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Analysis of Sediment Transport Patterns in Rivers Using Hydrological and Geomorphological Approaches

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ABSTRACT

Rivers as a crucial element in the hydrological system provide water for various human, agricultural, industrial and ecosystem needs. However, natural phenomena such as erosion and sedimentation can threaten the stability of rivers and the surrounding environment. This study outlines the impacts of sedimentation on the Bailang River and Sario River, highlighting the importance of hydrological and geomorphological approaches in understanding sediment transport patterns. Land conversion along the Bailang River has caused narrowing of the river channel and sedimentation, increasing the risk of flooding. Hydrological analysis shows that changes in water discharge and rainfall influence sediment transport in the Bailang River. In the Sario River, flooding and erosion affect river morphology, with large water discharges being the main cause of flooding. The hydrological approach considers factors such as water discharge and rainfall, while the geomorphological approach considers landforms, topography and river flow patterns. The analysis shows that interactions between hydrological and geomorphological factors influence sediment transport patterns in both rivers. The results of this research provide an in-depth understanding of sediment transport patterns in the Bailang River and Sario River. The implications include planning effective river management strategies, mitigating erosion, sedimentation and flood risk, as well as better spatial planning in riverbank areas. The contribution of this research is important for sustainable river management and environmental protection. Understanding sediment transport patterns provides the basis for developing more effective erosion and sedimentation mitigation strategies, with the aim of minimizing their negative impacts on rivers and their environment.

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INTRODUCTION

Rivers as an important element in the hydrological system have a significant role in providing water for human, agricultural, industrial and ecosystem needs. Apart from that, rivers also act as natural transportation routes that support community economic and social activities. However, natural phenomena such as erosion and sedimentation can threaten river stability and affect water quality and the surrounding environment. This sediment can cause shallowing of rivers when they reach their mouths, resulting in reduced flow capacity and affecting river particles. Continuous shallowing due to sedimentation can make it difficult for rivers to flow to the sea. Sediment particles carried by river currents tend to settle in estuaries, hindering the smooth flow towards the sea. High levels of sediment concentration can cause river water to become cloudy, reducing water quality and having a negative impact on the aquatic environment (Artia and Sitti, 2018).

The change in land use upstream of the river and population growth along the banks of the Bailang River have resulted in serious impacts, especially the narrowing of the river channel. This change has significant consequences in the form of sedimentation in the river, a phenomenon in which sediment particles are carried by the river flow, affecting the elevation of the river bed. This continuous sedimentation process can threaten the stability of river channels and reduce the carrying capacity of river sections. As a result, under certain conditions, rivers can overflow, causing detrimental floods (Tangkudung, H. 2022).

The position of the river estuary is often a place where sedimentation problems arise, disrupting the function of the river estuary. Sedimentation at river estuaries occurs due to the deposition of sedimentary material caused by active geomorphological processes in the area. Geomorphological processes, driven by water flow, waves, wind, and glaciers, produce diverse sediment grain size distributions and sedimentation mechanisms. River flows and sea waves are generally the dominant geomorphological processes that cause sedimentation at river estuaries. Analysis of sediment transport patterns in rivers using hydrological and geomorphological approaches is an important step in understanding the geomorphological processes that play a role in sedimentation at river mouths (Mananoma, T., & Sumarauw, JSF 2021).

The main problem that arises from sedimentation in rivers, for example the Bailang River, is changes in the river bed which can disrupt the stability of the channel and the carrying capacity of the river cross-section, thereby increasing the risk of flooding. Therefore, a holistic sediment transport analysis is needed by considering hydrological and geomorphological approaches. Then the next example is that the Sario River, as a network of natural channels on the earth's surface, has a central role in meeting human water needs. In the Sario watershed area, flooding and erosion problems have affected river morphology, with one of the main factors causing flooding in the Sario River being large flow rates. This increase in water discharge, along with erosion and sedimentation, reduces the river's carrying capacity and has the potential to cause changes in the river bed.

In the context of research limitations, the focus of analysis will be limited to bottom sediments (bed load), while discussion of measurement data is limited to selected locations. Calculations will be carried out using the Hydrologic Engineering Center-The Hydrologic Engineering Center-River Analysis System (HEC-RAS) computer program to analyze hydraulic aspects and sediment transport. This research will focus on analyzing sediment transport patterns in rivers using hydrological and geomorphological approaches. Sediment transport, which involves the movement of solid particles through river flows, is a major concern because it can influence river morphology and the condition of river ecosystems.

