The Influence of Sediment Loads on the Irrigation Discharge in The Upstream and Downstream of the Major River in Banyuwangi Regency

Z Erwanto¹, D Dwi Pranowo¹, D S W P J Widakdo² and N S R Wilujeng³

¹ Department of Civil Engineering, Politeknik Negeri Banyuwangi, Banyuwangi, Indonesia
² Study Program of Agribusiness, Politeknik Negeri Banyuwangi, Banyuwangi, Indonesia
³ Study Program of Animal Product Processing Technology, Politeknik Negeri Banyuwangi, Banyuwangi, Indonesia

E-mail: zulis.erwanto@poliwangi.ac.id

Abstract. In Banyuwangi Regency there are four major rivers include the Tambong, Bomo, Setail and Baru river. Those rivers often overflow due to the high sediment deposition in the weir. The purpose of the study is to determine the influence of sediment loads upstream and downstream of the four rivers on irrigation impact. Suspended load analysis used method of Engelund and Hansen; Einstein; and Chang Simons & Richardson. Bed load analysis using methods of the Meyer-peter; Duboys; and Shields. Loads of sediment, both suspended load and bed load on the irrigation discharge in both the upstream and downstream of the major rivers in Banyuwangi greatly influences the sedimentation of irrigation channels which affect on fluctuations of irrigation discharge to irrigate land of Agriculture. The Baru River carried the largest sediment load in irrigation intake of Karangdoro Weir that carried Qs of 385.96 tons/year and Qb of 6.37 tons/year. It is necessary to have policies and efforts to control sediment and study about the maintenance of weirs periodically to maintain the volume of irrigation water so that it can increase agricultural productivity in Banyuwangi Regency.

1. Introduction

1.1. Background

One of the decreasing capacity of a river is the sediment buildup called sedimentation in the river either in the middle flow of the river or in the estuary of the river. Sedimentation can lead the rise and fall of the riverbed elevation (river bed alteration). One of them also affects irrigation watering because the reservoir storage capacity is full of sediment deposits. Based on the priorities of regional development programmes in the field of food security in 2014 – 2019, that one of them is increasing the development and rehabilitation of reservoirs, dams and reservoirs with geo-membrane technology, maintaining the volume of water sources to maintain water availability throughout the year, and increasing the acceleration of development, maintenance and repair of infrastructure that supports the development of the agricultural sector and rural areas. From one of the problems in the agricultural sector, namely the fluctuations in climate change that disrupt agricultural production, where one of the
factors is the influence of the existence of floods and sediment loads that affect sedimentation in irrigation building infrastructure. The phenomenon of changes in sediment load has an impact on the danger of flooding and at the same time on the achievement of production and agricultural productivity [2]. Therefore, in maintaining the volume of water sources, it is necessary to study the impact of river sediment load on irrigation water in order to increase agricultural productivity.

Based on the Central Statistics Agency [1], there are 35 watersheds in Banyuwangi Regency itself. The largest watersheds include Tambong, Baru, Setail, and Bomo watershed. The majority of water springs and surface runoff come from Raung and Ijen Mountain with steep topographic relief and go directly to the Sea. This natural condition could potentially occur deliverable flood from upstream to downstream and if the watershed conditions are not well maintained it will result in easily eroded land due to high rainfall which causes high sediment loads in the four major rivers of the Banyuwangi Regency. Based on research [3], the evaluation of the flood hydrograph in the Major Rivers in Banyuwangi District has a 5-10 year flood return period. From these conditions, it shows the influence of discharge fluctuations in these rivers on sediment loads and impacts on irrigation. Therefore, it is necessary to study the influence of sediment load on both suspended load and bed load in upstream and downstream of the large rivers of Banyuwangi Regency on irrigation discharge in the technical weir.

