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Original Article

Analysis of the Influence of Flow Speed on the Distribution of Floating Sediment Transport in the Pattiro Irrigation Canal, Bone Regency

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Abstract *- The Pattiro Irrigation Canal in Bone Regency has sedimentation problems, which cause a reduction in the discharge capacity of the cross-section of the channel and reduce the efficiency of water distribution to agricultural areas. This study aims to analyze the influence of flow speed on the distribution of sediment transportation, examine sediment characteristics, and compare the flow speed between the upstream and downstream parts of the primary channel of Pattiro Irrigation. The data obtained show that the sediment transport process occurs when the shear stress of the flow exceeds the critical shear stress of the sediment particles. The distribution of sediment along the channel shows variety, where fine-sized materials are more dominant upstream, while coarse-sized materials are more prevalent downstream. The pattern indicates that flow energy has an important role in the transport and deposition of sediments. Hydrodynamic analysis showed that the flow speed in the upstream part reached 0.882 m/s with an average depth of 1.08 m, while in the downstream, the speed decreased to 0.556 m/s with a depth of 1.30 m. The decrease in speed caused some of the sediment carried from upstream to experience sedimentation downstream.*

Keywords *- Sediment, Flow rate, Shear stress, Irrigation channel.*

1. Introduction

Sediment transportation is one of the important processes in open channels that affects flow capacity, channel stability, and irrigation system performance. In irrigation canals, sediment accumulation can cause siltation of channels, reduce water distribution efficiency, and increase channel maintenance needs. Therefore, understanding the mechanism of sediment transport is an important aspect in the management of irrigation canals [1].

Various studies on sediment transportation have been carried out on natural rivers and artificial channels, both through theoretical and empirical approaches, and laboratory experiments. Classical models such as Einstein's equation and its development have been widely used to explain the relationship between flow velocity and the magnitude of sediment transport. However, most of these studies are conducted under controlled flow conditions or laboratory scale, so their application to irrigation canals with complex field conditions still requires further study [2].

Field research on irrigation canals also showed that there was a variation in the distribution of flow speed, and sediment concentration floating in the flow was not uniform. Direct measurements in irrigation canals in Yogyakarta show that the concentration of drifting sediment tends to increase near the bottom of the channel, while the vertical average value of sediment concentration is greater in the middle of the channel cross-section [3]. These results show a strong relationship between flow velocity distribution and sediment transport behavior.

Flow velocity is the main hydraulic parameter that determines the ability of the flow to transport floating sediment. Changes in flow velocity affect the balance between turbulence-induced lift and the heavy force of sedimentary particles. In irrigation channels dominated by fine-grained sediments, small changes in flow velocity can have a significant effect on the distribution of sediment transport. However, field-based studies that specifically analyze the relationship between flow velocity and sediment transport in irrigation canals are still relatively limited.

The primary channel of Pattiro Irrigation is one of the irrigation channels that experiences sedimentation problems that have the potential to reduce channel capacity. The sediment characteristics dominated by fine particles and variations in flow conditions make this channel a representative location to study sediment transport behavior based on field data.

Based on these conditions, this study is focused on answering how the relationship between flow speed and sediment transportation floats in irrigation canals based on field measurement data. In addition, this study also evaluates the extent to which the theoretical approach of the Einstein method is able to represent the real conditions of sediment transport in irrigation canals dominated by fine-grained sediments. The contribution of this research is expected to enrich empirical studies on sediment transport in irrigation canals and provide a scientific basis for sedimentation management based on flow characteristics.

2. Literature Review

2.1. Basic Concepts

Sediment consists of fragmented materials produced by physical and chemical weathering processes. These particles vary widely in size, ranging from coarse materials to fine colloidal fractions, and are transported and deposited by natural agents such as water, wind, or ice. In river systems, sediment characteristics are commonly evaluated through measurements of suspended sediment. Sedimentation occurs when the quantity of sediment transported by the flow exceeds the sediment transport capacity of the channel, leading to deposition within the flow system. [4].

Sediment granular particles in nature have irregular shapes. Therefore, each length and diameter will give meaning to the shape of the grain group. The transport of sediment at the bottom of the channel is greatly influenced by the initial motion of the sediment particle grains when their critical stress is exceeded. This causes the base material to be stationary. The movement of sediment transport in a river can take place in various ways, either through shifts along the riverbed or by being carried away in the stream. This movement pattern is strongly influenced by the characteristics of the sedimentary material, such as grain size and specific gravity, as well as by the hydraulic conditions of the flow, including the speed and depth of the water [5-6].

