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Sediment Characteristics and Prediction of Sediment Yield in Drainage Channel: A Study on Yos Sudarso Street Cikarang City

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Abstract

Yos Sudarso Street, Cikarang City, is crucial for mobility and economic activity. However, Yos Sudarso Street has waterlogging and flooding issues due to severe sediment accumulation, resulting in siltation of the channel, so it cannot flow stormwater properly. This study aims to identify sediment characteristics and predict sediment yield in the drainage channel on Yos Sudarso Street, Cikarang City. It's essential because sediment has negative impacts on drainage channels. The limited studies on sediment characteristics and sediment yield prediction in urban areas make this study necessary. The bed sediment samples were taken from 3 points in the drainage channel to identify the sediment characteristics. Sediment yield prediction using the Universal Soil Loss Equation method based on rainfall erosivity, soil erodibility, slope length, steepness, and crop management factors. The sediment characteristics at sites 1, 16, and 17 were dominated by large sand grains (0.82-1.81 mm) that were difficult to transport. Poorly sorted indicates low flow energy. Grain size distribution extends to fine grains. Sites 1 and 17 are concentrated at mean size, while site 16 is concentrated at the extreme size. The sediment yield prediction by the universal soil loss equation is 1.989 (t/ha/yr). This information can be used to formulate effective sedimentation control strategies.

Keywords: sedimentation, drainage channel, sediment characteristic, sediment yield

1. Introduction

A pipe culvert is a closed drainage channel that flows stormwater into water bodies. A pipe culvert is more effective than an open drainage channel in reducing trash and sediment before entering the water body. However, sedimentation still occurs at the bottom and side of the pipe culvert. Sedimentation is caused by particles solids suspended in drainage water flow, then settling at the bottom pipe culvert. The main source of particle solids is soil and mud from roads, sidewalks, building roofs, and drainage channels. In another case, construction activity also contributes sediment particles from waste construction materials. Several studies have analyzed sedimentation issues, such as the Tertiary basin in Johor, Malaysia [1], Sambas Estuary, West Kalimantan [2], Cirebon Harbor Waters [3], Walanae Watershed [4], Waridin Estuary, Wonorejo Village [5]. Based on the search results, limited studies related to sediment characteristics and prediction of sediment yield in urban areas, so this study is essential.

One site highlighted in this study is Yos Sudarso Street, Cikarang City. This street is crucial for mobility and economic activity in the surrounding area, with the presence of packmen and vehicular traffic. However, Yos Sudarso Street also confronts significant issues, i.e., waterlogging on the street surface, as shown in Fig. 1. After interviews with residents, the street area is waterlogged and flooded during long-term rainfall. Waterlogging on roadways causes damage to the asphalt aggregate. This results in a high risk of accidents for street users, especially motorcyclists. Most motorcycles skid when driving

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through the area. Several factors cause the problem; first, if seen in more detail in Fig. 1, the street's cross slope is not according to the Ministerial Decree PUPR No. 5 Year 2023 [6]; the cross slope of the street should be one-way slope from the cross-street axis to the pavement edge (not concave). This aims to ensure stormwater can flow properly to the drainage channel at the roadside. The second is caused by the deficiency of the drainage channel slope. However, direct slope measurement is unavailable because the drainage channel has been clogged with accumulated sediment, as shown in Fig. 2 and Fig. 3. Sediment accumulated significantly in the drainage channel, causing the drainage channel to be unable to drain stormwater. Residents said the issue of waterlogging due to the siltation of drainage channels has been going on for a long time but has not been appropriately addressed. This indicates that the sedimentation issue on Yos Sudarso Street needs special attention and proper handling, i.e., future study related to bed sediment characteristics and prediction of sediment yield needs to be conducted. Yos Sudarso Street's strategic and high traffic makes this study important to minimize the negative impact of sedimentation on the residents' mobility and safety of street users.

This study aims to identify sediment characteristics and predict sediment yield in the drainage channel on Yos Sudarso Street, Cikarang City. The study results are expected to be a basis for policy development, drainage management strategy, and effective mitigation measures in confronting sedimentation issues in urban areas, especially in the study area. Therefore, this study has the potential to make a significant contribution to improving environmental sustainability and the quality of people's lives in the study area.

Fig. 1 Study area

Fig. 2 Sediment and waste

Fig. 3 Sediment accumulation

2. Material and Method

2.1 Study area

The study was conducted in the Yos Sudarso Street drainage channel, Cikarang City, North Cikarang District, Bekasi Regency, West Java with total catchment area approximately 2 Ha. The study's starting location at Coordinates 6°15'21.07"S and 107°8'32.73"E, and the final location at Coordinates 6°15'23.74"S and 107°8'53.75"E. In Fig. 4, the upstream point of the drainage channel is marked as point 17, while the downstream point is marked as point 1. North Cikarang has a summer season of 5.5 months (May 7 to October 24) and a rainy season of 6.5 months (October 24 to May 7) [7]. Elevation ranges from 16 to 18 m where the slope varies from upstream to downstream of the drainage channel. The survey of study locations was conducted after the rain on November 5, 2023. On this date, the National Aeronautics and Space Administration [8] recorded a rainfall intensity of 27.87 mm/day.