2. Theoretical Basis
2.1. Sediment Loads
2.1.1. Suspended Load. To find the size of the suspended load, it is used the following 3 methods [4]:

- Engelund and Hansen. Engelund and Hansen assume that suspended load can be calculated using the equation:

  \[ q_{sw} = 0.05 \gamma_s V^2 \left( \frac{d_{50}}{g(\gamma_s - 1)} \right)^{1/2} \tau_o \left( \frac{\tau_o}{(\gamma_s - \gamma)d_{50}} \right)^{3/2} \]  
  \[ \tau_o = \gamma D S \]  
  \[ Q_{sw} = Wq_{sw} \]  
  \[ G_w = \gamma W D V \]  
  \[ C_t = \frac{Q_{sw}}{G_w} \text{ (ppm)} \]  
  \[ Q_s = 0.0864 \cdot C_t \cdot Q \]

  With, \( q_{sw} \) is suspended load charge (ton/day), \( \gamma_s \) is specific gravity of sediment (g/cm\(^3\)), \( \gamma \) is a specific gravity of water (1 ton/m\(^3\) = 1 gr/cm\(^3\) = 1000 kg/m\(^3\)), \( V \) is the average flow velocity (m/s), \( g \) is gravity force (9.81 m/s\(^2\)), \( d_{50} \) is the result of sieve test of 50 mm in diameter (mm), \( D \) is the depth of the river (m), \( S \) is the slope of the river bed, \( \tau_o \) is friction tension (kg/m\(^2\)), \( W \) is the width of a river (m), \( C_t \) is sediment concentration (ppm), \( Q_{sw} \) is charged suspended load per unit of width (ton/day), \( G_w \) is water pressure (ton/s), \( Q_s \) is sediment loads (ton/day).

- Einstein. Einstein assumed that suspended load can be calculated using the equation:

  \[ q_{sw} = 11.6 U' c_o a \left[ \left( 2.303 \log \frac{30.2D}{A} \right) I_1 + I_2 \right] \]
With, $q_{ow}$ is suspended Load charge (ton/day), $D$ is the depth of the river (m), $Ca$ is the concentration of suspended load at a distance $y$ and $x$ above bed load each or laboratory test results of sediment concentration (mg/l).

$$U' = U_* = (gRS)^{0.5} \text{ or } U_* = (gDS)^{0.5}$$

$$a = 2d_{65}, \text{ meter}$$

$$\Delta = k_s / x = d_{65}/x$$

Calculate the value of $\delta' = \frac{116 \times \nu}{U_*}$ with $\nu$, is a viscosity kinematic of water based on water temperature °C (cm²/s). Then calculate the value of $U' = \sqrt{gR_bS}$, with $R_b$ is a radius of hydraulic or depth of the river in meter, $S$ is the slope of the river bed, and $g$ is the gravity force = 9.81 m/s².

Calculate value of $\frac{k_s}{\delta} = \frac{d_{65}(R)^{1/2}}{\delta}$ in Figure 1 to get the value of $x$.

![Figure 1](image.png)

**Figure 1.** Correlation between $\frac{k_s}{\delta}$ and $x$ [5]

$I_1$ = Integrity numeric can find with Figure 2 for a value of $I_1$ and Figure 3 for a value of $I_2$
Figure 2. By using the value of $I_1$ it is found the value of $A$ and $Z$ [5].

Figure 3. By using the value of $I_2$ it is found the value of $A$ and $Z$ [5].

Calculate value of $Z = \frac{\omega}{0.4 \times U^*}$ and $A = \frac{2d_{65}}{D}$ at equation in Figure 2 and Figure 3. To find the value of the fall velocity can be searched by using the equation $\omega = \frac{1}{8} \gamma_s - \gamma \frac{g d_{35}^2}{V}$.

With, $\omega$ is fall velocity of sediment (m/s), $\gamma_s$ is specific gravity of sediment, $\gamma$ is a specific gravity of water (1 ton/m$^3$), $d_{35}$ is diameter of granules 35 mm (mm), $g$ is gravity force and $V$ is the average flow velocity (m/s) with equation $V = 5.75. U'_* \log(12.27. \frac{D}{kS}. x)$ and then continue calculation with equation (3), (4), (5), and (6).