2.2. Sediment Transport Mechanism

In general, sediments transported by river flows are classified into three main types, namely wash load, suspended load, and bed load. Wash loads consist of fine to very fine particles, including colloidal fractions, which have very low deposition velocities even when under calm flow conditions. This type of material generally does not come directly from the riverbed, but from external sources or the result of cliff erosion, so the amount of material in the bed material is relatively small and limited. In turbulent flow conditions that are common in rivers, the ability of the flow to transport the wash load is actually very large. Therefore, the amount of rinse load transported is mainly dependent on the availability of fine materials present in the riverbed [7]

Meanwhile, the bed load moves through a rolling, gliding, or jumping mechanism along the surface of the riverbed, following the direction of the water flow. The suspended load consists of fine particles that remain suspended in the flow due to the turbulence force that prevents the grains from precipitating immediately. The main sources of sediment formation in rivers come from erosion of mountainside surfaces, erosion of river beds and cliffs, as well as materials from active volcanic eruptions. These natural processes become the main providers of sediment, which is then transported through sediment transport mechanisms within the river flow system [8].

2.3. Theoretical Approach

Basically, it is very difficult to observe the movement of sediment particles within the channel. Sediment transport in open-channel flows can be analyzed using various empirical formulations, such as the Einstein, Meyer–Peter Müller, and Frijlink equations. Some of these equations are widely used in predicting the quantity of sediment transport and the magnitude of sedimentation rates that occur in open channels [9]. Flow velocity is one of the key parameters in the approach because it is directly related to the base shear force and the level of flow turbulence. Therefore, the accuracy of the measurement of flow velocity is an important factor in the analysis of sediment transportation. Based on this approach, a field data-based study is needed to evaluate the suitability of the empirical model for the real conditions of irrigation canals.

3. Materials and Methods

3.1. Research Location

This research was carried out on the primary channel of the Pattiro Irrigation Area, located in Bone Regency, South Sulawesi Province. This channel was chosen as the research location because it experienced sedimentation problems that had the potential to reduce flow capacity and was dominated by fine-grained sediments.

3.2. Research Data

Primary data were collected through direct field measurements, including flow velocity, flow discharge, channel dimensions, and sampling of drifting sediment. Secondary data was obtained from related agencies in the form of a network scheme and Pattiro irrigation building managed by the Pompengan River Area Unit in Jeneberang. Literature studies are carried out as a theoretical basis in data analysis and discussion of research results.

3.3. Primary Data

Primary data refer to information collected firsthand from the object of study.

Flow speed and discharge data capture procedures

1. Determine the channel depth and channel width.
2. Choosing a measurement point that is appropriate to the depth of the channel, in this study, it is (0.2H, 0.6H,

0.8H), where H is the depth of the channel. This method is commonly used in channels with a depth of more than 0.76 m and is considered to be able to represent the vertical distribution of flow velocity.
3. The current meter is mounted on a fixed measuring rod at the predetermined depth, after which the rod is placed into the flow with the propeller oriented in the direction of the current.
4. Before use, the current meter is calibrated according to the manufacturer's instructions to ensure the accuracy of the measurement results. The upstream and downstream measurement points were chosen to represent variations in flow conditions along the channel as well as capture differences in sediment transport characteristics in different segments.
5. The flow speed is obtained automatically on the current meter. Furthermore, the flow discharge (Q) is calculated as a result of the multiplication between the average flow speed and the wet cross-sectional area of the channel. The use of transient discharge data is intended to capture actual flow conditions at the time of sediment sampling.

Fig. 1 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 opened, the device was 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 escape when lifted to the surface.
5. Once closed, the tube is pulled to the surface along with the required water sample.

Fig. 2 Alat Van Dorn Bottle Sampler

Stages of Implementation,
1. At the preparation stage, data on channel dimensions and sampling points are known.
2. The stages of data collection include:
   a. Determine the sampling section at intervals of 50 meters downstream.
   b. Measuring the depth of each sampling point
   c. Retrieve flow rate data using the current meter tool at each predetermined point.
   d. Every data point obtained is recorded in a table that has been prepared.
   e. Sampling of floating sediment using the Van Dorn bottle sampler.
   f. Conducting sediment concentration testing and hydrometer testing in the soil mechanics laboratory to determine the gradation of granules and to determine the type of suspended sediment material.
   g. Next, the total suspension sediment discharge was calculated. The effect of flow speed on the distribution of sediment transportation in the Pattiro irrigation canal, Bone Regency.

