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Correlation Analysis Between Water Discharge and Suspended Load During The Rainy Season in The Downstream Ciliwung River, Jakarta

Nabilah Rizqah Afifah[1*], Liyantono[1,2], Satya Krido Saptomo[3]

[1]Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Engineering and Technology, IPB University, Lingkar Akademik Street, IPB Dramaga Campus, Babakan, Bogor, West Java 16680, Indonesia.
[2]Centre for Environmental Science, PPLH Building Floors 2-4, IPB University, IPB Dramaga Campus, Babakan, Bogor, West Java 16680, Indonesia.
[3]Department of Civil and Environmental Engineering, Faculty of Agricultural Engineering and Technology, IPB University, Lingkar Akademik Street, IPB Dramaga Campus, Babakan, Bogor, West Java 16680, Indonesia.
*Corresponding author, email: nabilahrizqahafifah@apps.ipb.ac.id

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Abstract

The Ciliwung River Basin originates at the foot of Mount Pangrango in West Java and flows downstream to Jakarta, with a catchment area of approximately 387 km². The downstream segment in Jakarta is highly vulnerable to sedimentation, which reduces flow capacity, damages infrastructure, and increases flood risk. These conditions highlight the urgency of analyzing the relationship between water discharge and total suspended solid (TSS) load in the downstream Ciliwung River as a scientific basis for river management in Jakarta. This study analyzed the correlation between water discharge and total suspended solids (TSS) in the downstream segment of the basin. Water samples were collected from three observation points, resulting in 11 observations and 33 samples in January 2025. The relationship between water discharge and TSS load was examined using linear regression correlation analysis in order to identify the degree of association and to establish the regression model between both variables. TSS ranged from 8.5 to 284.5 mg/L, while Water discharge varied from 2.55 to 45.47 m³/s. The correlation coefficients were obtained as 0.9721 at the upstream site, 0.9151 at the middle stream site, and 0.0006 at the downstream site. A strong positive correlation was found in the upstream and midstream segments, while the downstream segment showed no significant correlation, likely due to hydrological and tidal effects. These results contribute to a deeper understanding of sediment transport dynamics and can inform sustainable sediment management and dredging strategies in urban river systems.

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1. Introduction

Research on Total Suspended Solid (TSS) load transport has shown that variations in river discharge significantly influence the concentration and distribution of TSS, which contributes to channel siltation and affects downstream hydrological conditions (Banjarnahor et al., 2016). Similar findings were reported in the Brantas River, where TSS concentration was found to be directly

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associated with TSS load processes and provided important insights for sediment monitoring and management (Wiryamanta et al., 2021). These studies highlight the urgency of analyzing the relationship between water discharge and TSS load in the downstream segment of the Ciliwung watershed, where siltation and flood risks are increasingly critical due to urbanization pressures.

The lower reaches of the Ciliwung River particularly within the North Jakarta region frequently experience flooding due to reduced channel capacity. This condition is further aggravated by high pollutant loads and sediment influx into the river. One of the most evident consequences of sedimentation is siltation, characterized by the accumulation of TSS load that constricts the river channel. Such siltation directly reduces flow capacity, disrupts the urban drainage network, and increases the risk of flooding. Without sustainable management interventions, these conditions will escalate maintenance costs for routine dredging and further degrade the ecological integrity of the river (Rahman et al., 2016).

Sedimentation is influenced by various factors, including rainfall, land cover conditions, land use, slope gradients, and river discharge. In this context, river discharge plays a critical role, as it determines the amount of energy available for transporting sediment particles from upstream to downstream. Accordingly, an understanding of the relationship between river discharge and TSS load concentration is essential as a basis for analyzing sediment transport and assessing the potential for siltation (Chay., 2010).

Previous studies have examined the relationship between river discharge and TSS load. Nugroho (2015) reported a positive correlation between river discharge and TSS load concentration in the Progo River Basin, particularly during the rainy season. In the lower Ciliwung, (Asyifa &Prabowo., 2020) identified substantial fluctuations in TSS load, largely driven by variations in discharge and rainfall intensity. These findings underline the importance of considering TSS load as a representative parameter of TSS load in urban river systems.