2.2 Data sources

Identify sediment characteristics; the data required are bed sediment samples taken in the drainage channel on Yos Sudarso Street. Bed sediment samples were taken at 3 locations (at points 1, 16, and 17) along the channel based on the open manhole, as shown in Fig. 4. The data required to predict sediment yield are water samples taken in the drainage channel on Yos Sudarso Street at 3 locations (at points 1, 16, and 17) along the channel based on open manholes, as shown in Fig. 4. To predict sediment yield, the Universal Soil Loss Equation is also used; the data required is first, rainfall data for the 22 years (2011 to 2022) was obtained from Badan Meteorology, Climatology, and Geophysics Agency (BMKG) [9] at West Java Climatology station. Second, soil data for the year 2007 of Food and Agriculture Organization of the United Nations (FAO) [10] was used for computing soil erodibility index/factor. To compute the slope length-steepness factor (LS), elevation data with a spatial resolution of 10 meters from the 2018 Digital Elevation Model National (DEMNAS) was used [11]. Fourth, land cover data is taken by direct survey in the study area. In this study, catchment area data was obtained from Google Earth.

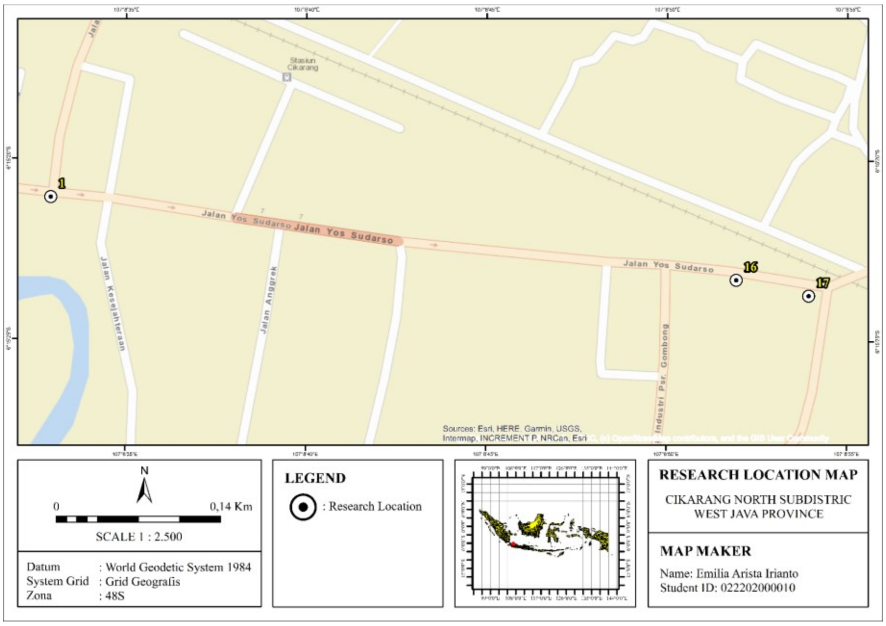

Fig. 4 Sediment sampling location map

2.3 Sediment grain size analysis

Sediment samples were conducted sieve analysis to determine grain size distribution and characteristics. Sieve analysis was conducted using mechanical sieving; these sieves have holes with clearly defined sizes according to standards like the American Society for Testing and Materials (ASTM) [12]. Grain size statistical parameters were calculated using graphical measures [13] as shown in Table 1. Four-grain size statistic parameters are available; the first is mean size, which is used to determine the center of sediment distribution. Second, standard deviation (sorting) describes the variation in sediment grain size. High values indicate poorly sorted with high grain size variability, while low values indicate well sorted with minimal grain size variation. Third, Skewness measures the Asymmetry of grain size distribution with a value range of -1.00 to +1.00; 0.00 indicates perfect symmetry. Positive Skewness indicates the dominance of fine particles, while negative indicates the dominance of coarse particles. Fourth, Kurtosis describes the shape of the grain size distribution's tail relative to a normal distribution (mesokurtic). High Kurtosis (leptokurtic) indicates excessively peaked with few extremes in size. Most sediment grains are clustered around the mean size. Low Kurtosis (platikurtic) indicates deficiently peaked with larger fine and coarse fractions than the average fraction.