4. Results and Discussion

4.1. Flow Characteristics

The flow speed is measured using *the current meter* obtained as a result of the flow speed value of each cross-section, as shown in Table 1. The average maximum speed is 1.22 m/s, while the average minimum speed is 0.58 m/s. The importance of water flow velocity data is to influence the distribution of sediment transportation by increasing the amount of sediment transported.

Table 1. Results Measurement of flow speed and water level

Cross Section	Average speed (m/s)	Average depth (m)
1	0.94	1.03
2	1.02	0.90
3	1.22	1.07
4	0.94	1.10
5	0.79	1.17
6	0.65	1.08
7	0.58	1.30

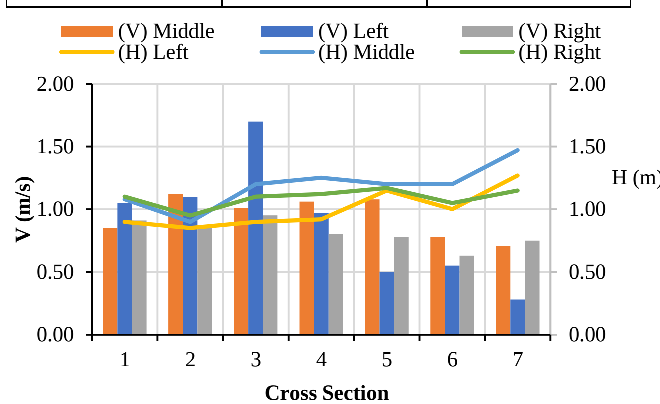

Fig. 3 The relationship between cross-section and flow rate *(V)* and water level *(H)*

A graph of the flow speed *(V)* and water level *(H)* at each channel cross-section, shown in Figure 3, shows that in the upstream part (section 1), the speed is greater than in the downstream part (section 7). The water level significantly affects the distribution of sediment transport. Changes in water level levels, such as flooding or receding, change the flow speed and sediment transport capacity. Rising water levels increase flow energy, resulting in erosion and greater sediment transport. Conversely, a drop in the water level can lead to sediment deposition. Changes in flow patterns due to changes in water level also have an impact on the shape of channels and the distribution of sediment along channels or other water bodies, affecting aquatic ecosystems and related infrastructure.

The flow discharge was obtained after measuring the cross-sectional area and flow speed, so that the flow discharge value of the Pattiro irrigation canal was obtained. Stream discharge and sediment transport are interrelated, and both are important in river management. The greater the flow discharge, the more sediment is transported. From the data obtained, the maximum discharge of 7.70 m^3/s can be seen in marker three, while the minimum discharge of 4.19 m^3/s can be seen in cross-section 6, for an average discharge of 5.58 m^3/s. The results of the calculation of channel discharge in each section are presented in the table.

Table 2. Flow discharge calculation results

Cross Section	*A*	*V*	*Q*
	(m2)	(m/s)	(m3/s)
1	6.42	0.884	5.67
2	5.63	0.955	5.37
3	6.67	1.155	7.70
4	6.85	0.895	6.13
5	7.33	0.750	5.50
6	6.77	0.619	4.19
7	8.10	0.557	4.52
Average			5.58

4.2. Sediment Characteristics

Factors that cause sediment transport to move, shift along the riverbed, or move drifting in the river flow, other than the flow characteristics, are the characteristics of the sediment. Sediment characteristics include size and specific gravity.

Table 3. Results of sediment size distribution filter analysis

Material	Hulu	Downstream
Pebbles	1.33%	13.67%
Sand	36.33%	36.00%
Coal	38.49%	38.12%
Clay	23.85%	12.22%

From Table 4 of sediment diameter, it can be explained that the average values of the sieve diameters are d50 = 0.320 mm and d65 = 0.586 mm. According to Wentworth's (1922) classification, sediments with a diameter of d50 = 0.320 mm include a classification of coarse sand with a grain size of 1 mm – 1/2 mm, while sediments with a diameter of d65 = 0.586 mm include a classification of medium sand with a grain size of 1/2 mm – 1/4 mm.