Despite these studies, research explicitly addressing the discharge–TSS load relationship in the lower segment of the Ciliwung River remains limited. This downstream section is under the highest pressure, as it receives cumulative flows from upstream while being surrounded by dense human activity. A quantitative analysis of the discharge - TSS load relationship is therefore essential to accurately map hydrological conditions and sedimentation potential in this critical reach.

This study analyzed the correlation between flow discharge and TSS load in the downstream segment of the Ciliwung River. The findings are expected to provide valuable input for sedimentation and flood control strategies, particularly in urban zones prone to inundation. Furthermore, the results will serve as a scientific basis for developing more effective and sustainable watershed management policies.

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2. Material and Methods

The study was conducted from November 2024 to June 2025, which falls within the rainy season. This study was conducted in the downstream segment of the Ciliwung River, located within the Jakarta Special Capital Region (DKI Jakarta). Therefore, the upstream-downstream location division did not use the upstream-downstream watershed principle, but rather used the upstream-downstream division based on administrative area.

Data collection was conducted at three observation points selected using a purposive sampling method show in Figure 1. the first point at the Lenteng Agung Yellow Bridge, which is considered upstream in Jakarta, the second point at Menteng, which is considered midstream in Jakarta, and the third observation point at Muara Angke, which is considered downstream in Jakarta. These points were selected to represent river flow conditions in densely populated and flood-prone areas.

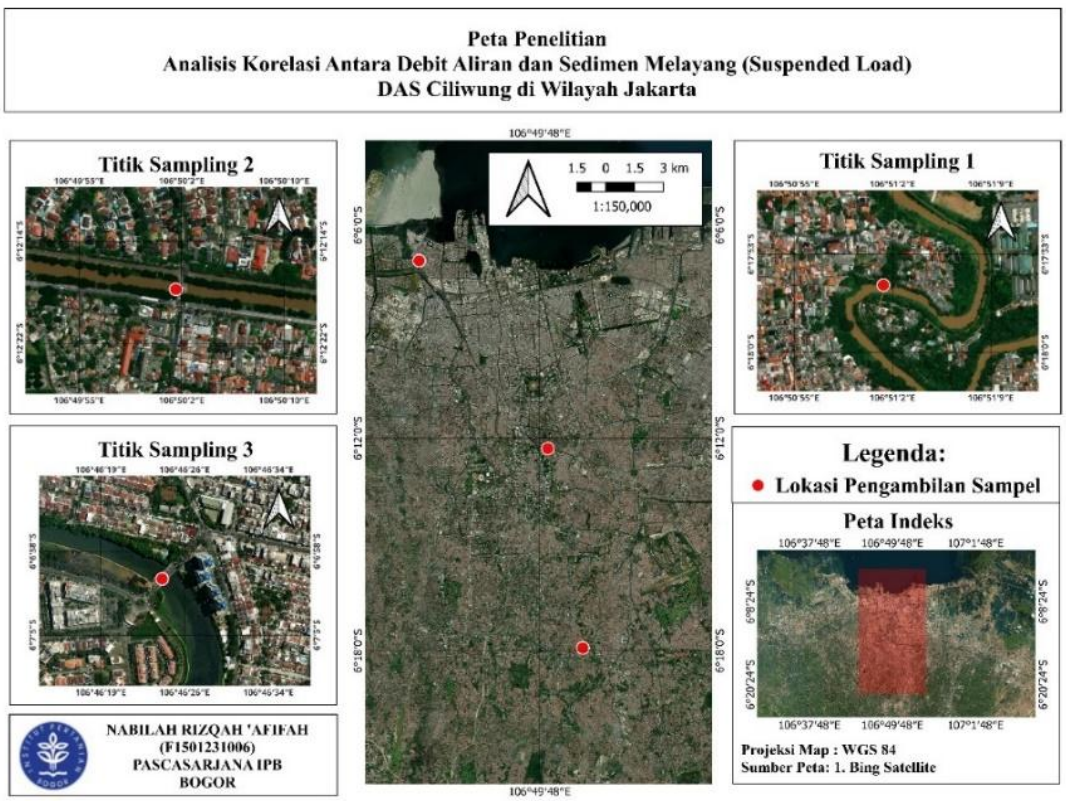

Figure 1. Research Map.