In analyzing sediment transport patterns in rivers, several approaches that can be used include aspects of hydrology, geomorphology, remote sensing, use of software, statistical analysis, and participatory GIS, as suggested by several studies (Lastra J, 2008; van Westen et al., 2011; Dao and Liou, 2015). In the context of this research, evaluation of sediment transport patterns in rivers was carried out using a geomorphological approach.

The hydrological approach will consider hydrological factors such as water discharge, rainfall and soil infiltration in detailing sediment movement patterns. Meanwhile, the geomorphological approach will focus on understanding landforms, topography and river flow patterns to analyze the impact of changes in river morphology on sediment transport.

The aim of this research is to obtain the magnitude of sediment transport patterns in the Bailang River and Sario River, especially in the selected sections. Through a hydrological approach, we will understand how changes in water discharge and rainfall patterns affect sediment transport. Meanwhile, a geomorphological approach will provide insight into changes in landforms and river topography which can strengthen understanding of sedimentation. In addition, this research also aims to provide a deeper understanding of the factors that influence sediment transport in rivers and how the interaction between hydrology and geomorphology can shape specific sediment transport patterns.

The benefits of this research include providing better information on the patterns and magnitude of sediment transport in rivers, with the hope of helping in designing sustainable river management strategies. By understanding the interaction between hydrology and geomorphology, it is hoped that this research will provide a strong foundation for more effective mitigation and spatial planning in riverbank areas.

By studying it in depth, it is hoped that this research can contribute to sustainable river management, environmental protection and better spatial planning. In addition, understanding sediment transport patterns in rivers can also be the basis for developing effective erosion and sedimentation mitigation strategies, so as to minimize negative impacts on rivers and their environment.

THEORETICAL REVIEW

Sediment Transport Analysis

Sedimentation is a process where materials resulting from erosion settle because they are carried by river flows. In the sediment transport process, the amount of sediment carried by the flow is influenced by several factors, including sediment size, river channel characteristics, water discharge, and the nature of the sediment particles themselves. According to Achmad (2019), sediment transportation can be divided into three types based on how it moves, namely bed load, suspension sediment, and wash load. In this research, sediment transport calculations were carried out using the Meyer-Peter & Muller method, which has a predetermined mathematical equation.

$$0,25\times\rho_{air}^{\frac{1}{3}}\times\frac{(g'_{sb})^{\frac{2}{3}}}{(\gamma_s-\rho_{air})\times g\times d}=\frac{\rho_{air}\times\xi M\times R\times I}{(\gamma_s-\rho_{air})\times g\times d}-0,047 \quad (3.15)$$

Dengan:

ρ_{air} = berat jenis air

γ_s = berat jenis sedimen

Hydrological Analysis

According to Triatmodjo (2008), various activities such as planning and operating water structures, providing water for various needs (including clean water, irrigation, fisheries and livestock), hydroelectric power plants, flood control, erosion and sedimentation control, water transportation, drainage , pollution control, waste water management, and other activities, are part of the activities related to water resources management.

In this research, hydrological analysis was carried out using the Nakayasu Synthetic Unit Method to analyze flood discharge. This method was developed by a Japanese researcher named Nakayasu, who conducted research on several rivers in Japan. The Nakayasu Synthetic Unit Hydrograph (HSS) Equation form is used to describe the characteristics of flood hydrographs.

$$Q_p=\frac{1}{3,6}\left(\frac{A\cdot \mathrm{Re}}{0,3T_p+T_{0,3}}\right) \quad (3.1)$$

Untuk menentukan Tp dan T0,3 dapat digunakan persamaan sebagai berikut:

$$T_p=t_g+0,8T_r \quad (3.2)$$

$$T_{0,3}=\alpha\times t_g \quad (3.3)$$

Untuk menentukan tg dan tr dapat digunakan persamaan sebagai berikut:

$$t_g=0,4+0,058L \text{ untuk } L>15\text{ km} \quad (3.4)$$

$$t_g=0,21\times L^{0,7} \text{ untuk } L<15\text{ km} \quad (3.5)$$

$$t_r=0,5\times t_g \text{ sampai } t_g \quad (3.6)$$

River Morphology:

River morphology includes geometric characteristics such as shape and size, as well as river properties and behavior that change over time and space. The process of changing the shape of a river has occurred since the river was formed and continues over time. Land use changes can affect the ability to reduce water infiltration and increase runoff, which in turn can increase river flow. Apart from that, natural factors such as tides, materials and transportation that form river banks, also play a role in changing river morphology. Extreme changes can endanger assets around the river (Tri Septarini, 2019). Another natural factor that influences the physical processes of river morphology is the energy contained in the water flow, which follows the transport of water and materials within the river and flood plains. Schumm (1977) identified 3 zones of water and land interaction in river systems.

Sediment Supply Zone: Located in the upper reaches of the watershed and characterized by steep slopes and high erosion activity from cliffs and riverbeds. The water flows rapidly at high speed, causing significant erosion.

Sediment Transport Zone: Located downstream of the sediment supply zone, a place where sediment from upstream is distributed downstream. Sediment varies from gravel upstream to mud and clay downstream. The river meanders begin to move laterally, and fine sediment fills the floodplain after the flood.

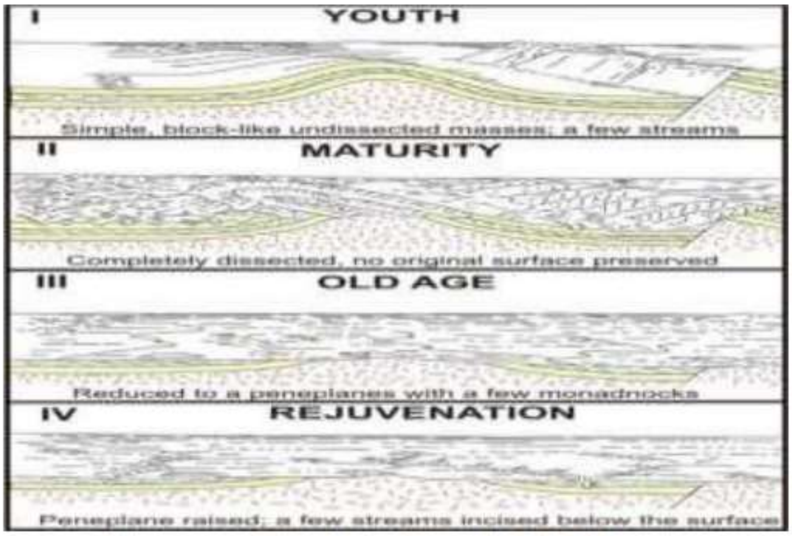
Sedimentation Zone: Located furthest downstream close to the estuary, the place where all the sediment from the previous zones collects. This zone is often a potential wildlife area.

River Flow Pattern:

Refers to the arrangement of river channels in an area without paying attention to whether these channels are permanent or not. Influenced by factors such as slope, type of bedrock, vegetation density, and climate in the area(Howard, 1967).

River Stage:

Regional stages describe the morphological transformation of a region from its original condition over time. The level of maturity of an area can be identified through observations of the natural landscape and river stages in the area. The formation of an area's morphology is usually influenced by a number of factors, including geological structure, lithology and geomorphological processes, both endogenous and exogenous. Lobeck (1939), grouped regional stages into four, namely:



Picture1. River Stadia Regional Division

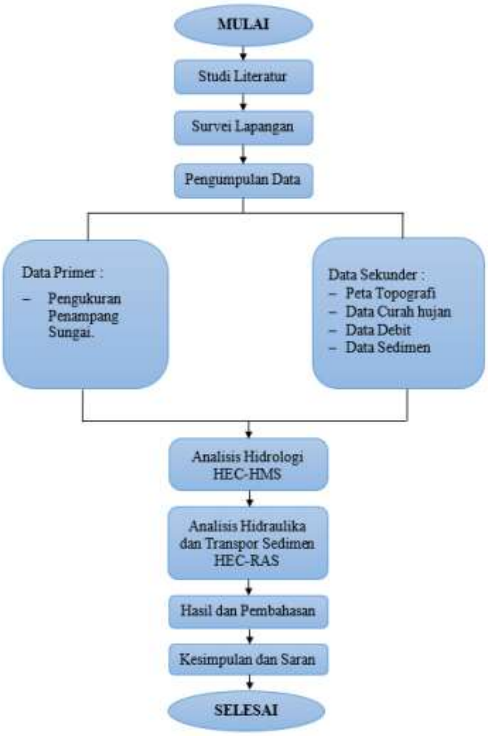
Geomorphology

Geomorphology is a branch of physical geography. Physical geography is a scientific discipline based on the basic principles of natural science. In this context, physical geography studies and integrates various fields of earth science to provide a comprehensive understanding of the characteristics of the environment that surrounds humans (Mananoma, T., & Sumarauw, JSF 2022).

METHODOLOGY

The research method used in analyzing sediment transport patterns in rivers using hydrological and geomorphological approaches follows a series of structured steps. First, an in-depth literature study was carried out to understand the basic concepts of sediment transport, hydrological theory, river geomorphology, and relevant analytical approaches. Research locations were selected based on their representativeness and significance in the context of analysis. Hydrological data such as water discharge, rainfall, and topographic data including elevation and river flow patterns are collected from various sources. This data is then processed and analyzed using hydrological and geomorphological techniques.

The hydrological approach is used to understand the hydrological factors that influence sediment transport, while the geomorphological approach is focused on understanding landforms and river topography. The analysis process involves evaluating sediment grain size distribution, sediment movement, and sedimentation mechanisms. Mathematical models such as HEC-RAS can be used for verification and simulation. The analysis results are analyzed and interpreted to understand the factors that influence sediment transport and the relationship between hydrology and geomorphology. These findings are then discussed in depth in the context of river management and environmental protection. The study conclusion summarizes the main findings and contributions to the understanding and sustainable management of rivers. Thus, this method provides a solid foundation for planning effective and sustainable river management strategies.



Picture2. Flow Chart

RESULTS AND DISCUSSION

Analysis of Sediment Transport Patterns in the Bailang River and Sario River

Analysis of sediment transport in the Bailang River using hydrological and geomorphological approaches shows that land conversion in the upper reaches of the river has caused the narrowing of the river channel. This results in sedimentation in the river, with sediment particles carried by the river flow and affecting the river bed elevation.

The hydrological approach helps in understanding the impact of changes in water discharge and rainfall patterns on sediment transport in the Bailang River. Increased water discharge and intense rainfall patterns can increase soil erosion and sediment contributions to rivers.

Watershed analysis to determine the size of the Bailang River Watershed at the Bailang Bridge location has been evaluated using Global Mapper software with Geographic Information System (GIS) data from the Sulawesi River Basin Center-1 (BWSS1). The results indicate that the area of the Bailang River Watershed at the Bailang Bridge point reaches 11.34 square kilometers. Information related to the dimensions of this watershed will be presented in Figure 3.

Picture3. Bailang Watershed at Bailang Bridge Point
Source: Global Mapper, BWSS-I GIS Data

Apart from that, rainfall analysis was also carried out in selected areas of the Bailang River Watershed (DAS). The maximum daily rainfall data used was taken from the Sulawesi I River Basin Center (BWSS1) with an observation range from 2010 to 2020. This analysis utilized one rain observation station, namely the MRG Bailang Rain Station. Maximum daily rainfall data during this period has been collected and will be used for further assessment.

Table1. Maximum Daily Rainfall Data

Tahun	Curah Hujan Harian Maksimum (mm)
	MRG Bailang
2010	123.00
2011	111.00
2012	75.90
2013	194.30
2014	201.00
2015	124.50
2016	65.10
2017	99.30
2018	78.80
2019	46.00
2020	88.20

Data Outlier Test has been carried out to evaluate the presence of data that deviates significantly from the rainfall data set. The results show that there is no rainfall data that is classified as an outlier, meaning that there is no data that shows a significant deviation from the data set. Next, the Rain Distribution Type is identified based on statistical parameters such as arithmetic average ($\bar{X}$), standard deviation (S), coefficient of variance (Cs), coefficient of variation (Cv), and coefficient of kurtosis (Ck). Information regarding the types of data distribution will be presented in Table 2.