Table 4. Sediment size diameter

Cross Section	D35	D50	D65	D90
	(mm)	(mm)	(mm)	(mm)
1	0.032	0.08	0.090	0.16
2	0.48	0.80	0.700	2.50
3	0.075	0.12	0.570	2.00
4	0.14	0.22	0.790	2.50
5	0.17	0.38	0.500	2.60
6	0.40	0.46	0.890	2.70
7	0.0001	0.18	0.560	2.30

4.3. Floating Sediment Transport

The results of the laboratory analysis showed that the sediment concentration in the Pattiro irrigation canal of Bone Regency on the left is presented in Table 5, the middle part is presented in Table 6, and the right part is presented in Table 7. The results of this laboratory analysis are then used as parameters to determine the sediment suspension discharge in tons/day.

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

Table 5. Results of the sediment transport quantity analysis left section

Cross Section	Cs	Qw	Qs
	(g/l)	(m3/s)	(tons/day)
1	0.3197	4.75	0.129
2	0.2897	4.97	0.122
3	0.2690	6.13	0.140
4	0.3014	4.85	0.124
5	0.2429	5.36	0.110
6	0.1812	3.77	0.058
7	0.1849	4.40	0.069

Table 6. Results of the analysis of the quantity of sediment transport in the middle section

Section	Cs	Qw	Qs
	(g/l)	(m3/s)	(tons/day)
1	0.3356	6.07	0.172
2	0.4118	5.37	0.187
3	0.2039	8.99	0.155
4	0.2763	7.28	0.170
5	0.2808	5.67	0.135
6	0.2222	4.79	0.090
7	0.1688	5.30	0.076

Table 7. Results of the analysis of the quantity of sediment transport in the right section

Section	Cs (g/l)	Qw (m3/s)	Qs (tons/day)
1	0.3529	6.21	0.186
2	0.2929	5.78	0.143
3	0.2374	8.02	0.161
4	0.3355	6.31	0.179
5	0.2157	5.48	0.100
6	0.1824	4.02	0.062
7	0.1611	3.86	0.053

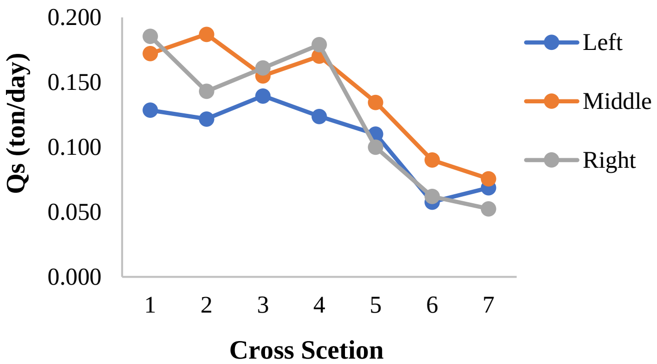

Fig. 4 A graph of floating sediment discharge (Qs) at each cross-section of the instantaneous discharge method

Suspended sediment transport was evaluated using the instantaneous discharge method shown in Figure 4 show differences in each section where the middle section is larger in several cross sections (2, 5, 6, and 7), while in the left section tends to be smaller in several cross sections (1, 2, 3, 4, and 6), this shows a flow with greater energy in the middle and able to transport more material.

In the calculation of the floating sediment charge by the Einstein method, it can be calculated as follows:

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

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

$$U_* = \sqrt{9{,}81\ x\ 1{,}08\ x\ 0{,}0008} = 0{,}090\ m/s$$

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

$$\frac{Ks}{\delta'} = \frac{0{,}090\ x\ 0{,}010}{11{,}6.\ 1x10^{-6}} = 77{,}94$$