The method water sampling was carried out directly in the field by lowering a container from the bridge using a rope as shown in Figure 2 to collect surface water from the river. The collected water was then placed into clean plastic bottles for subsequent laboratory analysis. Random selection of sampling time and location was intended to capture the natural variability of river discharge and TSS load present in the field (Susanto et al., 2017).

Figure 2. Water Sampling Equipment.

A total of 33 water samples were collected, representing three cross-sectional points of the river right, middle, and left based on the flow direction. The research flow diagram is presented in Figure 3.

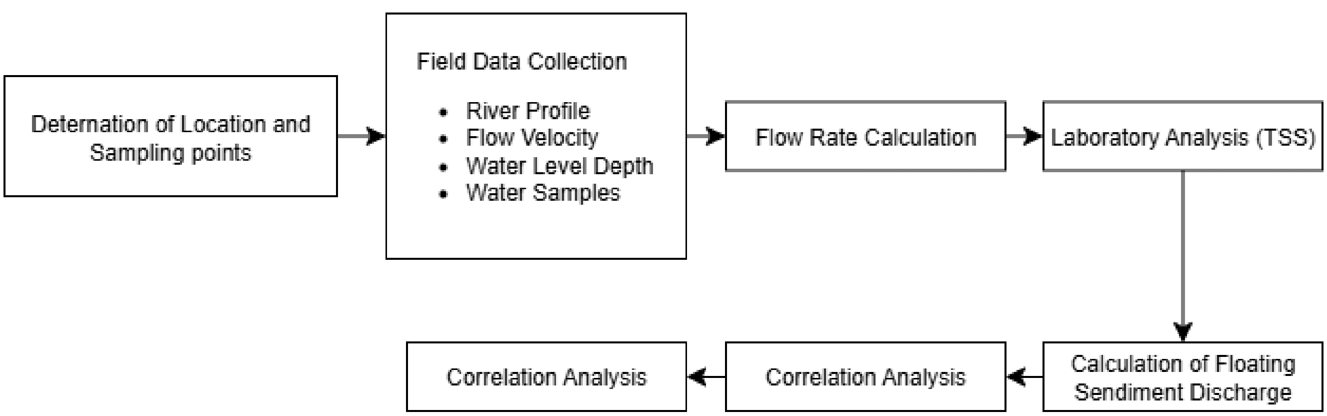

Figure 3. Research flow diagram.

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2.1 Water Discharge Measurement

Water discharge in this study was measured using the rating curve method, which was generated through a cubic spline interpolation-based calculation. This method employed the relationship between water level height (H) and water discharge (Q) obtained from field measurements. Water level height was measured using a manual sounding line (lead line), which is a scaled rope equipped with a weight at its end and lowered vertically until it touched the water surface. River width and depth data were obtained from secondary data provided by the Environmental Management Center (Pusat Pengelolaan Lingkungan Hidup, PPLH). Flow velocity was directly measured in the field using a flow meter or current meter at several points across the river cross-section. In addition to the rating curve, discharge calculation was also based on the fundamental area–velocity equation (Longo et al., 2021).

$$Q = A \times V \tag{1}$$

Where : Q = water discharge (m^3/s), A = wetted cross-sectional area (m^2), V = average flow velocity (m/s).

$$Q = a \times H^b \tag{2}$$

Where : Q = water discharge (m^3/s), a,b = empirical coefficients, H = water level height (m)

2.2 Total Suspended Solid (TSS) Load Analysis

The concentration of TSS load was determined in the laboratory using the filtration method. The water samples, as shown in Figure 4, were filtered through fine-pore filter paper to separate the TSS load from the water.

Figure 4. Collected water samples.