Table2. Determining Data Distribution Type

Tipe Sebaran	Syarat Parameter Statistik	Parameter Statistik Data Pengamatan	Keterangan
Normal	Cs = 0	Cs = 0,94	Tidak Memenuhi
	Ck = 3	Ck = 3,98	Tidak Memenuhi
Log Normal	$Cs = Cv^3 + 3 . Cv$ = 1,4484	Cs = 0,94	Tidak Memenuhi
	Ck = $Cv^8 + 6Cv^6 + 15Cv^4 + 16Cv^2 + 3$ = 6,948	Ck = 0,94	Tidak Memenuhi
Gumbel	Cs = 1,14	Cs = 0,94	Tidak Memenuhi
	Ck = 5,40	Ck = 3,98	Tidak Memenuhi
Log Pearson III	Bila tidak ada parameter statistik yang sesuai dengan ketentuan distribusi sebelumnya	-	Memenuhi

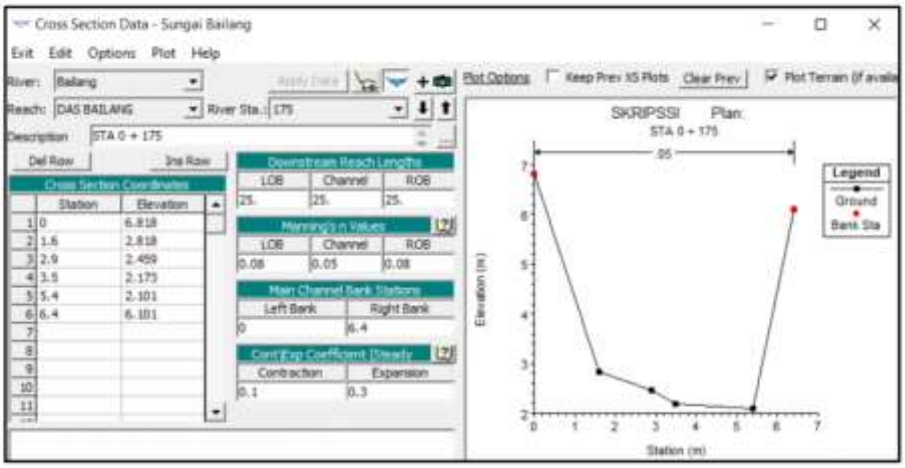
Evaluation of Planned Rainfall is carried out by applying the Log Pearson III distribution type. Data from the planned rainfall calculations will be presented in Table 3. This calculation involves steps such as calculating the arithmetic average, standard deviation, and coefficient of variance which describes the distribution characteristics of rainfall data. Thus, this evaluation provides a clearer picture of the expected rainfall patterns for the region.

Table 3. Precipitation Plan

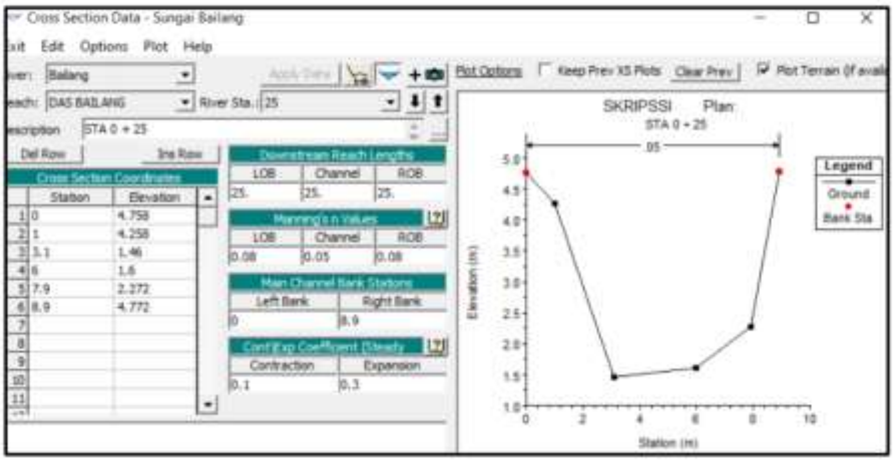
Kala ulang	Log X TR	X TR
2	1.999	99.858 mm
5	2.163	145.532 mm
10	2.250	177.737 mm
25	2.343	220.406 mm
50	2.404	253.543 mm

The planned flood discharge assessment will use rain flow modeling in HEC-HMS software by applying the HSS Soil Conservation Services method. In addition, the recession method will be used to calculate base flow.

