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Original Article

Characteristics of Flow and Sedimentation due to Variations in Sluice Gate Openings in the Langnga Irrigation Secondary Channel, Pinrang Regency

Alfiah Nurliana Basruddin[1], Farouk Maricar[2], Bambang Bakri[3]

[1,2,3]*Department of Civil Engineering, Hasanuddin University, Gowa, Indonesia.*

[1]*Corresponding Author : alfiahnurliana98@gmail.com*

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Abstract *- This study aims to analyze the effect of variations in sluice gate openings on the flow speed and concentration of sediment drifting in the secondary channel of Langnga Irrigation. The variety of sluice gate openings used consists of three conditions, namely 40 cm, 60 cm, and 80 cm. Flow velocity measurements were performed at three vertical depth points (0.2 m, 0.6 m, and 0.8 m from the surface), while drifting sediment sampling was performed at three different survey points. The data obtained shows that the larger the sluice gate opening, the flow speed tends to increase. This increase in flow speed has an effect on the decrease in the concentration of sediment floating along the channel. This is due to the greater ability of the flow to transport fine particles, so that it is difficult for sedimentary particles to settle at the observation point. The highest sediment concentration value was obtained at the 40 cm opening of 0.83 mg/l, while the lowest was at the 80 cm opening of 0.74 mg/l. The results of this study show that the regulation of sluice gate openings plays an important role in sediment control in open irrigation systems.*

Keywords *- Sluice gate opening, Flow speed, Sediment drifting, Secondary channel, Irrigation.*

1. Introduction

Irrigation is an effort to distribute water to support agricultural activities. Irrigation with an irrigation system is carried out to provide or drain water to agricultural land to support plant growth according to agricultural needs. Irrigation systems use an irrigation network that divides a certain amount of water from the primary network to the secondary network [1]. The secondary channel functions to channel water from the regulating building to agricultural land, so the sustainability and efficiency of the irrigation system are highly dependent on the performance of the channel. One of the main components in the secondary channel is the sluice, which functions to regulate the distribution of discharge as needed in the field. The variation of the opening of the sluice gate will affect the flow speed of a channel. In an open channel, the flow speed is not uniform across the entire depth of the flow. This is due to the shear stress in the channel wall, the bottom of the channel, as well as the free surface effect. Such shear stresses result in a slower velocity distribution near the base and faster near the surface [2]. The variation in speed will be related to the ability of the flow to transport sedimentary material.

Sediment is an important concern because it can have an impact on flow quality, water distribution efficiency, and the potential for siltation of channels. The main parameter that affects the distribution of sediment is the flow velocity. High flow speeds tend to increase the ability of water to transport sediment, so that the distribution and amount of sediment along the channel becomes more dynamic. On the other hand, low flow velocity can lead to sedimentation, which has the potential to shallow the channel, reduce the carrying capacity, and inhibit the flow [3].

Sedimentation is the process of deposition of sediment materials in the form of mud, clay, silt, sand, and gravel carried by water flows. Factors that affect sedimentation are erosion in channel geography, increased rainfall, and human activity in upstream areas, which can accelerate the rate of erosion and increase the amount of sediment entering the irrigation channel [4, 5]. One of the important factors in assessing the hydrological condition of an irrigation canal is drifting sediment, or suspended sediment. Drifting sediments have more complex transport characteristics and can spread further downstream. The distribution and concentration of drifting sediment can serve as an important indicator for assessing the condition and performance of irrigation canals [6]. Sedimentation is affected by the flow rate, where the flow velocity across the open channel cross-section is usually very different and uneven. There is a shear stress in the walls and

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bottom of the duct, which causes the difference in fluid viscosity and duct roughness. Maximum velocity usually occurs in open channel flows under a free surface as deep as 0.05 to 0.25 times its depth [7].

Erosion is a process that causes the removal of soil particles or sediment from their place of origin, as well as causing sedimentation downstream. This process occurs when the forces acting from the flow of water, such as lift and shear force, are greater than the forces that hold the particles to remain stationary, i.e., the gravitational force, the cohesion force between the grains, and the frictional force between the particles against each other. This condition mainly occurs in fine particles less than 0.2 mm in size, such as fine grains of sand or silt, which easily detach from the bottom of the channel when subjected to the influence of a considerable flow force.

