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Analysis of Changes in Erosion and Sedimentation Levels in the Tempuran Reservoir Catchment Area of Blora for the Years 2017-2021

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Abstract. Tempuran Reservoir, located at Blora Regency of Central Java Province of Indonesia, has a vital role in storing water in the rainy season, providing raw water, and irrigating around 420 ha of surrounding land, so it is necessary to maintain its management so that it can continue to function optimally. However, sedimentation is often the main problem for the reservoir, which occurs due to the erosion process in the Tempuran Reservoir Catchment Area, which settles at the bottom of the reservoir. Therefore, this study aims to determine the development of erosion rates and the level of erosion hazard in the Tempuran Reservoir catchment area in 2017-2021 and to predict the sediment yield flowing into Tempuran Reservoir in 2017-2021. The method used to predict erosion results is the Universal Soil Loss Equation (USLE), which utilizes the Sediment Delivery Ratio (SDR) to predict sediment yield entering the reservoir. Data required in USLE include rainfall, soil type, DEM, soil conservation measures, and Sentinel 2. The results showed a decrease in the erosion rate of -1773.357 tons/ha/year in 2019 and continued to decrease by -66.694 tons/ha/year in 2021. The most influential factor in reducing the erosion rate in the Tempuran Reservoir catchment area is the rain erosivity factor. Meanwhile, sedimentation carried to Tempuran Reservoir in 2019 decreased by -117.344 tons/ha/year; in 2021, there was also a decrease of -4.413 tons/ha/year.

Keywords: Tempuran Reservoir Catchment Area; Erosion Rate, Sediment, USLE

INTRODUCTION

The primary source of reservoir water comes from rivers flowing upstream of the reservoir and is accommodated for clean water needs, irrigation, drinking water, and many more. There are 18 reservoirs in the Jratunseluna River Basin, one of which is Tempuran Reservoir. This reservoir is one of the largest water storage reservoirs in Blora Regency. The existence of this reservoir has a vital role in maintaining the balance of life around it, so it needs to be managed so that it can continue to function optimally.

Tempuran Reservoir is one of the reservoirs that experienced sedimentation in 2021 in the working area of BBWS Pemali Juana. Although, sedimentation does not significantly affect the reservoir's water discharge [1]. However, maintenance and monitoring are still crucial to maintain the reservoir's functionality and avoid a lack of water supply. This is because Blora Regency is one of the regencies that often experience drought, with the main factors being the long dry season (low rainfall) and the type of soil [2]. In addition, climatic conditions are one of the factors that affect erosion [3]. Regarding climate, the El Nio phenomenon has been one of the triggers of recent droughts. El Nino occurred in the central equatorial Pacific Ocean from September 2018 to July 2019. Therefore, El Nino is predicted to affect changes in erosion and sedimentation rates.

The problems of erosion and sedimentation are inseparable. Starting from the erosion process, peeling, separating, moving, and deposition [4]. The deposition of soil particles will gather at a point of flow or water body and undergo sedimentation. However, direct erosion measurement requires a lot of money and time, so modeling can be an alternative to predict the amount of erosion.

Based on the development of previous research, the USLE method is considered efficient for handling large volumes of data in soil loss studies in watersheds [5]. During a comprehensive evaluation, the USLE approach was used for 80 years and applied in about 109 countries. It is the most commonly used approach [6]. One of the benefits that can be taken from the USLE method is that it is helpful as a guide for policymakers for soil erosion prevention and control measures [7]. The USLE method predicts land erosion from sheet and rill erosion [8]. The USLE method developed by Wischmeier and D. D. Smith [6] has parameters such as rainfall erosivity, soil erodibility, slope length and slope, and vegetation cover and land management. The research time taken is 2017, 2019, and 2021. This is done to determine the development of erosion and sedimentation in a certain period. Regarding USLE modeling, Geographic Information Systems (GIS) also play an essential role in calculating and mapping erosion rates [10]. Although data availability for erosion and sedimentation analysis is usually limited, integrating the USLE model with GIS erosion and sedimentation rates can be measured.