Sediment transport analysis will be carried out via HEC-RAS software by applying the Meyer Peter Muller (MPM) method. To carry out this analysis, input data is needed such as channel cross-sections, channel characteristics including the Manning coefficient (n), flood discharge and sediment data. The necessary detailed data will be prepared specifically for the Bailang River section at the Bailang Bridge. Cross-sectional data for STA 25 and STA 175 will be shown in Figure 4 and Figure 5.



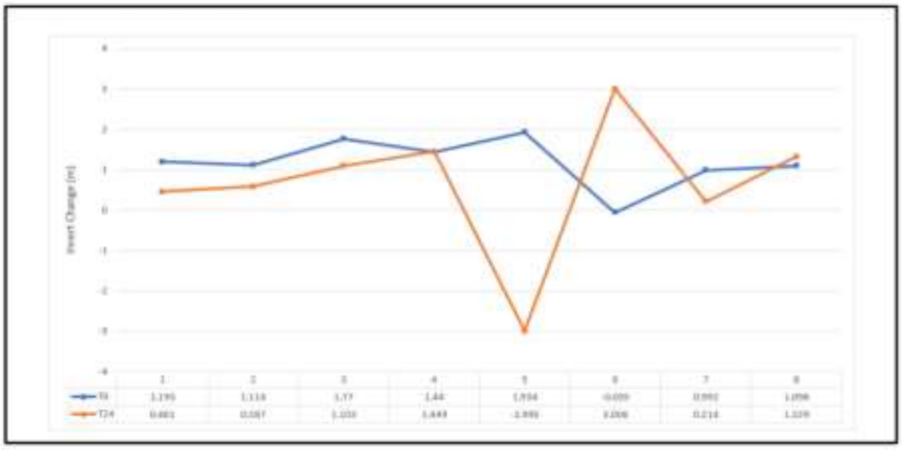
Picture 4. STA 0 + 175 (Upstream) cross section data



Picture 5. STA 0 + 25 (Downstream) Cross Section Data of the Bailang River

Table 4 Sediment transport with 2 year return period discharge (Q2)

River Sta.	ID Sta.	Elevasi Dasar Saluran		*Invert Change*	Keterangan
		T_0	T_{24}	(m)	
175	P1	1.195	0.461	-0.734	Erosi
150	P2	1.114	0.587	-0,527	Erosi
125	P3	1.77	1.103	-0.667	Erosi
100	P4	1.44	1.449	0.009	Sedimentasi
75	P5	1.934	-2.993	-4.927	Erosi
50	P6	-0.055	3.006	2,951	Sedimentasi
25	P7	0.992	0.214	-0,778	Erosi



Picture 6. Evaluation of Changes in River Bed Elevation T0 and T24 Using 2 Year Return Period Discharge

Based on analysis using a 2-year return period discharge of 18.8 m3/second as the dominant discharge, the Bailang River shows sedimentation and erosion phenomena in various river sections. Sedimentation occurred mainly at STA 50 and STA 100, while erosion occurred at the STA 25, STA 75, STA 125, and STA 175 sections.

From the results of sediment transport simulations using HEC-RAS software, it can be concluded that there is more erosion than sedimentation in the Bailang river. This means that the river tends to experience a decrease in soil volume (erosion) more than the accumulation of sediment (sedimentation). This explanation is important because erosion and sedimentation can have significant impacts on river environments, including changes in water flow patterns, loss of habitat, and even safety issues for infrastructure such as bridges. Therefore, a good understanding of this phenomenon is necessary to plan appropriate mitigation and river management actions.

A hydrological approach helps in understanding the impact of changes in water discharge and rainfall patterns on sediment transport in the Bailang River. Increased water discharge and intense rainfall patterns can increase soil erosion and sediment contributions to rivers. On the Sario River, flooding and erosion problems have affected river morphology. Sediment transport analysis using hydrological and geomorphological approaches shows that large water discharge is one of the main factors causing flooding. Increased water discharge, together with erosion and sedimentation, can reduce the carrying capacity of rivers and trigger changes in river beds.

