in the downstream and the occurrence of floods on July 24 and September 12 in 2012.

2. From the three sample locations, we found that the calculation of sediment transport with the Kalinske Method gave the closest result to the observation value.

Acknowledgement

We would like to thank to Andalas University supported this work and to the Public Works Service and other stakeholders to provide data for the research.

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