Study of the Impact of Sediment Rate on River Morphology Changes and Floods in the Sadar River, Mojokerto Regency

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Abstract. Kali Sadar is a collector canal of several river tributaries and is a floodplain that protects a 1.930-hectare of agricultural land areas in Mojokerto Regency, East Java Province. Flooding occurs frequently in the Sadar River's basin at Mojokerto Regency, East Java Province every year, causing a lot of material losses. The flood was caused by the narrowing and silting of the Kali Sadar River by sediment. Sediment and erosion can affect changes in river morphology which can cause a reduction in the capacity of the Kali Sadar river because it experiences scouring (degradation) and sedimentation (aggradation) every year. The methodologies used in this study are analyzing the potential for bedload sediment transport using the Engelund Hansen Method. The hydraulics analysis used the unsteady flow equation 1D and 2D models by including the planned flood discharge for 25th year return periods and cross-sectional data from upstream to downstream of Kali Sadar. the 1D model analysis resulted in changes in the long sections and cross-sections profile of the river that eroded and sedimented river sections. The results obtained in this study of changes in riverbeds experienced an average elevation as high as 1,45 m downstream of the river and degradation of an average of 1,5 m upstream. This needs to be handled by dredging the total sediment volume of 2.911 m^3 which is done periodically.

1. Introduction

Sadar River is a tributary of river's Porong that flows through the Mojokerto Regency. The Mojokerto Regency area has swiftly expanded into a prospective industrial, residential, and agricultural area as a result of its strategic location and proximity to the city of Surabaya; as a result, the problem of flooding has got significant attention from the government. Sadar River is a part of the primary drainage system in the Mojokerto Regency and City districts for flood control. The problem at Sadar River arises from flood inundation caused by tributaries of the river being unable to access the Sadar River due to the increasing height of it when the flow rate is high. This circumstance causes the process of flowing flood discharge to take a long time since the upstream part of the river has a pretty steep contour while the lower part of the river has a fairly mild contour. Flood-prone locations may be found in the districts of District Mojoanyar, District Mojosari, District Bangsal, District Pungging, and District Ngoro. The map of flood inundation in Mojekerto Regency is shown in Figure 1.

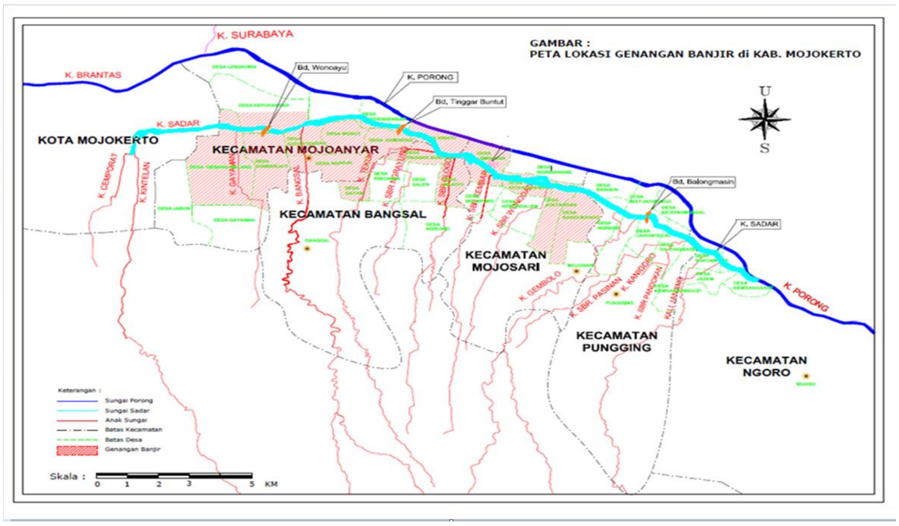

Figure 1. The Sadar River watershed's flood inundation area

As a result, land erosion in the Kali Sadar watershed, flood distribution, flood magnitude, and the influence of sedimentation, which causes changes in the channel bottom and affects the river's cross-sectional capacity, must all be investigated.