Erosion occurs when the shear force of the water flow is greater than the strength of the sediment to remain in place. When this strength limit is crossed, sediment grains will begin to lift and be carried away by the flow. If these conditions last long enough, the erosion process will continue until a lot of sediment is carried away by the flow [8]. This process does not always take place directly, as it takes time for the sediment grains to completely lift and move. The longer the water flows at high speed, the greater the likelihood of erosion. In other words, the flow speed and length of the flow time play an important role in determining how much sediment will be lifted and moved from the bottom of the channel. This shows that the relationship between fluid shear stress and the physical properties of sediment greatly determines the dynamics of sediment transport in an open flow system.

Sediment transportation is a water flow mechanism for transporting a number of sediments in a channel. This process describes how hydrodynamic forces work to lift, move, and distribute sedimentary particles along the stream. Understanding this mechanism is the basis for the analysis of channel conditions, because the main purpose of sediment transport knowledge is to find out whether, in certain circumstances, a channel is in a state of equilibrium, erosion, or sedimentation, as well as to determine the quantity of the process [9]. Although many studies have examined sediment transport and flow characteristics in open channels, studies that specifically link sluice opening variations to changes in flow velocity and sediment response in secondary channels are still very limited.

Most previous studies have focused on primary channels that only review the relationship between flow velocity and sediment without considering the role of sluice regulation as a hydraulic control variable. In addition, there has been no local study on Langnga Irrigation that quantitatively analyzes the relationship between changes in sluice gate openings, flow speed distribution, and sediment concentration.

Therefore, this study was conducted to analyze how variations in sluice gate openings affect flow characteristics, such as flow distribution, speed, and patterns, as well as their influence on sediment concentrations floating in the secondary channels of Langnga Irrigation, Pinrang Regency. The results of this analysis are expected to make a scientific contribution to understanding the hydraulic-sedimentation interaction due to the regulation of sluices, as well as provide a technical basis in an effort to reduce sedimentation and improve the efficiency of water distribution in the irrigation network.

2. Research Location

This research was carried out in Pinrang Regency, South Sulawesi Province, Indonesia, and was carried out on the secondary channel of the Langnga Irrigation Area, as shown in Figure 1.

Fig. 1 Research location of langnga irrigation secondary channel

3. Materials and Methods

3.1. Research Data

In supporting this research, there are several preparations to obtain research data to be used, so methods that are adjusted to the focus of this research are used.

1. Literature studies are carried out by collecting journals, scientific articles, and books that are in accordance with the research objectives.
2. Secondary data, in the form of data on the scheme of irrigation networks and buildings in the secondary irrigation channel of Langnga.
3. Primary data is data obtained directly from the field in the form of channel dimensions, flow velocity, and drift sediment collection.

3.2. Data Collection Process

Procedure for Capturing Flow Rate Data Using a Current Meter

1. Measuring the depth and width of the channel.
2. Determine the measurement point that is in accordance with the depth of the channel, so that it can be used for several vertical points, in this study, namely (0.2 h, 0.6 h, 0.8 h), where h is the depth of the channel.
3. The current meter is installed on a measuring pole (static) with a depth of 0.2h, 0.6h, and 0.8 h.
4. The flow speed is obtained automatically on the current meter.

Fig. 2 Current meter measuring instrument

Floating Sediment Data Collection Procedure

1. Preparing a floating sediment sampling tool (Van Dorn Bottle Sampler)
2. Before lowering, the two tube covers are hooked so that the tube cover is open.
3. After the lid opens, the device is lowered to the depth planned in this study, 0.5 of the depth of water.
4. After reaching the desired depth, the tube is closed by removing the ballast so that the water sample does not come out when lifted to the surface.
5. Once closed, the tube is pulled to the surface along with the required water sample.

Fig. 3 Van Dorn Bottle Sampler

Stages of Implementation

1. At the preparation stage, data on channel dimensions and sampling points are known.
2. The data collection stage includes:
    a. Collection of wet cross-section data of the channel
    b. Data retrieval at each point
    c. Regulating door openings, in this study, there are three variations of sluice gate openings with each opening height (40 cm, 60 cm, 80 cm)
    d. Set the distance of each sampling point at an interval of 50 meters downstream from the data collection point.
    e. Measuring the depth of each sampling point.
    f. Retrieve flow rate data using the current meter tool at each predetermined point.
    g. Every data obtained is recorded on the table that has been prepared.
    h. Sampling of floating sediment using the van Dom bottle sampler.
    i. Conducting sediment concentration and hydrometer testing in the soil mechanics laboratory to determine the gradation of butrian in determining the type of suspended sediment material.
    j. Next, the total suspension sediment discharge was calculated.
    k. From the results of data analysis, it will be possible to determine the variation in the opening of the sluice gate to the flow speed and concentration of sediment floating in the secondary irrigation channel of Langnga, Pinrang Regency.