MATERIAL AND METHODS

The research location is Tempuran Reservoir and Tempuran Reservoir catchment in Blora Regency. This research uses research time in 2017, 2019, and 2021. The data needed include administrative boundaries of Blora Regency in 2017, rainfall intensity (2017, 2019, and 2021), soil type of Blora Regency in 2015, DEMNAS, Sentinel-2 (2017, 2019, and 2021), interview results of soil conservation measures, and historical imagery in 2021. The method applied in this research is the USLE method, which integrates a Geographic Information System (GIS) to map the erosion hazard level in the area. Parameters in determining the erosion rate consist of rainfall erosivity (R), soil erodibility (K), slope (LS), land cover/vegetation (C), and soil conservation measures (P).

Soil erodibility and slope parameters in this study are considered to have no change from 2017-2021 because it takes a long time for soil and topography to change [11]. Rainfall erosivity, land cover, and soil conservation measures are the dynamic parameters in this study.

TABLE 1. Soil erodibility [12]

Soil Type	K
Mediterranean	0.31
Grumusol	0.48

TABLE 2. Slope [13]

Slope (%)	Classification	LS
0-8	Flat	0.4
8-15	Ramps	1.4
15-25	Slightly steep	3.1
25-40	Steep	6.8
>40	Very steep	9.5

Rainfall erosivity parameters are processed from rainfall data using the Bols formula to produce erosivity in 2017, 2019, and 2021. Rainfall erosivity utilizes daily rainfall data, such as the amount of rainfall (Rain) (cm), the number of rainy days in a month (Days), and the maximum amount of rainfall in a month (MaxP) (cm), which is calculated to obtain the rainfall erosion index in a month (El30) (ton.m/ha.cm/h). Furthermore, rain erosivity in a year (R) can be calculated.

$$El_{30} = 6.119 \times Rain^{1.21} \times Days^{-0.47} \times MaxP^{0.53} \quad (1)$$

$$R = \sum_{i}^{12} EI_{30_i} \tag{2}$$

Meanwhile, land cover parameters result from processing Sentinel 2 Level-1C imagery for 2017 and Sentinel 2 Level-2A imagery for 2019 and 2021. The sentinel-2 level 2A satellite imagery used has been geometrically corrected, and BOA (Bottom of Atmosphere) reflectance radiometric correction has been used, so in this study, no correction is needed again. However, because Sentinel-2 Level 2A satellite imagery is only available worldwide as of December 2018, this study also used Sentinel-2 Level 1C satellite imagery corrected by the SIAC algorithm using the Google Earth engine [14]. This SIAC (sensor invariant Atmospheric Correction) algorithm produces consistent atmospheric corrections for different sensors [15]. Based on this image, land cover mapping is carried out using supervised methods and Random Forest Classification for classification [16]. Furthermore, land cover accuracy utilizes the results of land cover processing and historical imagery in Google Earth Pro in 2021. The results of land cover mapping are classified into five classes: forest, agricultural land, wasteland, built-up land, and water body [17]. Then, the parameters of soil conservation measures are generated from the interviews with Cabang Dinas Kehutanan Region I staff so that information on soil conservation measures that have been carried out in the research area is obtained [18].