2. Study Area

Sadar River, Mojokerto Regency, East Java Province is the site of the research. The main channel of Sadar River has a length of + 23,211 km and a drainage area of +365.23 km^2 (primary data from long section measurements, in 2013 from BBWS Brantas). Mojokerto City is upstream and Kali Porong is downstream. The Sadar River's watershed is divided into eight primary sub-basins, each with eight tributaries. Figure 2 shows a map of the Sadar River watershed, as well as a table review of the Sadar River watershed.

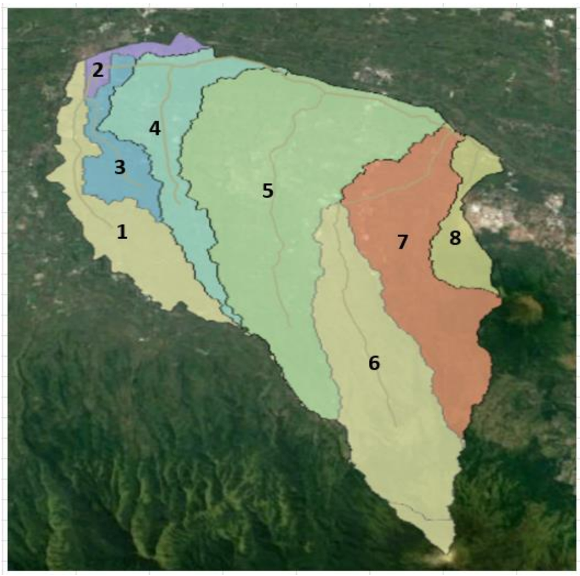

Figure 2. Location of the Sadar River Basin

Table 1. Data Sub-catchment area Sadar River

Sub-Catchment Area	Area Km^2	Length m	Slope
Sub CA 1	38.48	72.51	0.004
Sub CA 2	7.08	72.84	0.015
Sub CA 3	18.14	71.64	0.004
Sub CA 4	42.06	73.34	0.006
Sub CA 5	124.13	73.64	0.019
Sub CA 6	60.03	72.73	0.057
Sub CA 7	60.11	73.03	0.014
Sub CA 8	16.23	71.72	0.007

With a slope of 0.0005 to 0.004, the Sadar River is a reasonably straight river. Flood embankments area already in place on the left and right sides of the channel on the downstream side, and parapet embankments are in place on the upstream side. It has a very steep upstream slope and a level downstream slope.

3. Data

Secondary and primary data were used to compile the data for this investigation. Secondary data is typically gathered from earlier studies and updated with the most recent information until 2020. The Harmonized World Soil Database provided the data for topographic analysis in the form of Digital Elevation Model (DEM) data, land cover, and soil type data (HWSD). For 25 years, hydrological data such as rain data were collected at six rain stations in the Sadar River watershed: Pacet, Trawas, Mojosari, Ketangi, Promising, and Pundakssari (1996 to 2020). Figure 4 shows the daily field discharge statistics for one year (2018). Figure 3 show of the data on the Sadar River slope, grade, and area. Field data was also obtained, including instantaneous discharge, bed material, and suspended solid content.