- Chang Simons and Richardson. Chang and Simons Richardson assume that suspended load can be calculated using the equation:

$$q_{sw} = \gamma DG \left(V. I_1 - \frac{2U}{K} I_2 \right)$$

(8)

With, $q_{sw}$ is suspended Load Charge (ton/day), $\gamma$ is specific gravity of water, $k$ is Prandtl – Von Karman Constanta = 0.4, $V$ is the average flow velocity (m/s), $D$ is the depth of the river (m). And calculate $U'_* = U'_* = (gRS)^{0.5}$ or $U'_* = (gDS)^{0.5}$.

$Ca$ is the concentration of suspended load at a distance $y$ and $x$ above bed load each or laboratory test results of sediment concentration (mg/l), and $I$ is integrity numeric can be searched using Figure 5 for $I_1$ value and Figure 6 for $I_2$ value.

$$q_{bw} = K_r. V. (\tau_o - \tau_c)$$

(9)

$$\tau_o = \gamma. D. S$$

(10)
\[ \tau_c = \tau_o \cdot (\gamma_s - \gamma) \cdot d_{50} \]  \hspace{1cm} (11)

To get the value of Kt, calculate the value of
\[ \frac{V}{U^*} \cdot \frac{\tau_o - S}{(\gamma_s - \gamma) \cdot d_{50}} \]
and use Figure 4.

Figure 4. Correlation between \( \frac{V}{U^*} \cdot \frac{\tau_o - S}{(\gamma_s - \gamma) \cdot d_{50}} \) and Kt [5]

Figure 5. Correlation between \( \xi_a \) with \( Z_2 \) it is found a value of \( I_1 \) [5]

Figure 6. Correlation between \( \xi_a \) with \( Z_2 \) it is found a value of \( I_2 \) [5]

With, \( \gamma_s \) is specific gravity of sediment, \( \gamma \) is specific gravity of water, \( q_{bw} \) is bed load charge (ton/day), \( d_{65} \) is diameter of granules 65 mm (mm), \( d_{50} \) is diameter of granules 50 mm (mm), \( D \) is the depth of the river (m), \( V \) is the average flow velocity (m/s), \( \tau_o \) is basic tension (kg/m²), \( \tau_c \) is critical base friction tension (kg/m²), \( S \) is the slope of the river bed, \( B \) is the length of the river (m), \( g \) is
gravity force. Calculate $q_{SW} = q_{bw} \cdot R_s$, with $R_s = \frac{D}{0.84 \sqrt{V}} (V \cdot I_1 - \frac{2u_{cr}}{k} I_2)$, than calculate value of $\xi_a = \frac{a}{D} = \frac{2d_{65}}{D}$ and $z_2 = \frac{u}{u_{cr}}$ at equation Figure 5 and Figure 6.

2.1.2. Bed Load. To find the bed load using the following 3 methods [4]

- Meyer-Peter (1948) [5]. The basic equation of bed load using the Meyer-Peter can be written as follows:

$$q_{b}^{2/3} = 39.5 q^{2/3} S 9.95 d_{90}$$  

$$Q_b = q_b \cdot W$$  

With, $q_b$ is Bed Load charge (ton/day), $q$ is the discharge of river (m³/s), $S$ is the slope of the river bed, $d_{90}$ is diameter of granules of 90 mm (m), $W$ is width of river (m), $Q_b$ is charge Bed Load per unit of width (ton/day).