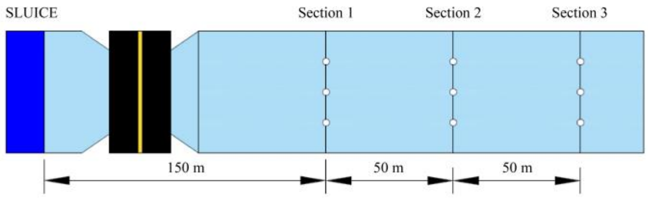

Fig. 4 Top view of observation points for data collection

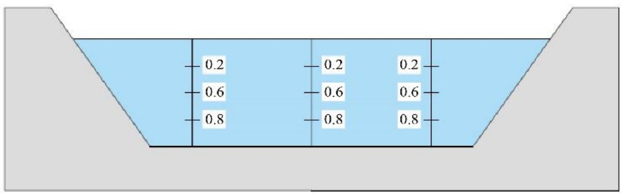

Fig. 5 Data retrieval point

4. Results and Discussion

4.1. Flow Speed

The value of flow velocity (v) in this study was obtained from direct measurements using a Current Meter. The results of the speed measurement are presented in Table 1.

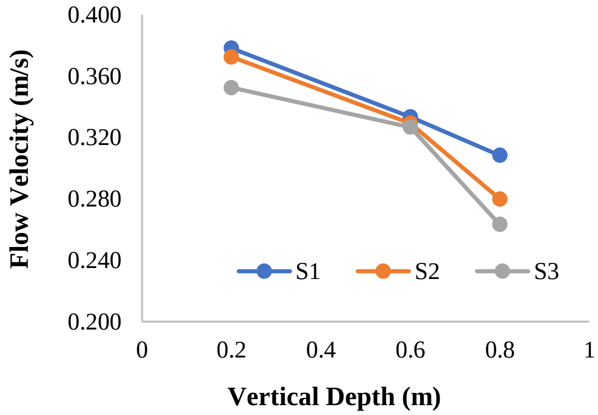

Fig. 2 Flow speed opening 40 cm

Table 1. Flow velocity

Gate Openings Level (cm)	Cross Section	Speed Point	Flow Velocity (m/s)
40	1	0.2	0.38
		0.6	0.33
		0.8	0.31
	2	0.2	0.37
		0.6	0.33
		0.8	0.28
	3	0.2	0.35
		0.6	0.33
		0.8	0.26
60	1	0.2	0.39
		0.6	0.34
		0.8	0.31
	2	0.2	0.38
		0.6	0.32
		0.8	0.30
	3	0.2	0.37
		0.6	0.32
		0.8	0.28
80	1	0.2	0.41
		0.6	0.36
		0.8	0.29
	2	0.2	0.40
		0.6	0.33
		0.8	0.29
	3	0.2	0.37
		0.6	0.32
		0.8	0.27