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The retained sediment was oven-dried at 105 °C for 24 hours until a constant weight was achieved, after which it was weighed to determine the TSS load concentration, expressed in mg/L. Particle size distribution was not directly analyzed in this study but was obtained from available secondary data.

After water sampling was conducted in the field, laboratory analysis was performed to determine the TSS load concentration (Total Suspended Solid, TSS). The concentration of TSS load was determined gravimetrically using the following Equation 3 (Chay., 2010) :

$$TSS = \frac{W2-W1}{V} \times 1000 \quad (3)$$

Where : TSS = suspended sediment concentration (mg/L), W2 = weight of the filter paper after drying (mg), W1 = weight of the empty filter paper (mg), V = volume of the water sample (L).

Subsequently, the suspended sediment load was calculated using Equation 4 (Susanto et al., 2017)

$$Qsm = Qw \times C \times K \quad (4)$$

Where : Q_{sm} = suspended sediment load (ton/day), Q_w = water discharge (m^3/s), C = sediment concentration (mg/L), K = conversion factor (0,0864).

2.3 Data Processing Method

The measurement data of water discharge and suspended sediment concentration obtained from the field were statistically processed to analyze the relationship between these two variables. The processing began with organizing the data into tabular form based on observation points and sampling dates. Water discharge values were derived from calculations using the river cross-sectional area and average flow velocity, while TSS concentrations were obtained from laboratory testing of water samples.

The relationship between water discharge and suspended sediment was analyzed using linear regression analysis. Linear regression was employed to determine the direction of the relationship, while the coefficient of determination (R2) was used to assess the extent to which water discharge contributed to variations in suspended sediment concentration. All data processing was carried out with the aid of Microsoft Excel software as a statistical analysis tool.

3. Results and Discussion

3.1 Water Discharge

The water discharge observed at three monitoring points in the downstream segment of the Ciliwung River exhibited significant variations, both between locations and across observation periods. The highest discharge, recorded at 45.47 m^3/s, was observed at point CLW 2-4 located in the Muara Angke area, while the lowest discharge, at 2.55 m^3/s, was recorded at point CLW 2-1 in the Menteng area. These discharge values were obtained through measurements of flow velocity and

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wetted cross-sectional area, and subsequently calculated using the rating curve equation (Rahman., 2016).

This variation in discharge was influenced by several factors, including the spatially uneven rainfall during the observation period, runoff response from impervious surfaces, and contributions from tributaries discharging into the main segment of the Ciliwung River. Furthermore, at point CLW 2-4, which is located in proximity to the tidal zone, interactions between river flow and tidal fluctuations were also likely to affect daily discharge measurements. Therefore, the high discharge values observed at the downstream point were not solely attributable to upstream runoff, but were also influenced by sea-level fluctuations and flow releases from surrounding flood control canals (Chay., 2010).

3.2 Suspended Sendiment Concentration

Sediment is the result of erosion occurring in lower-lying areas, particularly contributing to the siltation of canal mouths. Eroded materials transported by upstream water flow, upon entering low-gradient areas or channels, are not entirely carried away to the sea. A portion is deposited along its course, in channels, rivers, estuaries, and other water bodies it traverses. Deposits within the river lead to siltation and a reduction in storage capacity. When flooding occurs, sediment and mud are also deposited in the areas they pass through (Andayani & Yulianti, 2019).

Suspended sediment concentrations obtained from laboratory testing ranged between 8.5 mg/L and 284.5 mg/L. The highest concentration was recorded at point CLW 2-1 during medium discharge conditions, while the lowest concentration was measured at CLW 1-3. This finding indicates that the presence of suspended particles in river flow is not always linearly related to discharge magnitude, but is also influenced by activities around the riverbanks, such as construction, waste disposal, and localized erosion.

In general, TSS values tended to increase following rainfall, particularly in areas with limited vegetation cover and high human activity. In the CLW 2-1 and CLW 2-4 areas, suspended sediments were also suspected to originate from residual construction materials, riverbank erosion, and domestic waste discharge from densely populated areas (Kadri., 2006). Measurements of suspended sediment are presented in Table 1.