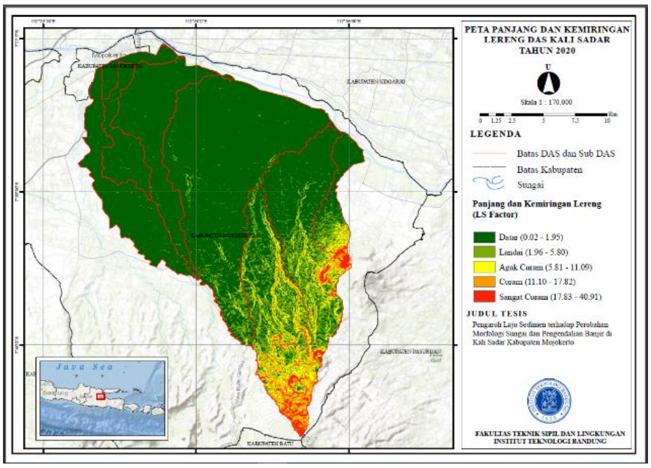

Figure 3. Land slope map Sadar River

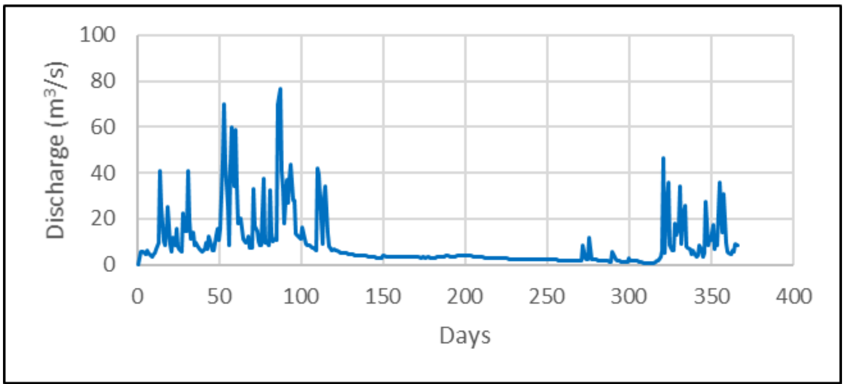

Figure 4. Maximum observed discharged data 2018

Daily discharge data will be used to input sediment transport simulation data using the method [5].

4. Methodologies

Watershed parameters such as watershed area, river length, length to the centroid, slope, CN, and others were analyzed using a Geographic Information System (GIS). Hydrological analysis consists of analysis of planned flood discharge at various return times, and analysis of planned flood discharge using HEC-HMS based on the Synthetic Unit Hydrograph (SUH) method, namely Soil Conservation Service (SCS) and Snyder. Flood hydraulics modeling analysis was performed using HEC-RAS 1D and 2D with Unsteady flow conditions. The boundary conditions used in the upstream model are flood discharge with a return period of 25 and 50 years according to the regulation of the Ministry of Public Works and Housing Number 28 of 2015. The boundary condition used in the downstream model is the highest water level in Porong River as an outlet river. The geometric data that will be used in the model are the existing conditions and designs obtained from the Survey, Design and Investigation (SID) Study of Kali Sadar Flood Control in 2018.

The results of the hydraulic analysis in the form of flood inundation area and flood height along the Kali Sadar river. Changes in river morphology were obtained by analyzing sediment transport using HEC-RAS 1D with sediment data limits and daily discharge and bankfull discharge as the upstream limit by Engelund Hansen equation:

$$q_s = 0.05.\gamma_s V^2 \left[\frac{d_{50}}{g\frac{\gamma s}{\gamma}-1}\right]^2 \left[\frac{\tau_o}{(\gamma s-\gamma)d_{50}}\right]^{3/2} \quad (1)$$

In this study also used the Manning's Equation for determined discharge bankfull capacity :

$$V = \frac{1}{n} R^{2/3} S^{1/2} \quad (2)$$

and then formula for discharge Capacity is Q = A x V. Bankfull capacity was used for calibrate flood discharge. After obtaining the results of flood inundation and changes in the riverbed that experienced aggradation and degradation, alternative solutions were given and conclusions were drawn.