TABLE 3. Land cover (C) and soil conservation measures (P)

Tutupan Lahan	C	P
Waterbody	0	1 (none)
Built up land	0.044	1 (none)
Forest	0.01	1 (none)
Agricultural land	0.1	0.2 (terrace bench)
Wasteland	0.05	1 (none)

The USLE method is processed by overlaying these parameters with the intersection. Therefore, the erosion rate (A) result can be calculated based on the USLE equation. In addition, the erosion hazard level can also be generated from the results of the erosion rate by classifying the erosion hazard level with the following classification [19].

$$A = R \times K \times LS \times C \times P \tag{3}$$

TABLE 4. Classification of erosion hazard levels

Erosion Hazard Level	Erosion Rate (ton/ha/yr)
Very low	<15
Low	15-60
Medium	60-180
High	180-480
Very high	>480

The result of sediment or sediment yield carried into the reservoir (SY) can be obtained by approaching the results of USLE and SDR erosion predictions using total erosion results derived from the Reservoir catchment area (T) and watershed area (A).

$$SDR = 0.41 \times A^{-0.3} \tag{4}$$

$$SY = T \times SDR \tag{5}$$

RESULTS AND DISCUSSIONS

Erosion Rate

The level of erosion hazard from 2017, 2019, and 2021 has developed for the better. This can be seen in the high and medium-class erosion hazards, which have decreased in the area over time. In contrast, the shallow erosion hazard level experienced a significant increase in area, especially in 2019. The level of erosion hazard that tends to be low is produced by factors with low erosion potential values, such as low rainfall, soil types that are less sensitive to erosion, sloping slopes, land cover with vegetation cover, and soil conservation measures that are by conservation rules, and so on.