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

$$a = 2\ x\ 0{,}010 = 0{,}020$$

To find the value *of x*, see Figure 5

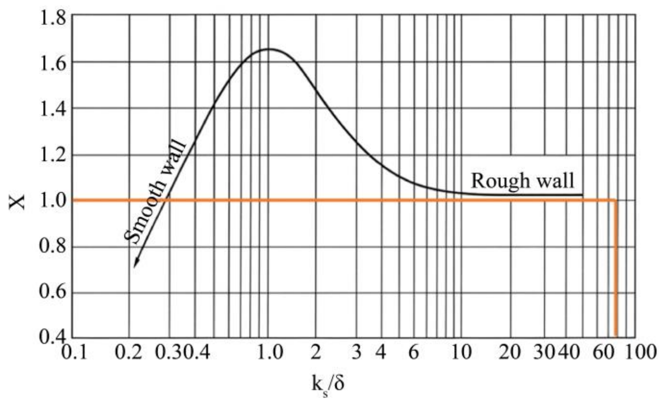

Fig. 5 The graphics relationship between and $\frac{Ks}{\delta'}x$

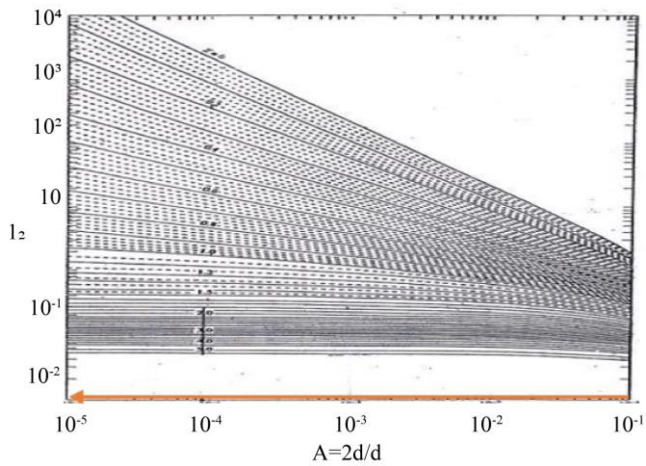

Fig. 6 Graphics relationship between I_1 and A by Z

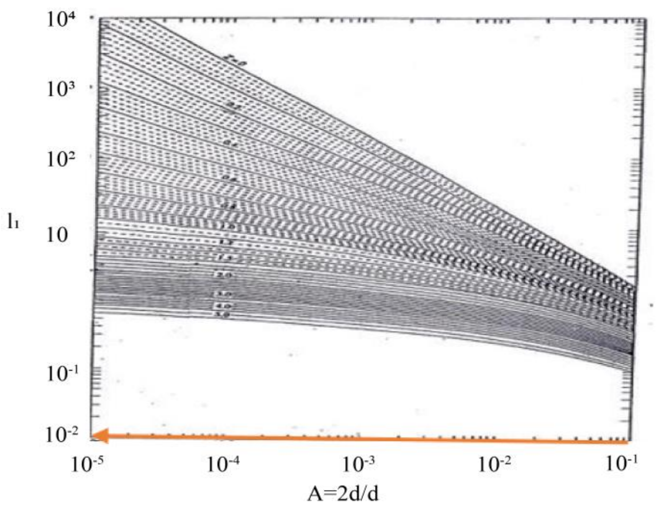

Fig. 7 Graphics relationship between I_2 and A by Z

From the graph of the relationship between and $\frac{Ks}{\delta'}x$, the value x = 1.0

$$\Delta = \frac{Ks}{x} = \frac{d_{65}}{x} = \frac{0{,}010}{1{,}0} = 0{,}010$$

Assume *d65*

$$A = \frac{2.d}{H} = \frac{0{,}010}{1{,}08} = 1{,}9x10^{-2}$$

$$\omega = \left(\frac{g.d^2}{18.v}\right).\left(\frac{\gamma_s}{\gamma}\right)$$

$$\omega = \left(\frac{9{,}81\ x\ 0{,}010^2}{18\ x\ 1x10^{-6}}\right).\left(\frac{2655}{1000}\right) = 144{,}698$$

$$Z = \frac{\omega}{0{,}4\ .\ U_*} = \frac{144{,}698}{0{,}4\ x\ 0{,}090} = 4001{,}35$$

From the graph of the relationship between I_1 and A with Z = 4001.35 and A = 1.9x10-2, the value of I_1 = 0.01 and I2 = -0.01

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

$$Qs = 11{,}6\ x\ 0{,}090\ x\ 0{,}49\ x\ 0{,}020\ x\ \left[\left(2{,}303\log\frac{30{,}2\ x\ 1{,}08}{0{,}010}\right)0{,}01 - 0{,}01\right]$$

$$Qsw = 7{,}3x10^{-5}\ kg/s/m$$
$$Qsw = 7{,}3x10^{-5}\ x\ 8 = 5{,}8x10^{-3}\ kg/s$$
$$Qsw = 0{,}162\ ton/hari$$