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Table 1. Laboratory Measurements of Suspended Sediment.

Sampling Point (CLW 1-3)	TSS Test Results (mg/L)	Sampling Point (CLW 2-1)	TSS Test Results (mg/L)	Sampling Point (CLW 2-4)	TSS Test Results (mg/L)
1.	71.8	1.	98.0	1.	18.5
2.	31.5	2.	39	2.	940
3.	284.5	3.	223.5	3.	18.8
4.	165.5	4.	197.0	4.	8.5
5.	29.0	5.	39.5	5.	20.5
6.	19.5	6.	53.8	6.	20.5
7.	132.0	7.	283.0	7.	30.0
8.	29.5	8.	27.0	8.	13.8
9.	26	9.	52.8	9.	18.0
10.	49.0	10.	107.9	10.	47.0
11.	50.5	11.	103.3	11.	64.5

3.3 Correlation Between Water Discharge and Suspended Sediment

The suspended sediment discharge was calculated by multiplying the water discharge (Q) by the suspended sediment concentration and converting the result into units of tons per day (Susanto et al., 2017). Three observation points were selected to represent the upstream, middle, and downstream segments of the Ciliwung River flow within the Jakarta region. The suspended sediment discharge varied significantly, ranging from 4.30 to 587.96 tons/day. The highest discharge was recorded at the CLW 2-4 point, coinciding with the day when the water discharge also reached its maximum value. Correlation analysis indicated a strong relationship at the first two points, namely CLW 1-3 (R^2 = 0.9721) and CLW 2-1 (R^2 = 0.9151), following a positive linear regression model. This indicates that higher water discharge is associated with greater suspended sediment transport, consistent with previous findings (Herawati et al., 2022). However, at the CLW 2-4 point, the relationship was found to be very weak (R^2 = 0.0006) and statistically insignificant.

This pattern, as presented in Table 2, was most consistently observed at CLW 1-3 and CLW 2-1, which are still directly influenced by local rainfall and runoff from residential areas. Conversely, the daily flow at CLW 2-4 did not exhibit a uniform pattern. Variations in discharge and suspended sediment at this point were not aligned, reinforcing the assumption that external factors such as marine influences or technical disturbances from river infrastructure affect flow stability.

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Table 2. Observation data of water discharge and suspended sediment discharge.

Sampling Point (CLW 1-3)	Water Discharge (m^3/s)	Sediment Discharge (ton/day)	Sampling Point (CLW 2-1)	Water Discharge (m^3/s)	Sediment Discharge (ton/day)	Sampling Point (CLW 2-4)	Water Discharg e (m^3/s)	Sediment Discharge (ton/day)
1.	5.89	36.57	1.	8.85	74.91	1.	22.97	36.71
2.	4.22	6.85	2.	4.52	12.30	2.	34.73	117.03
3.	17.49	430.01	3.	20.36	393.12	3.	35.72	587.96
4.	6.26	89.54	4.	8.85	150.59	4.	43.50	31.95
5.	4.22	10.56	5.	3.50	11.96	5.	45.47	80.54
6.	2.55	4.30	6.	3.00	13.92	6.	43.82	77.62
7.	4.03	45.99	7.	4.32	105.55	7.	43.02	111.49
8.	4.03	10.28	8.	3.80	8.88	8.	33.07	39.43
9.	4.59	10.32	9.	3.62	16.52	9.	34.31	53.36
10.	3.73	15.81	10.	3.56	33.21	10.	36.44	147.98
11.	3.91	17.07	11.	6.99	62.39	11.	36.88	205.51