From the results of measurements of the Sario river section in 2019 and 2021, an overlay was carried out to calculate the volume of storage capacity. Thus, it was identified that the difference in volume between 2019 and 2021 was 252.50 tons. Analysis of bed load transport based on discharge Q5 = 26.99 m3/second for 2019 and 2021 using the MPM equation shows a difference in total bed load of 333.35 tonnes.

Table 5. Prediction Results of Sediment Transport Magnitude

Metode	Selisih *Bedload* Tahun 2019 dan 2021 (ton)
Overlay	252,50
Meyer Peter Muller	333,35
Hec - Ras	1143,55

Simulation results using the HEC-RAS program indicate that there is a difference in total bed load between 2019 and 2021 of 1,143.55 tons. Differences or variations in sedimentation volume resulting from measurements and analysis using the MPM equation can be caused by several factors, including changes in the discharge amount used in the analysis.

The interaction between hydrological and geomorphological factors in the Sario River is key in understanding sediment transport patterns. An increase in water discharge can trigger changes in river shape, and conversely, changes in river morphology can influence flow patterns and sediment distribution.

In this research, sediment transport patterns in the Bailang River and Sario River were analyzed using hydrological and geomorphological approaches. The main focus of the analysis is on bed load and several selected locations in the two rivers.

Hydrological Approach

According to Triatmodjo (2008), various activities such as planning and operating water structures, providing water for various needs (including clean water, irrigation, fisheries and livestock), hydroelectric power plants, flood control, erosion and sedimentation control, water transportation, drainage , pollution control, waste water management, and other activities, are part of the activities related to water resources management.

In this research, hydrological analysis was carried out using the Nakayasu Synthetic Unit Method to analyze flood discharge. This method was developed by a Japanese researcher named Nakayasu, who conducted research on several rivers in Japan. The Nakayasu Synthetic Unit Hydrograph (HSS) Equation form is used to describe the characteristics of flood hydrographs.

A hydrological approach is used to consider hydrological factors such as water discharge and rainfall in understanding sediment transport patterns. This analysis is carried out by taking into account changes in water discharge and rainfall which affect river flow and sediment transport.

Geomorphological Approach

The geomorphological approach focuses on understanding landforms, topography, and river flow patterns that influence sediment transport. Geomorphological processes active in these areas, such as erosion and sedimentation, are also considered to understand sediment transport patterns.

Analysis Results

Based on the analysis carried out, an in-depth understanding of sediment transport patterns in the Bailang River and Sario River was obtained. Changes in water discharge, rainfall, landforms, topography and river flow patterns have a significant impact on sediment transport in the two rivers.

Implications and Benefits

This research provides important information for sustainable river management. With a better understanding of sediment transport patterns, effective river management strategies can be designed to mitigate erosion, sedimentation and flood risk. Apart from that, understanding the interaction between hydrology and geomorphology also helps in better spatial planning in riverbank areas.

Research Contribution

This research is expected to make a significant contribution to sustainable river management, environmental protection and more effective spatial planning. Understanding sediment transport patterns in rivers is the basis for developing more effective erosion and sedimentation mitigation strategies, so as to minimize negative impacts on rivers and their environment..

CONCLUSION

In order to address sedimentation problems in the Bailang River and Sario River, this research combines hydrological and geomorphological approaches to understand sediment transport patterns. Comprehensive analysis shows that changes in water discharge, rainfall, landforms, topography, and river flow patterns have a significant impact on sediment transport in both rivers.

Key findings include an in-depth understanding of the erosion and sedimentation processes that occur along rivers, as well as the identification of key factors that influence sediment transport patterns. This research also underlines the importance of interactions between hydrological and geomorphological factors in shaping specific sediment transport patterns in rivers. The implications of this research include providing important information for sustainable river management, including the development of erosion, sedimentation and flood risk mitigation strategies. In addition, a better understanding of sediment transport patterns can also help in more effective spatial planning in riverbank areas.

In conclusion, this research makes a significant contribution to the understanding and sustainable management of rivers and environmental protection. Thus, understanding sediment transport patterns in rivers becomes the basis for developing more effective erosion and sedimentation mitigation strategies, so as to minimize negative impacts on rivers and their environment.

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