Table 8. Recapitulation of the quantity of floating sediment with the Einstein formula

Cross Section	Sediment float Einstein formula (tons/day)		
	Skin	Middle	Right
1	0.138	0.162	0.180
2	0.090	0.290	0.092
3	0.072	0.024	0.068
4	0.201	0.083	0.141
5	0.075	0.132	0.063
6	0.092	0.111	0.079
7	0.037	0.038	0.050
Average	0.100	1.120	0.096

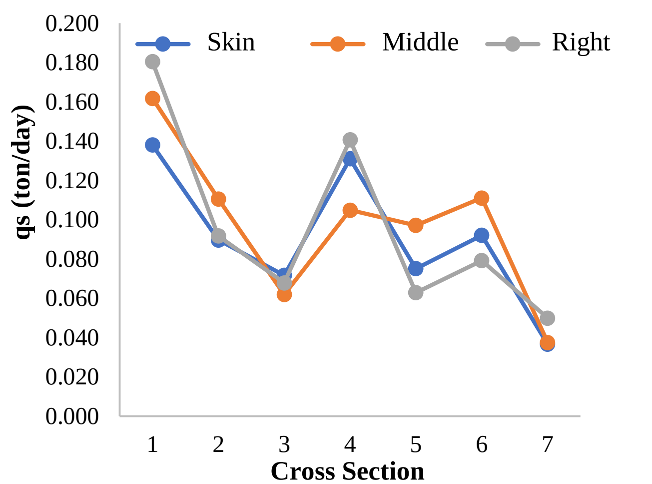

Fig. 8 Graph of floating sediment discharge (Qs) at each cross-section with Einstein's formula

Suspended sediment transport was evaluated using the instantaneous discharge method shown in Figure 8 show differences in each section where in the middle section it is larger in several cross sections (2, 5 and 6), while in the left section tends to be smaller in several cross sections (1, 2, and 7), this shows a flow with greater energy in the middle and able to transport more material.

Table 9. Comparison of instantaneous discharge methods and the Einstein formula

Cross Section	Einstein Formula	Deviant discharge method
	(tons/day)	(tons/day)
1	0.160	0.158
2	0.157	0.139
3	0.167	0.152
4	0.142	0.154
5	0.090	0.108
6	0.094	0.063
7	0.041	0.062

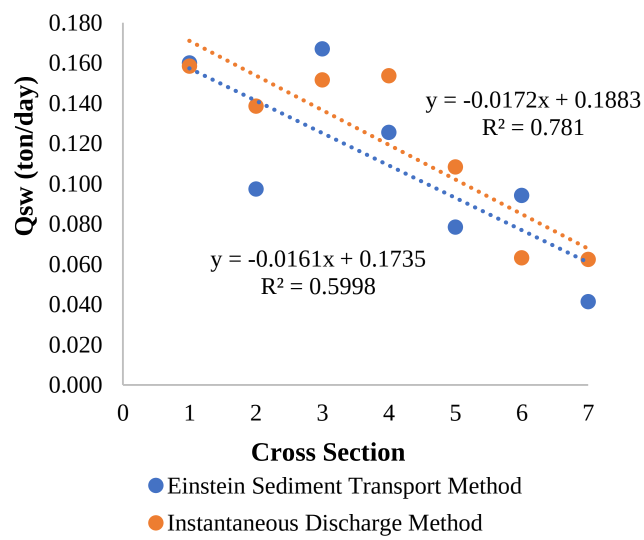

Fig. 9 Floating sediment discharge chart *(q_{Sw})* on each cross-section of the stray discharge method and Einstein's formula

The result *(qsw)* of the Einstein formula and the instantaneous discharge method in Table 9 are depicted in a graph of the relationship between *(qsw)* in each cross section to validate the measurement results data with the deviant discharge. Figure 9 shows the relationship of sediment discharge drifting at each cross-section with the same graph trend, where the drifting sediment discharge shows a decrease downstream in the two methods. However, a greater trend is shown by the instantaneous discharge method compared to the theoretical results of Einstein's formula. This is because the calculation of sediment transportation with momentary discharge uses the flow velocity variable as the parameter, while the Einstein formula emphasizes the shear speed, sediment fall velocity, and sediment grain size.