- Duboys [5].

$$q_b = \psi \left( \frac{\tau_o - \tau_c}{\gamma} \right)$$  

$$\tau_o = \gamma D S$$  

$$Q_b = q_b \cdot W$$

With, $q_b$ is Bed Load charge (ton/day), $\tau_o$ is friction tension (kg/m³), $W$ is width of river (m), $Q_b$ is charge Bed Load per unit of width (ton/day), $\psi$ is the coefficient that depends on the size of a grain of the average sediment. Value of $\psi$ can be found using the equation $\psi = \frac{\tau_o - \tau_c}{\gamma}$, with $\tau_c$ is a critical base friction tension (kg/m³), can be searched using the equation $\tau_c = \frac{\tau_o}{\gamma (\gamma_s - 1) D}$.

- Shields [5]. Shields determine the magnitude of the bed load with empirical formula, can be seen in the equation:

$$q_b = 10 q S \left( \frac{\tau_o - \tau_c}{(\gamma_S - \gamma)^2} \right)$$  

$$\tau_o = \gamma D S$$  

$$Q_b = q_b \cdot W$$

With, $q_b$ is Bed Load charge (ton/day), $q$ is the discharge of river (m³/s), $\tau_c$ is critical base friction tension as shown in Figure 7, $D$ is the depth of the river (m), $\gamma_s$ is specific gravity of sediment, $V$ is the average flow velocity (m/s), $\gamma$ is specific gravity of water, $S$ is the slope of the river bed, $\nu$ is kinematic viscosity (cm²/s), $W$ is width of river (m), $Q_b$ is charge Bed Load per unit of width (ton/day). Calculate the value of $\frac{V \cdot D}{\nu}$ at the equation in Figure 7.
3. Methodology

3.1. Location Of Study
In the upstream of the river among others were Tambong River (Poncowati Weir), Bomo River (Gembleng Weir), Setail River (Jambewangi Weir), and Baru River (Karangdoro Weir). In the downstream of the river among others were Tambong River (Pondok Nongko Bridge, Sukojati), Downstream Bomo River (Mangir Village, Wonosobo Bridge), Setail River (Dam 1, Kradenan), and Sungai Baru River (Watu Kemeloso Weir, Barurejo).

3.2. Data Collection
Primary data collection was obtained directly to study location, in the form of river condition survey, suspended load sampling with a 3 bottle sediment sampler each, 15 kg of bad load sample taken with a Van Veen Grab Sampler tool, measurement coordinates and elevation with GPS, and measurement of flow discharge with the Current Meter tool. Sediment sampling was carried out 6 times in a row. As well as testing sediment samples in the laboratory in the form of sieve analysis, hydrometer, specific gravity, and sediment concentration with filter paper.

Secondary data collection was obtained from other sources such as irrigation discharge data in the Banyuwangi Regency Water Service, and daily river discharge data in the Technical Management Unit of the Water Resources Management of the Sampean Baru River Region in Bondowoso Regency.

4. Results And Discussion

4.1. The Results Of The Sediment Load In The Major Rivers
4.1.1. Tambong River. The results of measurements of the average river discharge per segment in the Upstream of Tambong river is 1.57 m$^3$/s and in the Downstream of Tambong river is 2.11 m$^3$/s. The correlation between sediment load and discharge at upstream and downstream Tambong River can see in Figure 8 – 11.

Based on Figure 12, it shows that in the irrigation intake in the Poncowati weir with a total annual average irrigation discharge of 6.54 m$^3$/s carries an annual suspended load of 21.89 tons/year while the annual bed load is 6.92 tons/year. Fluctuations in sediment load follow the irrigation discharge and are still stable and the irrigation conditions are rather turbid. Based on Figure 13, it shows that in the irrigation intake in the Downstream of Tambong River with a total annual average irrigation discharge of 63.35 m$^3$/s carries an annual suspended load of 166.06 tons/year while the annual bed load is 35.98 tons/year. It is known that in January-April during the rainy season the suspended load condition is higher than the intake discharge of the irrigation causing high turbidity and sedimentation, while during the dry season the river conditions seem clear because the content of suspended load is very low. The condition of bed load follows the fluctuation of irrigation discharge and is still stable.
Figure 8. Suspended Load Rating Curve at Upstream Tambong River