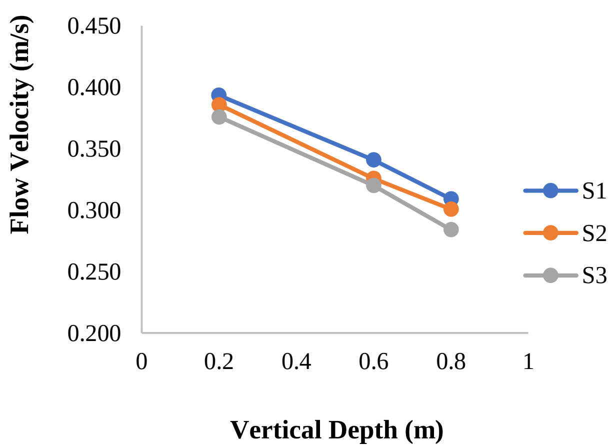

Fig. 7 Flow speed opening 60 cm

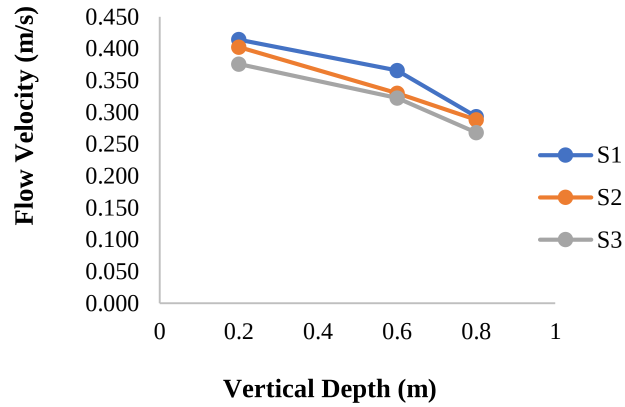

Fig. 8 Flow speed opening 80 cm

The vertical flow velocity at the three different sluice openings in Figures 6-8 for the 40 cm, 60 cm and 80 cm openings shows that at point 0.2 there is a greater flow velocity than at other vertical velocity points, which is affected by the free surface not having friction like the base, so that the flow near the surface is free from the basic friction force. As a result, the velocity at 0.2 m from the surface is greater than at other points.

4.2. Sediment Concentration

The sediment concentration is obtained from the results of laboratory tests to find out how much material in the form of soil particles, fine sand, and mud is carried by the water flow. This data was obtained after sampling of floating sediment using a Van Dorn Bottle Sampler. The sediment concentration data in this study are presented in Table 2.

Table 2. Sediment concentration

Cross Section	Sediment Concentration (mg/l)		
	Gate Opening 1 (40 cm)	Gate Opening 2 (60 cm)	Gate Opening 3 (80 cm)
1	0.62	0.59	0.58
2	0.81	0.64	0.61
3	0.84	0.74	0.67

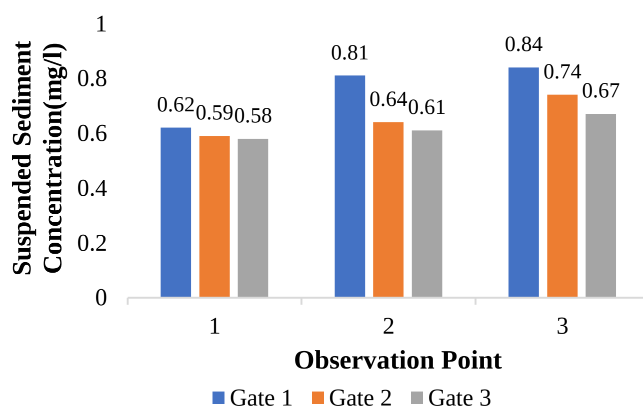

Fig. 9 Sediment concentration recapitulation

Figure 9 presents the data in Table 2, where opening 1 with an opening of 40 cm has the largest amount of sediment concentration compared to opening 2 (60 cm) and 3 (80 cm), while the largest sediment concentration for the section under review is in section 3 for each opening.

This is because the larger the sluice gate opening, the greater the flow density. When the sluice gate opening is smaller, the flow speed tends to decrease, so the basic shear force acting on the sediment particles is also smaller.

This condition causes sediment particles to settle easily, so that the concentration of sediment in opening 1 is higher. Conversely, at larger openings, the flow speed increases and causes lift. As a result, sediment is carried away faster by the stream, resulting in a lower concentration of measured sediment.

4.3. Sediment Size Analysis

The gradation and size of sediment grains were obtained through hydrometer tests at the Soil Mechanics Laboratory. The results of the distribution of material size are shown in Figure 10.

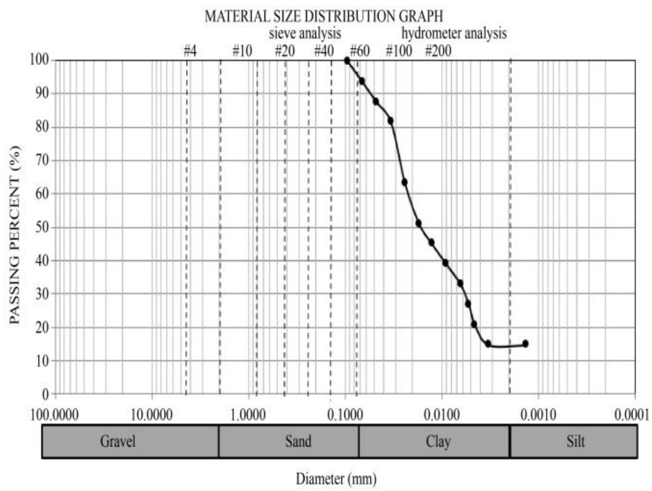

Fig. 10 Material size distribution

The results of the analysis in Figure 10 show that the grain gradation is at a vulnerability of 0.0013 mm - 0.0661 mm, so that there are 84.60% silt and 15.40% clay from the sediment samples obtained.