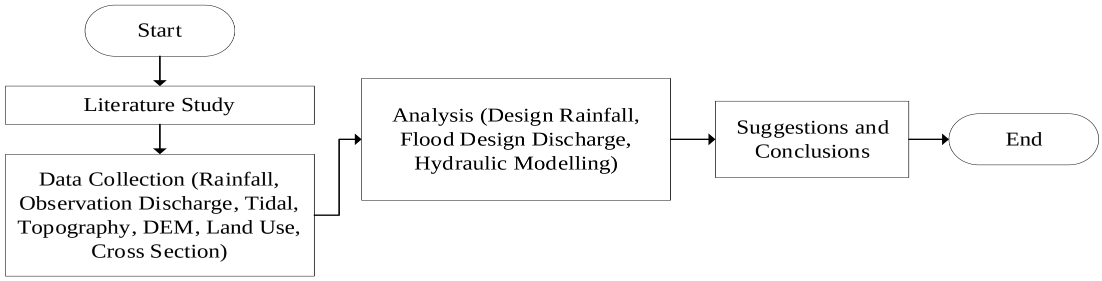

Figure 5. Flowchart of study

5. Results and Discussions

5.1 Topographic Analysis

The area of the watershed can be defined using GIS-based software, and then the coefficients for the Thiessen rainfall area and the amount of the watershed can be calculated for rainfall area and rainfall abstraction, respectively. The watershed is 365.23 km^2 in size, and the Curve Number (CN) values are listed in Table 2.

Table 2. CN Composite Sub-catchment Area Sadar River

Sub-Catchment Area	Area Km^2	CN Composite
Sub CA 1	38.48	72.51
Sub CA 2	7.08	72.84
Sub CA 3	18.14	71.64
Sub CA 4	42.06	73.34
Sub CA 5	124.13	73.64
Sub CA 6	60.03	72.73
Sub CA 7	60.11	73.03
Sub CA 8	16.23	71.72

5.2 Hydrologic Analysis

Due to a lack of daily data in the field, a hydrological analysis was carried out using data from 6 rain stations throughout the Sadar river watershed, and a hydrological study was carried out with the results of the return flood discharge in compliance with SNI (Standardization National of Indonesia) rules [1]. The results of the return flood discharge will be used as input for hydraulic and sediment analysis modeling later on. Figure 6 shows hydrograph for each return period in one of Sadar river's largest sub-basins, Sub-das 5, as well as a summary of each rainfall in table 5.

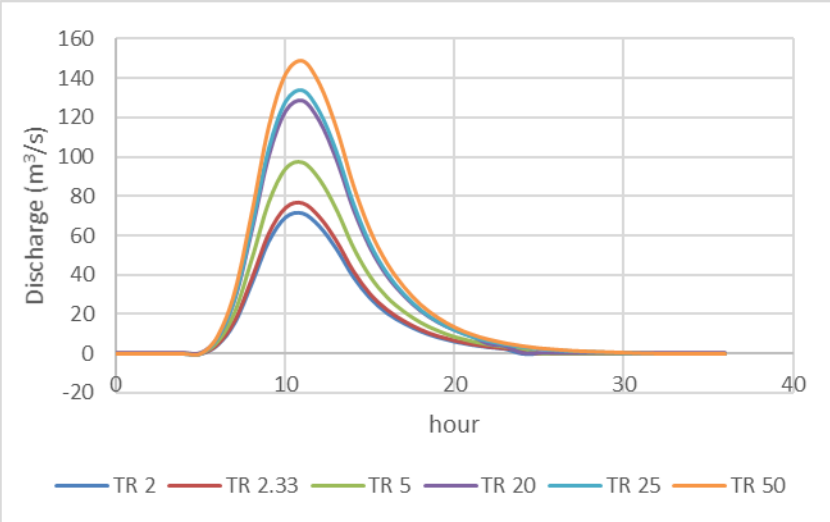

Figure 6. Hydrograph Sadar River subcatchment area 5

Table 5. Peak Flood Discharge return periods Sadar's watershed

Sub-Catchment Area	Discharges (m^3/s)				
	Q_2	Q_5	Q_{20}	Q_{25}	Q_{50}
Sub CA 1	19.60	32.30	47.00	49.80	55.10
Sub CA 2	5.10	8.20	11.80	12.30	13.80
Sub CA 3	9.20	16.30	24.80	26.00	29.50
Sub CA 4	14.60	26.40	40.20	41.30	47.10
Sub CA 5	71.20	96.90	128.60	133.60	148.60
Sub CA 6	51.70	55.80	74.90	109.60	115.30
Sub CA 7	22.50	38.10	64.30	68.90	83.70
Sub CA 8	10.70	19.70	35.50	38.40	47.80