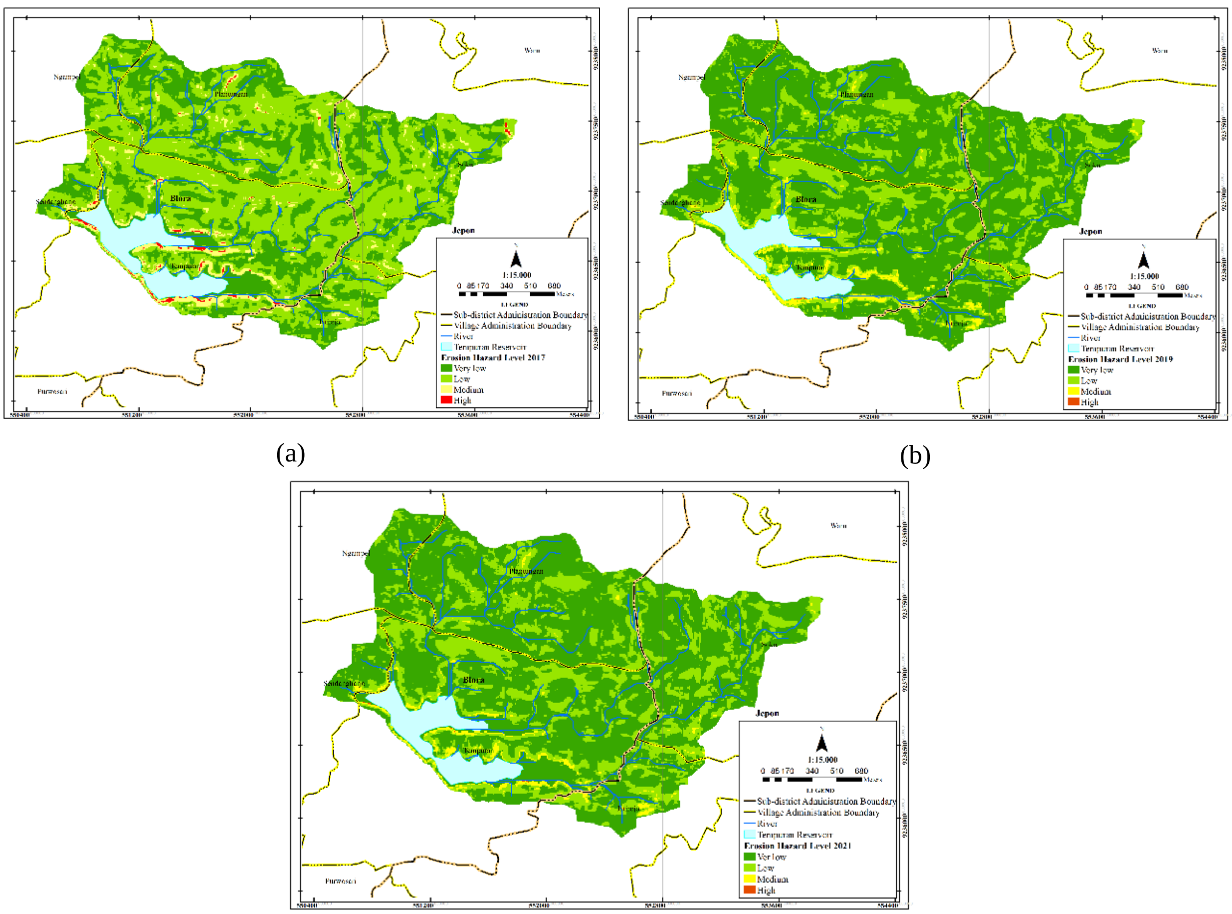


FIGURE 1. Erosion hazard level of Tempuran Reservoir catchment (a) in 2017, (b) in 2019, and (c) in 2021

Dynamic factors, such as rainfall erosivity, land cover, and soil conservation measures, influenced this study's reduction in the erosion hazard level. Among the three parameters, rainfall erosivity is considered the most influential factor [20]. Changes in rainfall erosivity occurred due to the long dry season in 2019. This was conveyed by the Head of BMKG, Dwikorita K., who said that the drought that year was triggered by the El Nio phenomenon, which is expected to be active from September 2018 to July 2019. Therefore, in 2019, there was a significant decrease in the erosion rate compared to 2017. This happened because the low rainfall intensity reduced the potential for converting water into runoff and transporting dispersed soil particles. Although, in 2021, the erosivity of rain increased, the slight increase did not have a fatal effect on the erosion rate.