4.4. Floating Sediment Transport

The data on the transport of floating sediment is calculated using the calculation of the sediment discharge in tons/day as in Equation (1). The data on the quantity of floating sediment transportation is shown in Table 3.

$$Qs = 0.0864 \times Cs \times Qw \qquad (1)$$

Table 3. Floating sediment transport quantity

Openings (cm)	Cross Section	V (m/s)	Qw (m^3/s)	Cs (mg/l)	Qs (tons/day)
40	1	0.34	1.32	0.62	0.070
	2	0.33	1.27	0.81	0.089
	3	0.31	1.22	0.84	0.089
60	1	0.35	1.38	0.59	0.071
	2	0.34	1.34	0.64	0.074
	3	0.33	1.30	0.74	0.083
80	1	0.36	1.46	0.58	0.073
	2	0.34	1.39	0.61	0.074
	3	0.32	1.32	0.67	0.076

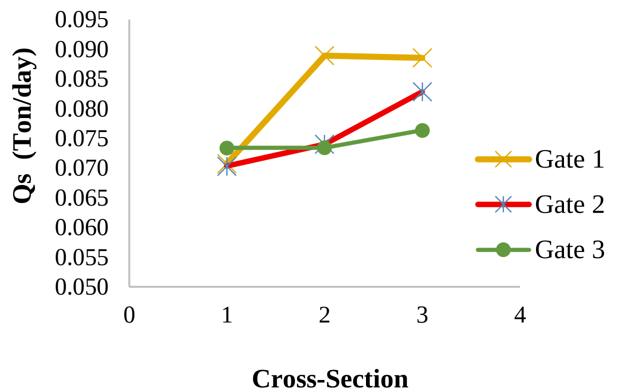

Fig. 3 Floating sediment discharge (Qs) at each opening

The results of the floating sediment transport presented in Figure 11 show that the highest floating sediment discharge (Qs) occurred at opening 1 (40 cm), while the lowest Qs value was found at opening 3 (80 cm). This condition is caused by a smaller flow rate that makes sediment particles tend to be suspended, resulting in a larger measured Qs value.

The transport of floating sediment can also be calculated using the empirical equations proposed by Einstein. The data from the analysis of floating sediment transport using Einstein's equation are presented in Table 5, which is calculated based on Equation (2).

$$qs = 11{,}6\,.\,U'.\,\mathrm{Ca}\,.\,\mathrm{a}.\left[\left(2{,}303\log\frac{30{,}2\,D}{\Delta}\right)I_1 - I_2\right] \qquad (2)$$

$$a = 2.\,d_{65}$$

$$a = 2\ x\ 0{,}0231 = 0{,}04619$$

$$U'_* = U_* = \sqrt{g.R.So}$$

$$U_* = \sqrt{9.81\ x\ 0.453\ x\ 0.0007} = 0.0558\ m/s$$

$$\frac{Ks}{\delta'} = \frac{U_*\,.d_{65}}{11{,}6\,.\,v}$$

$$\frac{Ks}{\delta'} = \frac{0{,}0558\ x\ 0{,}04619}{11{,}6\,.\,8.93x10^{-7}} = 1.24$$

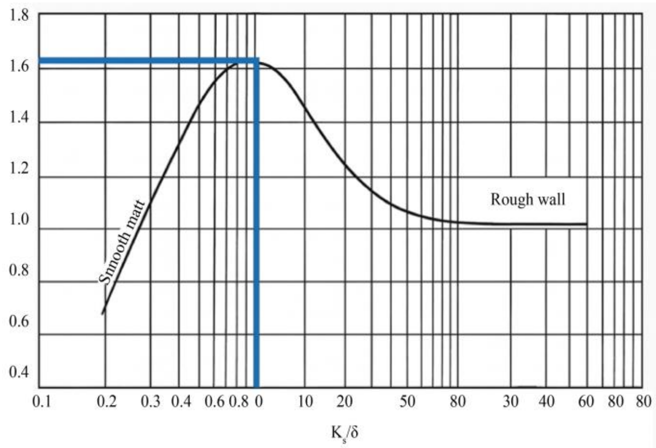

Fig. 4 Graph of the relationship between Ks/δ' and x

From Figure 12, the relationship between Ks/δ' and x is obtained the value x = 1.6