5.3 Calibration of Hydrologic and Hydraulic Models

The calibration of the flood discharge during the return period is carried out using a bankfull capacity, due to the limitations of field discharge data. Bankfull discharge is the discharge capacity that can be fully accommodated in a cross river. The cross section for calibration of the discharge is taken at the outlet/most downstream section of STA 22+700, this is because the flood event validation has been carried out on the cross. With the manning value based on Chow, 1997 with natural channels, the net is straight with n = 0.030 (the value of n is close to the field results).

$$Q=\frac{1}{n}R^{\frac{2}{3}}S^{\frac{1}{2}}A=\frac{1}{0.03}\left(\frac{190}{44.98}\right)^{\frac{2}{3}}(0.0005)^{\frac{1}{2}}=275{,}27\ m^3/s$$

Table 6. Peak Flood Discharge Synthetic Unit Hydrograph SCS and Snyder

Return Periods	HEC-HMS (SCS) m^3/s	HEC-HMS (Snyder) m^3/s
2	203,50	181,10
5	249,30	209,70
10	275,61	232,20
20	301,10	253,50
25	308,60	259,90
50	331,00	273,50
100	353,30	298,40
200	372,90	324,30

Based on the value of each return flood discharge, the result of a bankfull discharge is close to the 10 year return period of 275.61 m/s (in the HSS SCS method). The results of the return discharge for each Subdas Sadar River will be the input of the return discharge for the hydraulics calculation using HEC-RAS with 1 dimension and 2 dimension.

5.4 Hydrolic model Analysis
Hydraulic analysis was carried out for modeling flood conditions at Sadar River. The modeling is done using software [4] for the unsteady flow type with 1 dimension. Data used cross section measurement data in 2019 for the main river of Kali River at Sta.0+000 to Sta.23+000. Data for the cross section of tributaries are not available, so the modeling is only on the main river. The 25 and 50 year return discharges for each sub-basin (tributary) will be included as a boundary with the lateral inflow hydrograph at several points of the upstream boundary at the confluence. Tributaries of sub-catchment area 1 and 3; STA 1+100 : Lateral inflow Flood hydrograph at the confluence of sub-catchment area 2 tributaries; STA 4+200 : Lateral inflow Flood hydrograph confluence of tributaries of sub-catchment area 4; Sta 12+450 : Lateral inflow Flood hydrograph at the confluence of sub-catchment area 5 tributaries; Sta 18+400: Lateral inflow Flood hydrographs of sub-catchment area 6 and sub-catchment area 7; Sta 20+350 : Lateral inflow Flood hydrograph Confluence of tributaries of sub-catchment area 8; and the downstream boundary with the water level of the outlet river, namely the Porong River, the results of field measurements are 8.8 m. Input 3 movable weir with a full door opening operation pattern during a flood with the number and height of door openings for the Wonoayu Weir at sta. 4+950 with 6 gates with openings of 3.28 m high; Weir Tinggar Buntut at sta. 9+650 with 8 gates with openings of 3.35 m high; Balong Masin Weir at sta. 18+620 with 10 gates with openings of 3.18 m high.

According to the modeling results, the water discharge from the upstream to the center reaches a height of 0.8 m in the middle of Sta 12+150 after a 25-year return time. The majority of the runoff occurred in the middle of the river over the 50-year return period, with the largest discharge of 1.15 m at sta 12+150.