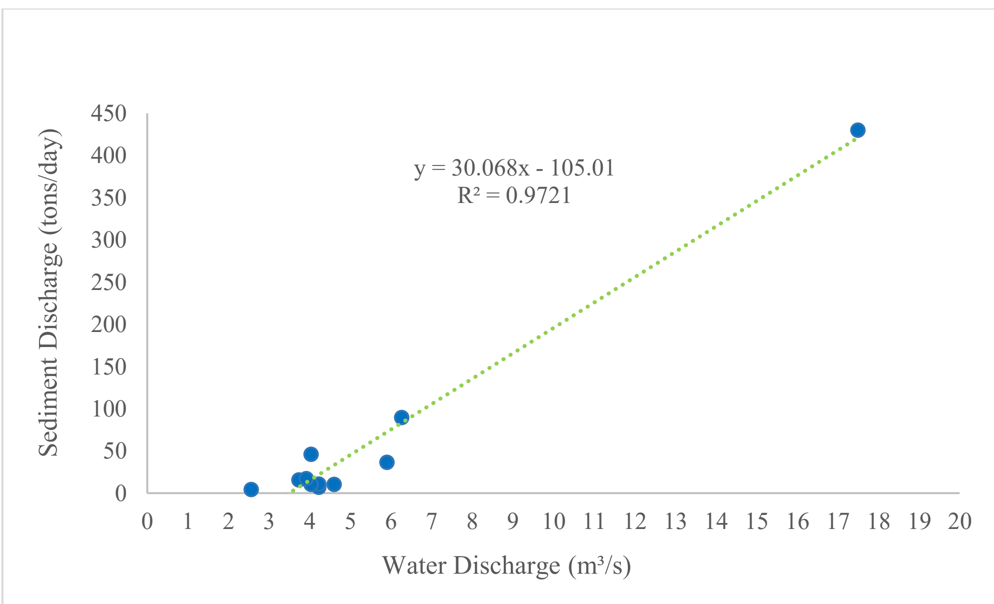

Figure 5. Correlation graph between water discharge and suspended sediment at CLW 1–3.

Figure 5 illustrates the relationship between water discharge (m^3/s) and suspended sediment discharge (ton/day) at the CLW 1–3 location. Based on the linear regression analysis, the trendline equation was obtained as $y = 30.068x - 105.01$, with a coefficient of determination (R^2) of 0.9721. The correlation results indicate a very strong relationship between discharge and sediment, suggesting

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that in the upstream segment, sediment transport processes are highly dependent on river discharge. When discharge increases, particularly during rainfall events, sediment is eroded from riverbanks or the riverbed and transported by the current, causing suspended sediment levels to rise in a linear pattern with increasing discharge. This condition supports the theory that erosion in upstream areas is one of the main contributors to sediment load (Wibowo et al., 2016).

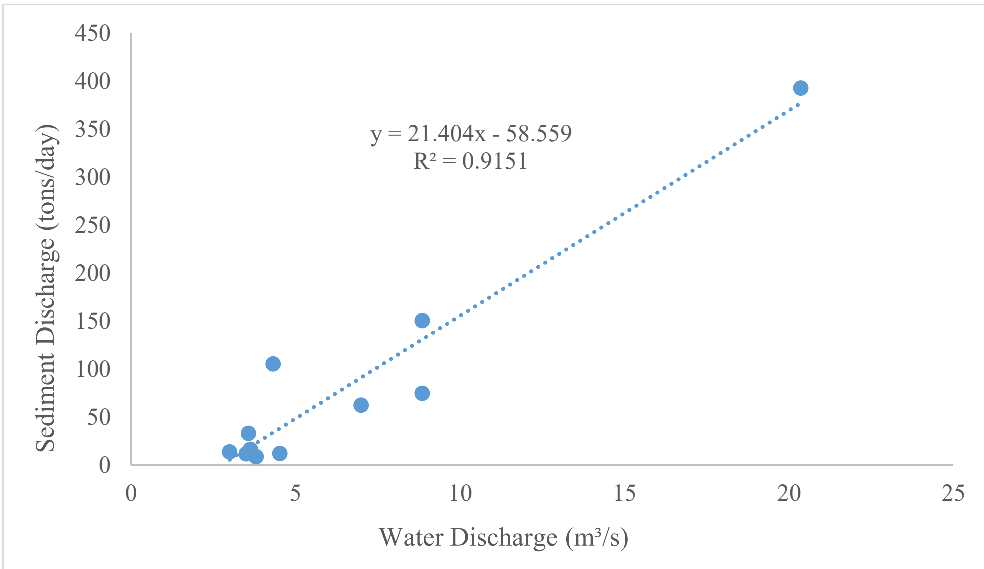

Figure 6. Correlation graph between water discharge and suspended sediment at CLW 2-1.