$$\Delta = \frac{Ks}{x} = \frac{d_{65}}{x} = \frac{0,00023}{1.6} = 0,00014$$

Assume *d65*

$$A = \frac{2.d}{D} = \frac{2 \times 0.00023}{1,08} = 4.28\, x10^{-4}$$

$$F = \left[\frac{2}{3} + \frac{36v^2}{gd^2\left(\frac{\gamma s}{\gamma} - 1\right)}\right]^{0.5} - \left[\frac{36v^2}{gd^2\left(\frac{\gamma s}{\gamma} - 1\right)}\right]^{0.5}$$

$$F = \left[\frac{2}{3} + \frac{36 \times 7.9 \times 10^{-13}}{9.81 \times 5.04 \times 10^{-6} \times 1.54}\right]^{0.5} - \left[\left[\frac{36 \times 7.9 \times 10^{-13}}{9.81 \times 5.04 \times 10^{-6} \times 1.54}\right]\right]^{0.5}$$

$$F = 0.815$$

$$\omega = F\left[d_{50}\, g\, \left(\frac{\gamma_{s-}\gamma}{\gamma}\right)\right]^{0.5}$$

$$\omega = 0.815[0.0002 \times 9.81 \times 1.54]^{0.5}$$

$$\omega = 0.0415$$

$$Z = \frac{\omega}{0,4\,.U_*} = \frac{0.0415}{0,4\, x\, 0,0558} = 1.861$$

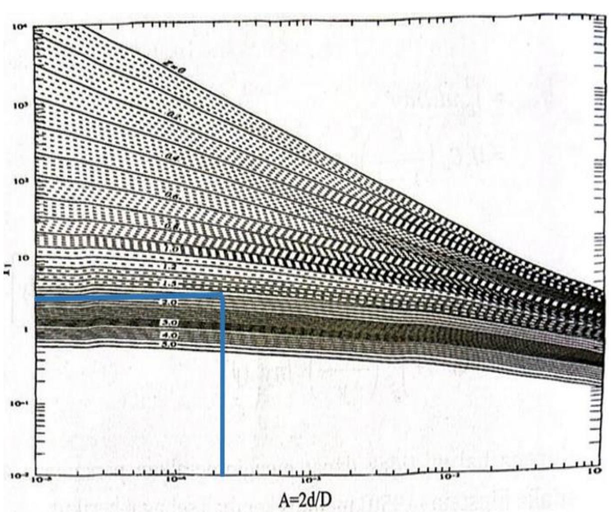

Fig. 5 Graph of the relationship between I1 and A with Z

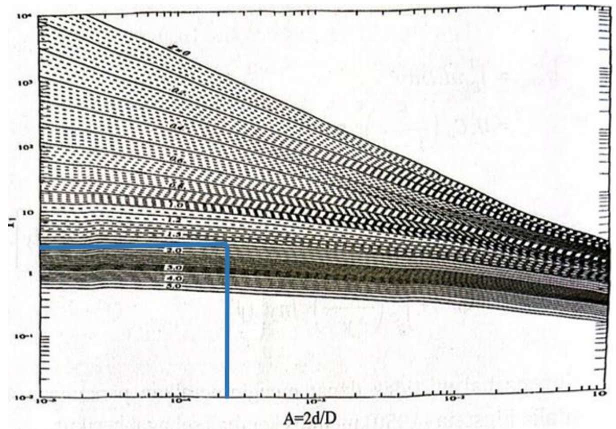

Fig. 14 Graph of the relationship between I2 and A with Z

From Figures 13-14 the relationship between I_1 and I2 where Z = 1.861 and A = 0.9466 is obtained the value I_1 = 4.68 and I2 = 1.41

$$qs = 11,6\,.U'.\mathrm{Ca}\,.\,\mathrm{a}\,.\left[\left(2,303 \log \frac{30,2\, H}{\Delta}\right) I_1 + I_2\right]$$

$$qs = 11,6 \times 0,056 \times 0.617 \times 0,046 \times \left[\left(2,303 \log \frac{30,2\, x\, 1,08}{0,00014}\right) 4,68 + 1,41\right]$$

$$qs = 0.10596\, kg/s/m$$

$$Qs = 1,31758 \times 9,05 = 11,9241\, kg/s$$

$$Qs = 1,030\, ton/day$$

Table 4. Sediment transport drifts Einstein's formula

Cross Section	Sediment float Einstein formula (tons/day)		
	Opening 1 (40cm)	Opening 2 (60cm)	Opening 3 (80 cm)
1	0.110	0.107	0.106
2	0.144	0.115	0.112
3	0.150	0.133	0.122
Average	**0.135**	**0.118**	**0.113**