The spread of floods that occurred in the Sadar River watershed was determined using 2-dimensional modeling. The data was collected using DEM data from Sadar River with return discharges of 25 and 50 years, resulting in a distribution of floods in the middle of the river that was similar to that found in the 1-dimensional flood distribution modeling shown in Figure 7.

The worst inundation occurred in the middle of the river, this can be calibrated with the results of flood inundation in the field which was severe also in the middle of the river, because there were input discharges from several tributaries. Changes in water level at station 12+000 (middle part) at an elevation of 16,6 m with a maximum water level of 2,1 m as shown in Figure 8.

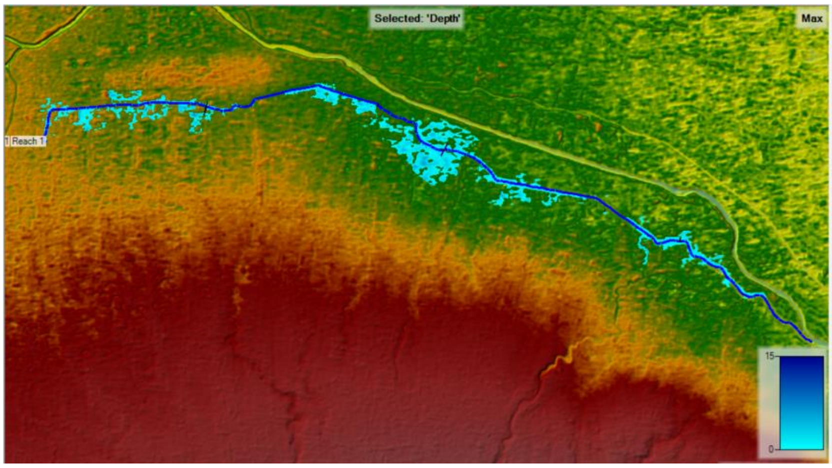

Figure 7. Distribution of the Sadar river flood inundation

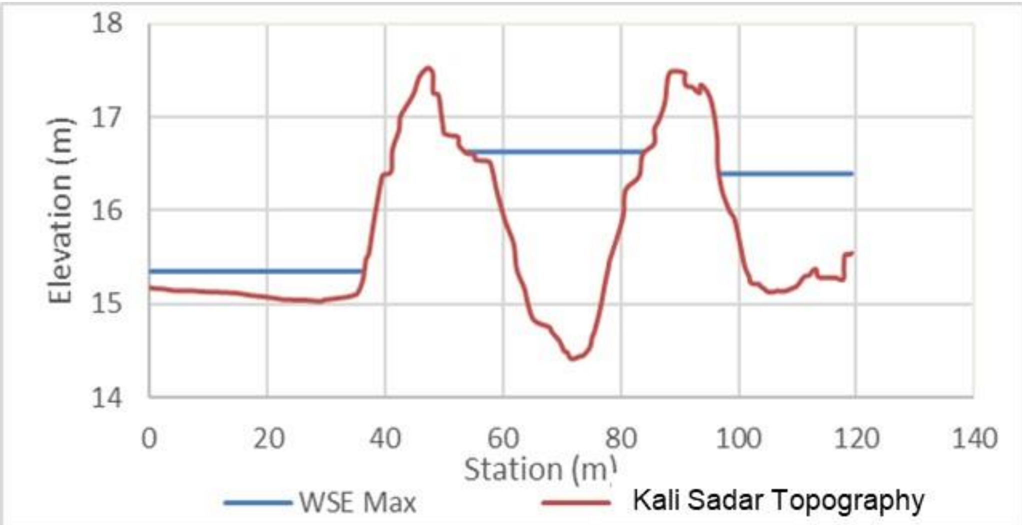

Figure 8. Water surface elevation on cross section station 12+000

5.5 Sediment Transport Analysis

Sediment modeling is geometrically the same as hydraulics modeling [3], but using different discharge inputs with 2 scenarios, namely using daily discharge from data and sediment input in the field at 7 points along the river and the floating sediment rating curve in the upstream river as shown in Figure 9. The modeling input layout in Figure 10.