Figure 9. Suspended Load Rating Curve at Downstream Tambong River

Figure 10. Bed Load Rating Curve at Upstream of Tambong River

Figure 11. Bed Load Rating Curve at Downstream of Tambong River

Figure 12. Annual Average of Intake Discharge and Sediment Load at Poncowati Weir Upstream of Tambong River

Figure 13. Annual Average of Intake Discharge and Sediment Load at Tambong Intake Downstream of Tambong River
4.1.2. Bomo River. The result of measurement of the average river discharge per segment of the Bomo river Upstream is 2.56 m$^3$/s and in the Bomo river Downstream is 0.37 m$^3$/s. The correlation between sediment load and discharge at upstream and downstream Bomo River can see in Figure 14 – 17.

Based on Figure 18, it shows that in the irrigation intake in the Gembleng weir with a total annual average irrigation discharge of 20.76 m$^3$/s carries an annual suspended load of 196.24 tons/year while the annual bed load is 35.81 tons/year. It is known that in July and December the suspended load conditions are very high and bed load sedimentation occurs in October. River and irrigation intake categories in the Gembleng irrigation area are very high in sediment loads. There are also many sand mining in the upstream Bomo river. Based on Figure 19, it shows that in irrigation intakes in Maron of Wonosobo in the Downstream of Bomo with total annual average irrigation discharge of 2.43 m$^3$/s carries the annual suspended load of 0.18 tons/year while the annual bed load is 2.45 tons/year. It is known that the conditions of the suspended load is lower than intake irrigation discharge so that it
looks clear and has low sedimentation, while for bed load condition in October or in dry season, there is large deposition and the discharge of the river recedes, so that it is widely used for mining of sand in the vicinity of the downstream of Bomo river.

**Figure 18.** Annual Average of Intake Discharge and Sediment Load at Gembleng Weir Upstream Bomo River

**Figure 19.** Annual Average of Intake Discharge and Sediment Load at Maron Wonosobo Intake Downstream Bomo River

4.1.3. **Setail River.** The results of measurements of the average river discharge per segment at Setail River Upstream is 4.29 m³/s and at Setail River Downstream is 0.69 m³/s. The correlation between sediment load and discharge at upstream and downstream Setail River can see in **Figure 20 – 23**.

**Figure 20.** Suspended Load Rating Curve at Upstream Setail River

**Figure 21.** Suspended Load Rating Curve at Downstream Setail River
Based on Figure 24, it shows that in the irrigation intake in the Setail weir with total annual average irrigation discharge of 49.53 m$^3$/s carries an annual suspended load of 126.44 tons/year while the annual bed load is 54.61 tons/year. It is known that in October the suspended load condition is greater than the irrigation intake discharge, causing high turbidity and sedimentation and bed load conditions follow the fluctuation of the irrigation discharge and are still stable. Based on Figure 25, it shows that in irrigation intakes in DAM 1 "K" in the Downstream of Setail River with total annual average irrigation discharge of 45.29 m$^3$/s carries an annual suspended load of 85.70 tons/year while...
the annual bed load is 2.14 tons/year. It is known that the condition of the sediments load is still stable and follows the fluctuations of discharge of irrigation.

**Figure 26.** Suspended Load Rating Curve at Upstream Baru River

**Figure 27.** Suspended Load Rating Curve at Downstream Baru River

**Figure 28.** Bed Load Rating Curve at Upstream Baru River

**Figure 29.** Bed Load Rating Curve at Downstream Baru River
4.1.4. Baru River. The results of measurements of the average river discharge per segment of the Baru River Upstream is 7.10 m$^3$/s and in Baru River Downstream is 4.40 m$^3$/s. The correlation between sediment load and discharge at upstream and downstream Baru River can see in Figure 26 – 29.