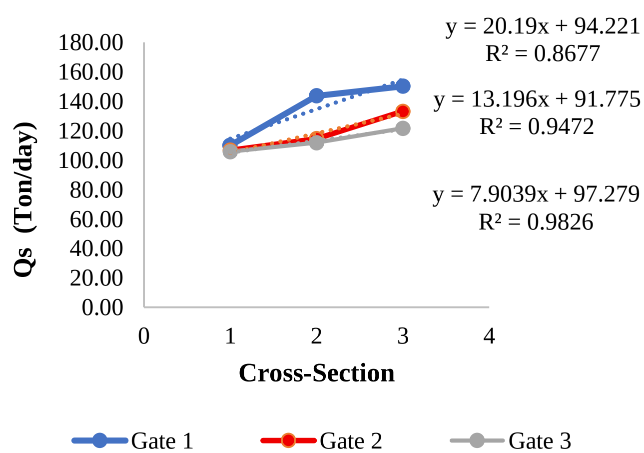

Fig. 15 Floating sediment discharge (Qs) Einstein formula

Table 4 shows the number of sediment transports floating in (tons/day) using the Einstein formula at each opening at each survey point. Based on the calculation results, the average value of Qs at opening 1 reached 0.135 tons/day, at opening 2 it was 0.118 tons/day, and at opening 3 it was 0.113 tons/day. The results of the analysis of the quantity of floating sediment transport shown in Figure 13 show that opening 1 has the largest floating sediment discharge, while opening 3 shows the smallest value.

The results of the calculation of the instantaneous discharge method and Einstein's formula are compared and presented in Table 5. This comparison was carried out to assess the degree of compatibility between the results of theoretical calculations and empirical conditions in the field. This approach aims to evaluate the extent to which the mathematical model of the Einstein formula is able to represent the value of sediment transport obtained from direct measurements. Thus, the results of the comparison of the two can be used as a basis for determining the most accurate and relevant method for the hydraulic characteristics of the river being studied. Based on the recapitulation of the results of the analysis of the instantaneous discharge method, it relies on flow velocity as the main parameter in estimating the amount of sediment transported, while the Einstein formula does not take into account the flow velocity directly, but rather focuses on the parameters of shear velocity, sediment particle falling velocity, and sediment grain size as the dominant factor in the calculation process.

Table 5. Comparison of the average sediment transportation momentary discharge method and einstein formula

Openings (cm)	Momentary Method	Einstein Formula
	Qs (Tons/day)	Qs (Tons/day)
40	0.083	0.135
60	0.076	0.118
80	0.074	0.113

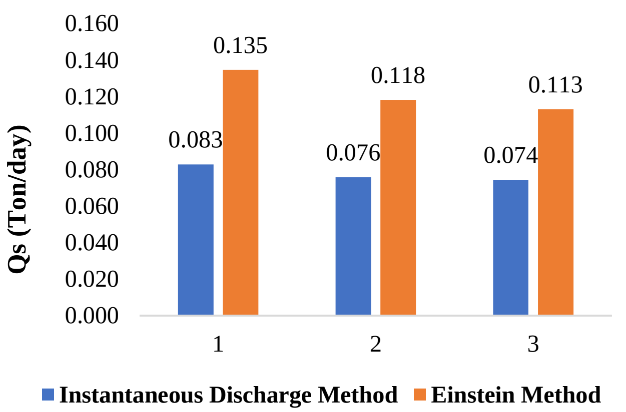

Fig. 16 Comparison graph of floating sediment discharge (Qs) using instantaneous discharge method and einstein formula

The results of the sediment transport (Qs) measurements at each opening are presented in a single graph showing the comparison of Qs values between the Einstein formula and the instantaneous discharge method, as shown in Table 5. Based on the analysis of each cross-section, the relationship between the sediment discharge floated shows a downward trend from opening 1 to opening 3.

The Qs value obtained through Einstein's formula shows a higher yield compared to the momentary discharge method. This is because Einstein's formula takes into account parameters such as shear velocity, sediment grain size, and sediment particle drop velocity, while the instantaneous discharge method is more representative of actual conditions in the field at the time of measurement. Therefore, the Qs value calculated by the instantaneous method tends to describe the maximum sediment transport capacity of a stream.

The result of the comparison between the instantaneous method and Einstein at apertures 1, 2, and 3 is 1:1.63, respectively; 1:1.55 and 1:1.53. Overall, the results of calculations using the Einstein formula consistently resulted in an estimated sediment transport rate of about 1.5 to 1.6 times greater than the results of direct measurements with the instantaneous discharge method.