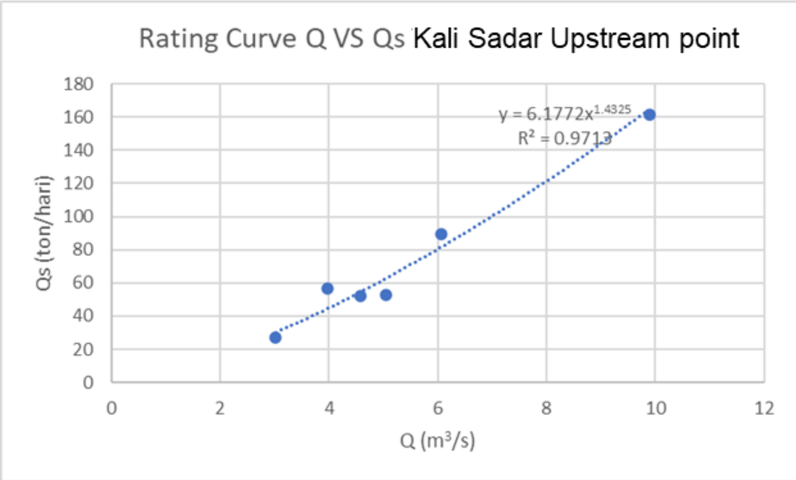

Figure 9. Rating Curve suspended sediment

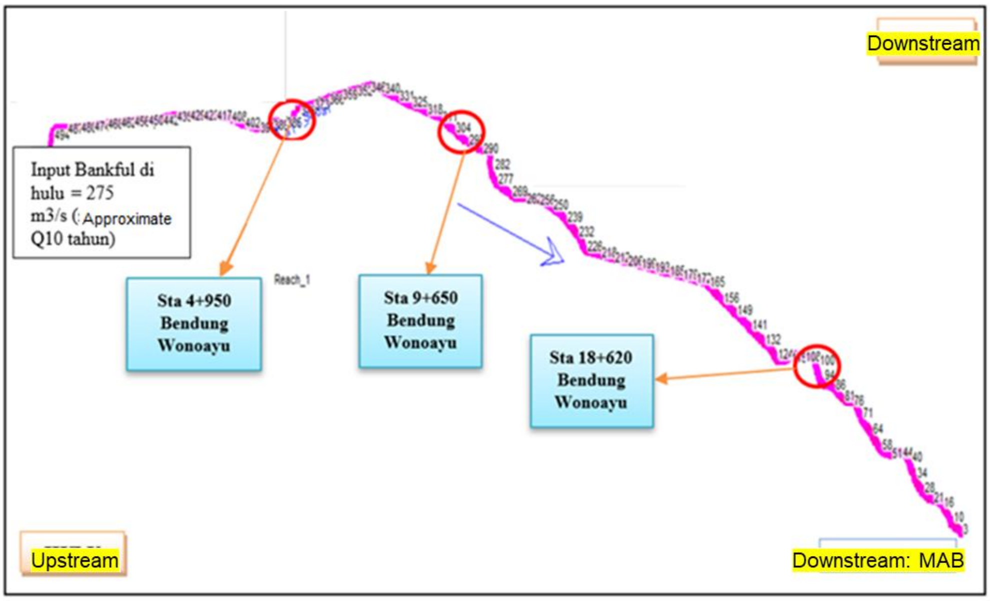

Figure 10. Sediment Transport Analysis modelling scheme

5.5.1 Sediment Transport Analysis Simulation 1

Simulation I used the Engelund Hansen method to estimate sediment transport utilizing daily flow from observation discharge for a year (2018), and the findings were in line with field discharge. The primary sediment grain size is sand. Figure 11 depicts the results.