Based on Figure 30, it shows that in the irrigation intake in the Karangdoro weir with a total annual average irrigation discharge of 144.53 m$^3$/s carries an annual suspended load of 385.96 tons/year while the annual bed load is 6.37 tons/year. It is known that in October the suspended load condition is greater than the irrigation intake discharge, causing high turbidity and sedimentation and bed load conditions follow the fluctuation of the irrigation discharge and are still stable. Based on Figure 31, it shows that in the irrigation intake in the Watu Kemeloso Weirs in Downstream of Baru River with a total annual average irrigation discharge of 18.25 m$^3$/s carries an annual suspended load of 0.76 tons/year while the annual bed load is 21.13 tons/year. It is known that the condition of the suspended load is smaller than the bed load. It can be concluded that the process of erosion is greater so the sedimentation is very high. Many sand minings are also found from the impacts of sedimentation.

5. Conclusions

Loads of sediment, both suspended load and bed load on the irrigation discharge in both the upstream and downstream of the major rivers in Banyuwangi greatly influences the sedimentation of irrigation channels which affect on fluctuations of irrigation discharge to irrigate land of Agriculture. The irrigation intakes in Poncowati weir carried Qs of 21.89 tons/year; Qb of 6.92 tons/year. Irrigation intakes in the Downstream Tambong river have Qs of 166.06 tons/year; Qb of 35.98 tons/year. Irrigation intakes in Gembleng weir have Qs of 196.24 tons/year; Qb of 35.81 tons/year. Irrigation intakes of Maron Wonosobo in the Downstream Bomo river have Qs of 0.18 tons/year; Qb of 2.45 tons/year. Irrigation intakes in Setail weir have Qs of 126.44 tons/year; Qb of 54.61 tons/year. The irrigation intakes of DAM 1 "K" in the Downstream Setail river have Qs of 85.70 tons/year; Qb of 2.14 tons/year. Irrigation intakes in Karangdoro weir have Qs of 385.96 tons/year; Qb of 6.37 tons/year. The irrigation intakes of Watu Kemeloso Weirs in Downstream Baru river have Qs of 0.76 tons/year; Qb of 21.13 tons/year. It is necessary to have policies and efforts to control sediment and...
study about the maintenance of weirs periodically to maintain the volume of irrigation water so that it can increase agricultural productivity in Banyuwangi Regency.

Acknowledgments
Thanks to Regional Development Planning Agency of Banyuwangi Regency for the funding that has been given in the scheme research on regional government cooperation with universities from Banyuwangi Regency Budget funding sources in 2018. Our respect is given to Politeknik Negeri Banyuwangi for their support for our research. The appreciation is also given to the research team for their cooperation so that we can complete our research.

References
[1] Badan Pusat Statistik 2017 *Banyuwangi Dalam Angka Tahun 2017* (Banyuwangi)
[2] Dewan Riset Daerah Provinsi Jawa Timur 2015 *Jakstrada Iptek. Kebijakan Strategis Pembangunan Daerah Iptek, Agenda Riset Daerah Provinsi Jawa Timur 2014-2019* (Surabaya: Jalin Matra)
[3] Erwanto Z and Ulfiyati Y 2017 *Evaluasi Hidrograf Aliran Dengan Agiel NN Pada Sungai-Sungai Besar Kabupaten Banyuwangi* (Bali: Logic Jurnal Rancang Bangun dan Teknologi) [S.l.], v. 16, n. 1, http://ojs.pnb.ac.id/index.php/LOGIC/article/view/122
[4] Wardani F Y, Erwanto Z and Ulfiyati Y 2018 *Studi Muatan Suspended Load Dan Bed Load Pada Upstream Bendung Di Hulu Sungai-Sungai Besar Kabupaten Banyuwangi* (Bali: Logic Jurnal Rancang Bangun dan Teknologi) [S.l.], v. 18, n. 1, p. 12-19, mar. 2018 ISSN 2580-5630, http://ojs.pnb.ac.id/index.php/LOGIC/article/view/789
[5] Yang C T 2003 *Sediment Transport Theory and Practice* (Malabar, FL: Krieger Publishing Company)