4.5. Effect of Sluice Gate Opening on Flow Speed

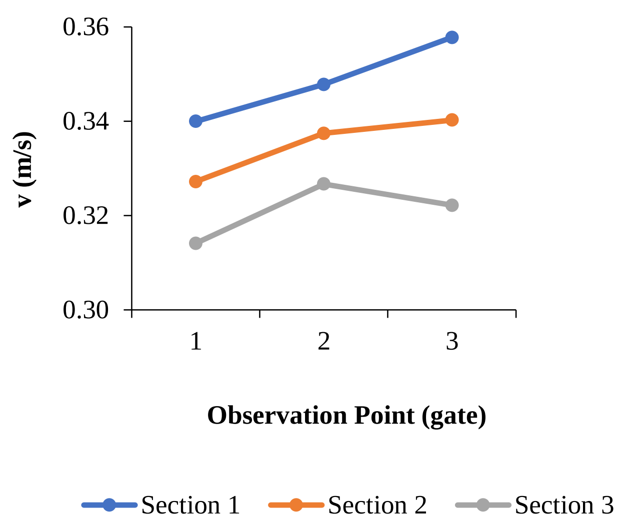

Fig. 6 Effect of sluice gate opening on flow speed

Figure 17 shows the effect of the sluice gate opening on the flow speed; the larger the sluice opening, the greater the flow speed. The flow speed in each section varies, where Section 1 is closer to the opening of the sluice gate than Sections 2 and 3, with a distance of 50 m downstream from Section 1 to Section 2 and Section 3. So that the farther the Section point, the flow speed will be slower compared to Section 1, which is located at the opening of the sluice.

4.6. The Effect of Flow Speed on Sediment Transportation Distribution

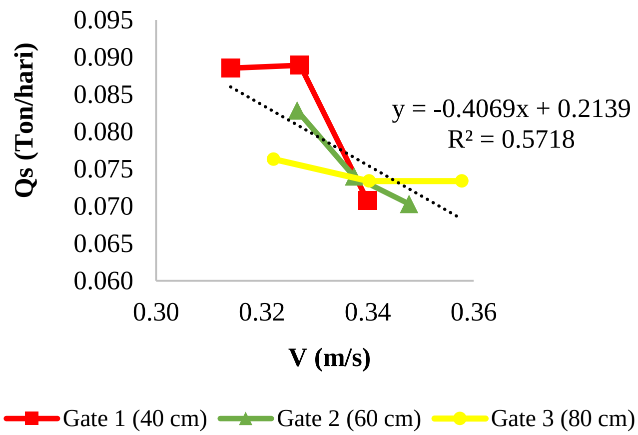

Fig. 18 Effect of flow speed on sediment transport distribution

The graph in Figure 18 shows the relationship between flow velocity (m/s) and sediment concentration (tons/day) in three variations of sluice openings, namely opening 1 (40 cm), opening 2 (60 cm), and opening 3 (80 cm). Increased flow speed leads to a decrease in sediment concentration. In opening 1 with the lowest flow velocity, the sediment concentration was recorded as the highest, while in opening 3 with a greater flow velocity, the sediment concentration became smaller. This is because at high flow speeds, fine sediment particles will remain suspended longer and carried farther away from the measurement point, so that the value of sediment concentration at the observation site is reduced. In contrast, at lower flow rates, sediment particles tend to settle and produce higher concentration values. Thus, the relationship between flow velocity and sediment concentration shows an inverse gravitational tendency, where an increase in flow velocity reduces the measured amount of sediment at the observation point.

5. Conclusion

The results of the study show that the variation of the sluice gate opening affects the flow speed, where this change in speed determines the amount of sediment transportation in the Langnga Irrigation Canal. In the small opening, the flow speed decreases so that the fine sediments that dominate the study site measure 0.0013–0.0661 mm with a composition of 84.60% silt and 15.40% clay, and tend to settle around the sluice. In contrast, larger openings increase flow speed, keep particles suspended, and reduce the potential for local sedimentation. This suggests that proper sluice opening arrangements are necessary to maintain channel capacity, support more efficient water distribution, and reduce the need for repetitive dredging.

Conflicts of Interest

The writing of this article was carried out for academic purposes, namely as one of the requirements in completing studies in the Master of Civil Engineering program. All data, analysis, and conclusions presented in this article are objectively compiled based on actual research results, without any intervention from other parties.

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