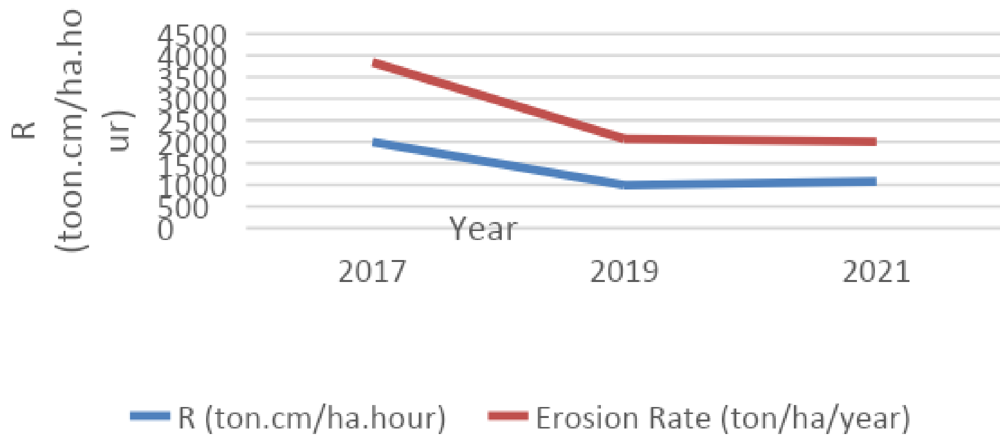
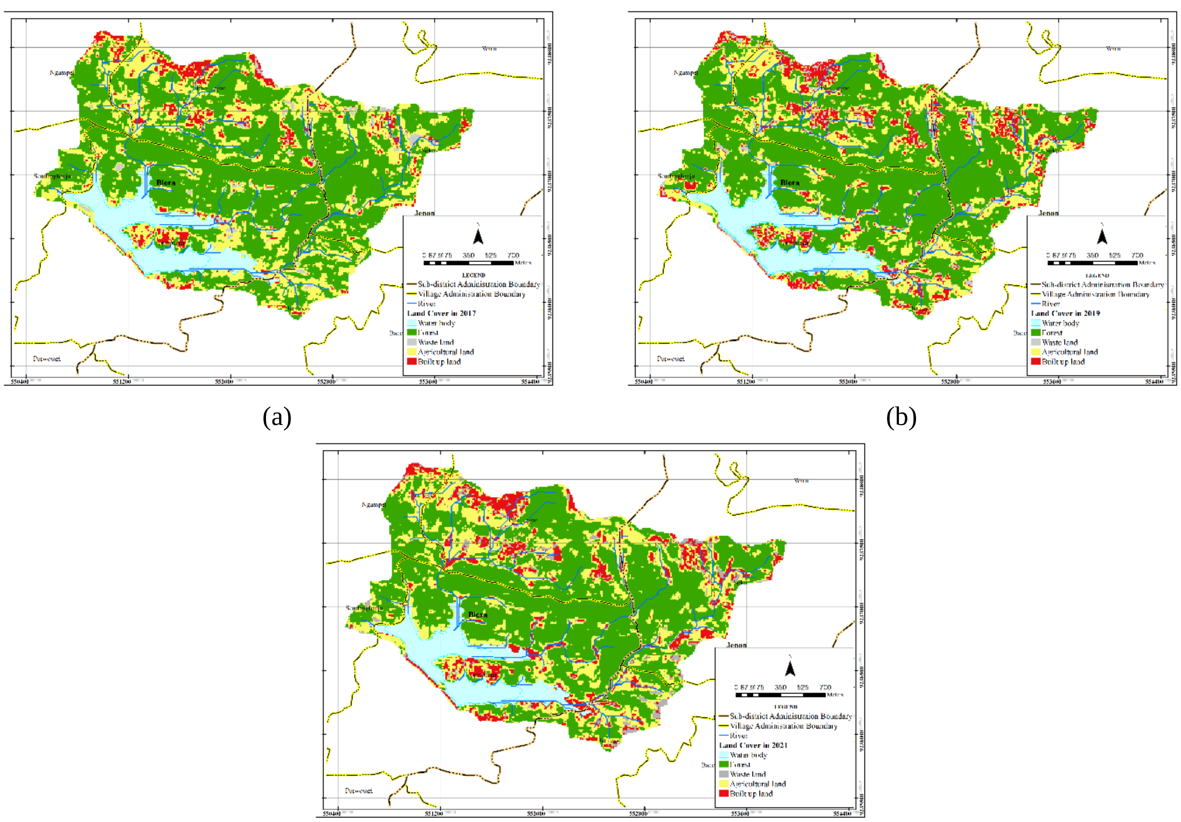


FIGURE 2. Relationship between rainfall erosivity and erosion rate

In addition to rainfall erosivity, land cover parameters and soil conservation measures experience dynamic changes over time. Land cover is included in the vegetation factor that influences the level of rainfall on the soil and the rate of flow movement [4]. Therefore, land covers such as forests with high vegetation and conservation capabilities can reduce the erosion potential generated [21]. This is by the research area, where forests still dominate the land cover area in 2017, 2019, and 2021. However, it can be accepted that built-up land cover has increased each year in the area around Tempuran Reservoir [22].



(a) (b)

(c)

FIGURE 3. Tempuran Reservoir catchment land cover (a) in 2017, (b) in 2019, and (c) in 2021