Table 1 Formula used in calculating the grain size parameters [13]

Parameter	Formula	Description
Mean Size	$M_z = \frac{\emptyset16+\emptyset50+\emptyset84}{3}$	M_z is mean size, and Ø16, Ø50, and Ø84 represent the grain sizes at the 16th, 50th, and 84th percentiles in the grain size distribution.
Standard Deviation	$\sigma_I = \frac{\emptyset84-\emptyset16}{4} + \frac{\emptyset95-\emptyset5}{6.6}$	σ_I is standard deviation, and Ø5, Ø16, Ø84 and Ø95 represent the grain sizes at the 5th, 16th, 84th, and 95th percentiles in the grain size distribution.
Skewness	$Sk_I = \frac{\emptyset16+\emptyset84-2(\emptyset50)}{2(\emptyset84-\emptyset16)} + \frac{\emptyset5+\emptyset95+2(\emptyset50)}{2(\emptyset95-\emptyset5)}$	Sk_I is skewness, and Ø5, Ø16, Ø50, Ø84, and Ø95 represent the grain sizes at the 5th, 16th, 50th, 84th, and 95th percentiles in the grain size distribution.
Kurtosis	$K_G = \frac{\emptyset95-\emptyset5}{2.44(\emptyset75-\emptyset25)}$	K_G is kurtosis, and Ø5, Ø25, Ø75, and Ø95 represent the grain sizes at the 5th, 25th, 75th, and 95th percentiles in the grain size distribution.

2.4 Point Integration Method

The point integration method uses a tool, as shown in Fig. 5 [14]. The tool is applied by dropping the measurement tool into a point of a certain depth, where the water and sediment samples are taken from that point. The flow rate, sediment concentration formula can be seen in Table 2.

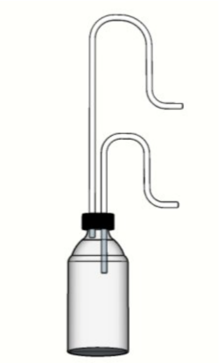

Fig. 5 Measurement tool for suspended sediment transport using bottles

Table 2 Formula used in calculating sediment concentration and flow rate

Parameter	Formula	Description
Sediment yield	$Q_s = 0.086\ x\ C_s\ x\ Q$	Q_s is Sediment yield (t/day), 0.086 is Conversion value C_s is Sediment concentration (mg/l), Q is Runoff flow (m^3/s)
Sediment concentration	$C_s = \frac{G_2 - G_1}{V_{water}}$	C_s is Sediment concentration (mg/l), G_2 is Sediment weight and filter paper in dry condition (mg), G_1 is Weight of filter paper (mg), V_{water} is Water volume (liter).
Flow rate	$Q = \frac{V_{water}}{t}$	Q is Runoff flow (m^3/s), V_{water} is Water volume (liter), t is time

2.5 Universal Soil Loss Equation (USLE)

Several factors affect soil erosion, as described by the USLE model developed by [15]. This model aims to estimate the amount of soil erosion caused by rainfall and surface runoff. USLE, which is based on empirical data, can provide an estimate of average annual soil loss over the long term considering various conditions such as climate, soil type, topography, vegetation, and conservation practices, the formula shown in Table 3. Rainfall erosivity (EI) is the rate of the rainfall's ability to erode a site. It means, erosivity describes how far rainfall can damage or erode the land during rainfall. Soil Erodibility (K) describes the sensitivity of soil to erosion caused by EI or rainfall factors. The soil erodibility value is determined based on the soil type, The erodibility value of yellow-red podzolic soil is 0.166 (t ha h/ha Mj cm). The LS factor indicates the effect of topography on soil erosion, the steeper and longer the slope, the higher risk for erosion. Factor C is a crop management factor. This factor shows crop planting and management's effect on erosion rate. Meanwhile, Factor P is a support-practice factor. This factor indicates the effect of soil conservation practices such as grass strips, terracing, planting strip crops, and others in reducing erosion [16]. The CP value for Settlement is 0.05 [17].

Table 3 Formula used in calculating USLE parameters

Parameter	Formula	Description	Source
Soil loss	$A = EI.K.L.S.C.P$	*A* is soil loss (t/ha/yr), *R* is rainfall erosivity factor (Mj cm/ha h yr), *K* is soil erodibility factor (t ha h/ha Mj cm), *L* is the slope length factor (unitless), *S* is the slope steepness factor (unitless), *C* is cover and management factor (unitless), and *P* support practice factor (unitless).	[15]
Rainfall erodibility factor	$EI = 6.119\ (Rain)^{1.2} x (Days)^{-0.47} x (MaxP)^{0.53}$	*EI* is the rainfall erosivity (Mj cm/ha h yr), *Rain* is the monthly rainfall (cm), *Days* is the number of rainy days per month (days), and *Max P* is the maximum rainfall in 24 hours per month (cm).	[18]
Length and steepness factor	$LS = \left(\frac{\lambda}{22.1}\right)^m x \left(\frac{0.43+0.030s+0.043s^2}{6.613}\right)$	*LS* is the slope a, *λ* is slope length (m), *m* is the constant value, which is: 0.5 for slope >5%, 0.4 for slope 3.5% - 5%, 0.3 for slope 1% - 3%, and 0.2 for slope <1%, *s* is slope steepness in percentage (%).	[15]