Figure 6 illustrates the relationship between water discharge (m^3/s) and suspended sediment discharge (ton/day) at the CLW 2–1 location. Spatially, this site represents the middle segment of the river, where the flow is relatively more stable yet not significantly influenced by tidal effects. The linear regression analysis produced the equation $y = 21.404x - 58.559$, with a coefficient of determination (R^2) of 0.9151, which is slightly lower than that observed in the upstream segment. This indicates that, although still predominantly influenced by water discharge from upstream, there is a potential reduction in sediment load due to the decreasing kinetic energy of the river or the occurrence of local sediment deposition. Such processes are commonly observed in the middle reaches of rivers, which act as transitional zones between erosion and deposition (Wiryamanta et al., 2021).

Figure 7 presents the relationship between water discharge and suspended sediment discharge at the CLW 2–4 location, which is part of the Ciliwung West Canal sub-watershed and represents the downstream segment. This location exhibits markedly different characteristics, as it is directly influenced by tidal fluctuations and interactions with the Jakarta coastal estuarine system. Based on the linear regression analysis, the resulting equation is $y = -0.5799x + 157.03$, with an extremely weak coefficient of determination ($R^2 = 0.0006$). This indicates that sediment load at this location is not predominantly determined by river discharge.

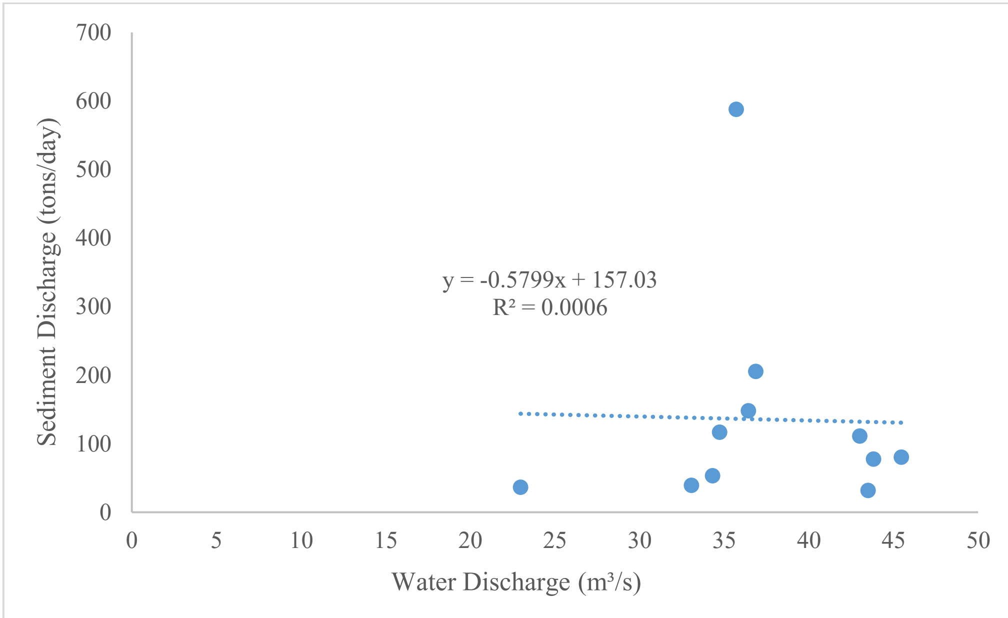

Figure 7. Correlation graph between water discharge and suspended sediment at CLW 2-4.

Such a condition is expected, as river discharge at the estuary is strongly affected by tidal dynamics. During high tide, seawater flows into the river in large volumes but with low velocity, resulting in a relative decrease in sediment concentration due to dilution by the incoming marine water mass. Conversely, during low tide, water flows outward from the estuary with high discharge and velocity, leading to an increased transport of sediment toward the sea rather than deposition. This condition suggests that siltation processes are not dominant in the downstream segment, as the backflow from the sea more effectively transports sediment away toward the open ocean (Banjarnahor et al., 2016).