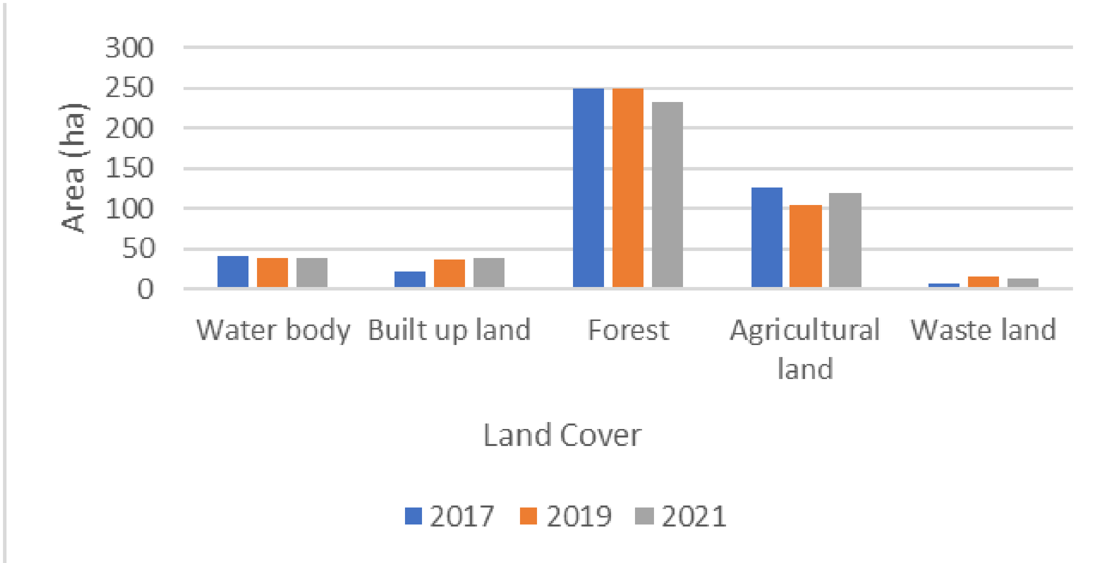
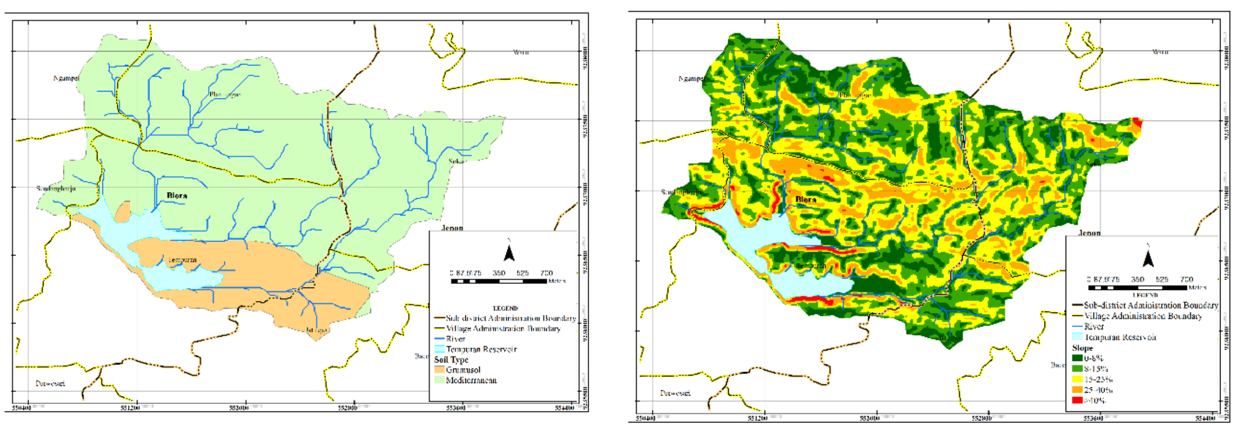


FIGURE 4. Land cover change

As a mechanical soil conservation technique, the soil conservation measures implemented are bench terraces on agricultural land. This aims to reduce the speed and amount of surface flow and increase the infiltration process to control erosion potential [23]. In addition to mechanical conservation techniques, vegetative soil conservation techniques have been applied using plants as erosion control, including pine, sengon, calliandra, dog fruit, stink bean, and coffee trees. This is due to the presence of soil types in the Tempuran Reservoir catchment that have medium-high productivity (Mediterranean soil) and medium productivity (grumusol soil).