2.6 Sediment yield

Sediment Yield was predicted using the Sediment Delivery Ratio according to [19]. sediment delivery ratio is the quantity of sediment transported from the land surface to drainage channels or rivers. This research uses the Sediment Delivery Ratio formula by [20]:

$$SDR = 0.566 \text{ x } A^{-0.11} \quad (1)$$

Here, *SDR* is sediment delivery ratio, and *A* is Catchment Area (ha). Sediment Yield is the total amount of sediment produced by a catchment area due to erosion and deposition processes over time [21]. Sediment yield can be predicted using the formula by:

$$S_y = SDR\ x\ A \quad (2)$$

Here, S_y is sediment yield (t/ha/yr), *SDR* is sediment delivery ratio, and *A* is soil erosion rate (t/ha/yr). The sediment yield was estimated by taking the average sediment yield per year, then this result was verified and validated by field measurements obtained using the point integration sampling method.

3. Results and Discussion

3.1 Textural characteristics/grain size statistics

Grain size analysis of sediment samples taken from three locations (Sites 1, 16, and 17) in drainage channels along Yos Sudarso Street showed mean sizes ranging from 0.82 mm to 1.81 mm (Table 4) indicating a dominance of coarse sand, which is difficult to transport, causes siltation and reduced flow capacity. Standard deviation values ranged from 2.34 (very poorly sorted) to 1.13 (poorly sorted) (Table 4), i.e., sediments have varied in size, indicating the channel's energy is so low that it cannot transport or sort the sediment grains by size and weight. Skewness values at all sites ranged from 0.92 (very fine skewed) to 0.76 (fine skewed) (Table 4). Highly to fine skewed indicates the sediments grain size distribution has an elongated tail to finer (smaller) grain sizes. The kurtosis values indicate that the sediment grain size distribution at sites 1 and 17 is centered on the mean value, while at site 16, it is more concentrated at the extremes of grain size (very fine or very coarse).

Table 4 Grain size statistic parameter results

Location Point	Mean	Standard Deviation	Skewness	Kurtosis	Mean	Standard Deviation	Skewness	Kurtosis
1	1.81	2.34	0.90	1.94	Sand very coarse	Very poorly sorted	Very fine skewed	Very leptokurtic
16	1.14	1.13	0.76	0.83	Sand very coarse	Poorly sorted	Fine skewed	Platykurtic
17	0.82	1.14	0.92	1.74	Sand coarse	Poorly sorted	Very fine skewed	Very leptokurtic

3.2 Validation and predicting sediment yield by USLE model

Prediction of sediment yield using the Universal Soil Loss Equation (USLE) model verified with field measurements obtained by point integration sampling method. Water samples were taken from 3 locations along the drainage channel on Yos Sudarso Street in November. The result of sediment yield based on point integration sampling (average monthly rate = 0.128 t/ha/month) is a bit smaller than the value of sediment yield by USLE (average monthly rate = 0.231 t/ha/month; EI calculation used rainfall data in November only). The comparison shows that the simulated sediment yield rates are in similar differences, so calculations using the USLE method can be used. The calculation of the annual average sediment yield prediction from 2011 to 2022 is 1.989 (t/ha/yr). The sediment yield prediction results from the Universal Soil Loss Equation method can be used for the long term [22]. However, land conditions in urban areas can change quickly due to development and changing land use. If there are significant changes in land cover and slope, the USLE prediction need to be updated.

4. Conclusions

The sediment characteristics at the drainage channel study locations are dominated by relatively large sand grains, ranging from 0.82 mm to 1.81 mm, which are not easily transported. The sediment is poorly sorted, indicating low energy within the channel, which affects its ability to separate sediment grains effectively by size and weight. The sediment grain size distribution exhibits an elongated tail toward finer grain sizes. Specifically, Sites 1 and 17 show a higher concentration around the mean grain size, while Site 16 exhibits a higher concentration of extreme grain sizes. The predicted sediment yield, calculated using the Universal Soil Loss Equation (USLE) method, is 1.989 tons per hectare per year (t/ha/yr). This estimate is based on the average sediment yield over a 12-year period, from 2011 to 2022.

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