3.4. Effect of Flow Speed on Sediment Transport Distribution

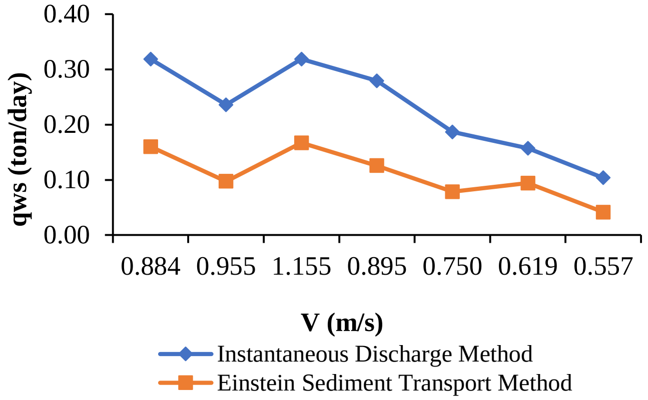

Fig. 10 The effect of flow speed on the disbursement of floating sediment transport

Figure 10 shows the high speed of water flow upstream (cross-section 1), causing bottom erosion and carrying sediment downstream (cross-section 7). In the downstream area, the flow speed slows down so that some sediment is deposited. Flow velocity in the upstream reach (cross-section 1) is around 0.884 m/s with a depth of 1.08 m, while in the downstream part (cross-section 7) the flow speed is around 0.557 m/s with a depth of 1.30 m. The sedimentation rate is affected by water quality parameters, especially current speed and depth; the deeper the waters, the lower the current speed, so that less sediment is carried by the current. The slower or stopped the speed downstream, the more sediment will settle.

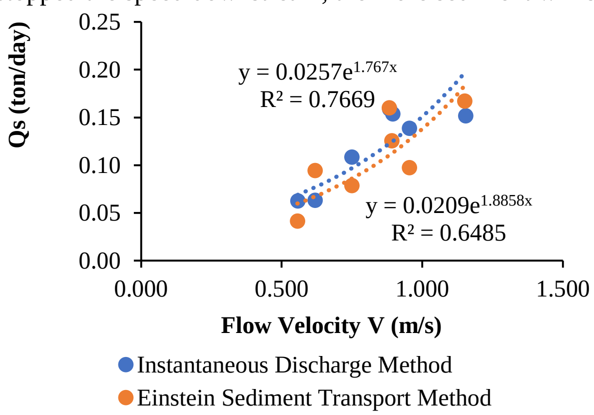

Fig. 11 Relationship of flow velocity to drifting sediment discharge

Figure 11 shows the exponential relationship between the flow velocity and discharge of drifting sediment based on instantaneous field data and calculations using the Einstein method. An R^2 value of about 0.62–0.63 indicates that most of the variation in sediment discharge is affected by the flow velocity.

The two curves are close together, although the theoretical curve is slightly more sloping. At high speeds, instantaneous data results in greater sediment discharges, reflecting more complex field conditions than the model assumes. This pattern is in line with the theory of sediment transport, which states that increased velocity amplifies turbulence and increases the mass of suspended sediment.

5. Conclusion

Based on the analysis of the sediment transport floating in each channel location, which was reviewed using the instantaneous discharge method and the Einstein equation, the results obtained from sediment characteristics in sediment distribution showed that there were variations in sediment transport along the river. In the upstream area, it is dominated by finer materials, while in the downstream, coarser materials tend to be more abundant, indicating that flow energy plays a role in the selectivity of the size of the deposited granules.

Comparison of flow speed in the upstream and downstream parts to sediment transportation in the Pattiro Irrigation channel. Indicates a greater rate of water flow upstream (cross-section 1), causing soil erosion and carrying sediment downstream (cross-section 7). In the downstream area, the flow speed slows down so that some sediment is deposited; this condition is reflected in the measured flow velocity at the upstream section (cross-section 1), around 0.882 m/s, with a depth of 1.08 m, while in the downstream part (cross-section 7), the flow speed is around 0.556 m/s, with a depth of 1.30 m.

Conflicts of Interest

This article was compiled to meet the academic needs in completing studies in the Master of Civil Engineering Program. All data, analysis, and conclusions presented are the results of research conducted in real life.

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