(a) (b)

FIGURE 5. (a) soil type and (b) slope

The rate of erosion or soil loss in the Tempuran Reservoir catchment in 2017 was around 3842.852 tons/ha/year; in 2019, it was 2069.495 tons/ha/year, and in 2021, it was 2002.801 tons/ha/year. Based on the calculation results of the USLE Method, the development of the erosion rate continues to improve. This certainly positively impacts the environment around the Tempuran Reservoir catchment area and the reservoir itself because the smaller the possibility of erosion as the years go by. The development of erosion rates can be seen from the following mapping of erosion hazard levels. An interesting difference occurs in the erosion hazard level 2017, where the year is dominated by the low erosion hazard level. Meanwhile, in 2019 and 2021, the erosion hazard level in the Tempuran Reservoir catchment is dominated by a shallow erosion hazard level. Meanwhile, the level of erosion hazard in Tempuran Reservoir catchment in 2017, 2019, and 2021, with medium and high classes, dominated the area around the edge of Tempuran Reservoir. The slope contributes to the potential erosion hazard level in the reservoir edge area. This is because the surface flow velocity is directly proportional to the slope. [19]. This means that the higher the hill, the higher the surface water flow velocity, which causes higher erosion.

Sedimentation

TABLE 5. Erosion and sediment rate prediction

Year	Erosion Rate (ton/ha/yr)	Sediment Yield (ton/ha/yr)
2017	3842.852	254.285
2019	2069.495	136.940
2021	2002.801	132.527

$$SDR = 0.41 \times (436.910)^{-0.3}$$

$$SDR = 0.066$$

The sedimentation value is calculated from the total annual erosion rate multiplied by the SDR value. In this study, the SDR value was 0.066. The SDR value of 0.066 or 6.6% indicates that the sediment carried by the water flow is 6.6%, and 93.4% of other erosion results do not enter the reservoir. Based on the calculation results, it is known that the highest sedimentation value occurred in 2017. Meanwhile, in 2019, it decreased by -117.344 tons/ha/year and continued to decline in 2021 by -4.413 tons/ha/year. The most significant change occurred from 2017 to 2019. This is closely related to the existing annual erosion rate, where the lower the erosion rate, the less sedimentation will occur. Thus, the sediment flowing into Tempuran Reservoir in 2019 and 2021 continues to decrease compared to 2017. The decrease in sedimentation depends on the results of land erosion generated from the Tempuran Reservoir catchment area. This is because the reservoir becomes an outlet point or a place where the water velocity will slow down to a standstill so that it becomes a place of deposition or sedimentation process [19].

CONCLUSION

Based on the processing and analysis results that have been carried out in the study, it can be concluded that there was a decrease in the erosion rate of -1773.357 tons/ha/year compared to 2017 and continued to decrease by -66.694 tons/ha/year in 2021. The most influential factor in reducing the erosion rate in the Tempuran Reservoir catchment is the rain erosivity factor. This analysis is in accordance with research conducted by Huang [17], which states that climate change, such as changes in rainfall, can significantly affect erosion, where an increase in rainfall intensity will result in higher erosion rates. This is because when the rain intensity is high, most of the water will become runoff flow and easily transport soil particles that have been dispersed [4]. Therefore, runoff flow and erosion rates will decrease as rainfall intensity decreases.

Predicted sediment yields that flow into Tempuran Reservoir have decreased. Based on the study's results, sedimentation in 2019 decreased by -117.344 tons/ha/year; in 2021, there was also a decrease of -4.413 tons/ha/year. The decline in sedimentation is influenced by the results of land erosion generated from the Tempuran Reservoir catchment area itself. This is because sedimentation is produced from erosion, as Arsyad explained [16]. Sediment resulting from the erosion process and carried by the water flow will be deposited where the water velocity slows down until it stops.

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