In addition, variations in measurement timing also influenced the results. This factor affects tidal conditions, rainfall, and river flow activity. Under low discharge conditions, it is likely that tidal inflow from the sea (high tide) was occurring. Conversely, under high discharge conditions, it is likely that ebb flow from the river to the sea was taking place. Therefore, the timing and frequency of measurements should be considered as important aspects in future research. A similar phenomenon has been observed at the Wulan River estuary (Demak) and the Ciberes River estuary (Cirebon), where tidal fluctuations and seawater mixing exert a greater influence on sediment dynamics than river discharge itself (Purnama et al., 2015).

3.4 Siltation

At site CLW 2-4, estuarine conditions are highly influenced by seawater movement. One of the main phenomena observed at this location is the dilution process of suspended sediment concentration (Purwanto., 2017). During high tide, seawater with high salinity and relatively greater

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clarity enters the river body. This inflow carries a large volume of water but with low velocity, thereby diluting the suspended sediment concentration originating from the river. As a result, even under low or moderate river discharge conditions, the sediment concentration at the observation point is not excessively high.

The incoming seawater reduces, rather than increases, sediment concentration. Furthermore, the ebb current during low tide carries water back to the sea with a high discharge, but the sediment previously mixed has been more homogeneously suspended. Under these conditions, sediment tends to be transported to the sea rather than deposited on the riverbed. Consequently, significant siltation does not occur at this site.

At sites CLW 1-3 and CLW 2-1, the relationship between discharge and suspended sediment shows a strong correlation. If left unmanaged, the river's wetted cross-sectional capacity will continue to decrease, leading to an increased risk of overflow, particularly during high discharge events. Unaddressed siltation also poses the risk of disrupting urban drainage system operations and increasing the frequency and cost of dredging. By understanding the relationship between water discharge and suspended sediment load, sediment management and siltation prevention can be planned and implemented periodically.

3.5 Implications for Management

The findings of this study carry important implications for sediment management in the Ciliwung River. In the upstream and middle segments, the high correlation between water discharge and suspended sediment concentration indicates the need for erosion control measures along the riverbanks, such as riparian vegetation planting, bank stabilization, and surface runoff management from residential areas. In contrast, in the downstream segment, management efforts should be more focused on tidal control and optimization of the drainage system, given that siltation is not the dominant issue. Furthermore, regular monitoring of discharge and sediment in all river segments is strongly recommended to build a long-term database, enabling adaptive and evidence-based management policies.

4. Conclusion

Based on the analysis results, it was found that the relationship between water discharge and suspended sediment concentration in the downstream segment of the Ciliwung River varied across observation points. The suspended sediment discharge was recorded to range from 4.30 to 587.96 tons/day. A strong positive correlation was identified at points CLW 1–3 and CLW 2–1, with R^2 values of 0.9721 and 0.9151, respectively. This indicates that an increase in discharge significantly enhances the flow's capacity to transport sediment, particularly during high-flow conditions or the rainy season. In contrast, at point CLW 2–4, the correlation was found to be extremely weak, with an R^2 value of

0.0006, suggesting a dominant influence of tidal fluctuations that lead to dilution processes and unstable current direction changes. Therefore, it can be concluded that sedimentation processes are more likely to occur in the upstream and middle segments due to sediment accumulation and reduced flow energy, whereas in the downstream segment, sedimentation does not occur. This is attributed to differences in measurement times and daily hydrological conditions.

Recommendation

Regular monitoring of discharge and sediment in the upstream and middle segments of the Ciliwung River within the Jakarta region is required to anticipate sedimentation. In the downstream segment, management efforts should be focused on tidal control and the optimization of the drainage system. Future research is recommended to integrate discharge, sediment, and tidal data spatially and temporally to obtain more comprehensive insights into sediment dynamics across all river segments.

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