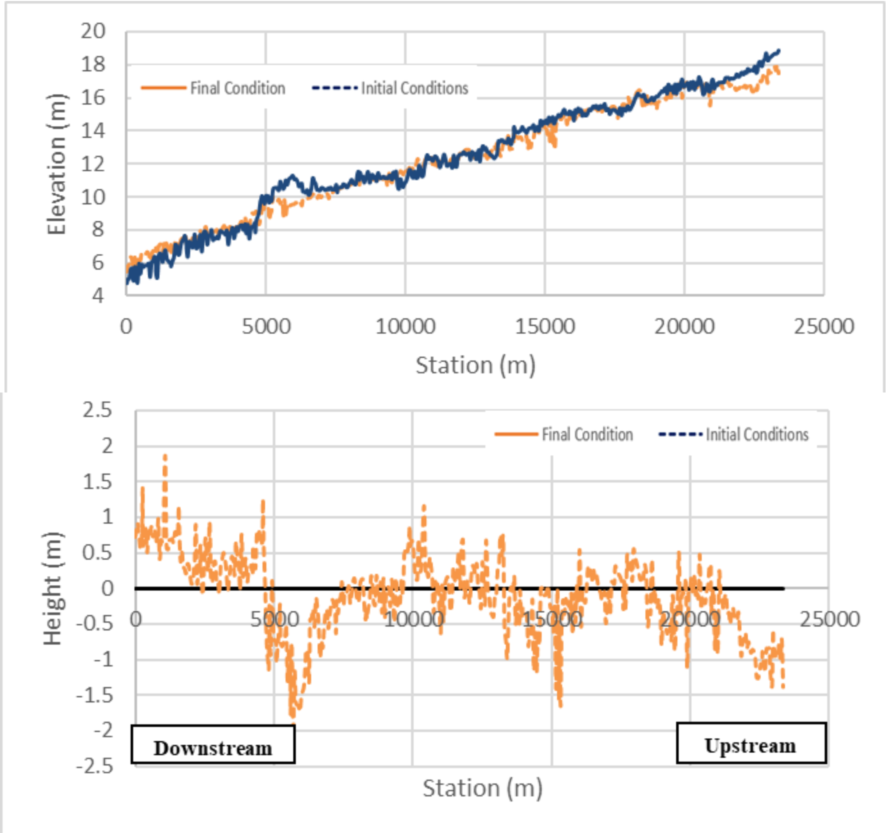

Figure 11. *Change of riverbed with daily discharges*

The total sediment transport rate is 11,267 tons/year, based on modeling findings with daily discharge for a year. There is upstream deterioration with a maximum height of 2 m and downstream degradation (sedimentation) with a height of 1.8 m. The largest annual cumulative sedimentation along the Sadar river was 5,097 tons. The steep slope upstream of the river causes strong flow velocity, which erodes the riverbed, resulting in dominant degradation upstream from Sta 0 to Sta 3+600 with a total degradation of 3,602 tons/year and a deteriorated volume of 27,500 m^3. While the majority of sedimentation occurs in the river's downstream section, between sta 19+000 and sta 23+000 (downstream of the river), this is due to the river's gentle slope and sediment output from eight subwatersheds that flow into Sadar river, with a total sediment volume of 73,741 m and a total sediment volume of 105,100 tons per year. A total of 511 tons of sediment is deposited annually downstream of Sadar River. The volume of silt entering the river is 50,806,972 tons per year, and the volume leaving the river is 50,806,859 tons per year, resulting in sedimentation of 112 tons per year. The river receives 77.2 percent of the total land sediment in the Sadar River Basin, which is 65,804,107 tons per year.

5.5.2 Sediment Transport Analysis 2

Simulation II of sediment transport modeling uses a bankfull discharge for 1 year of 275 m^3/s. The results are shown in Figure 12.

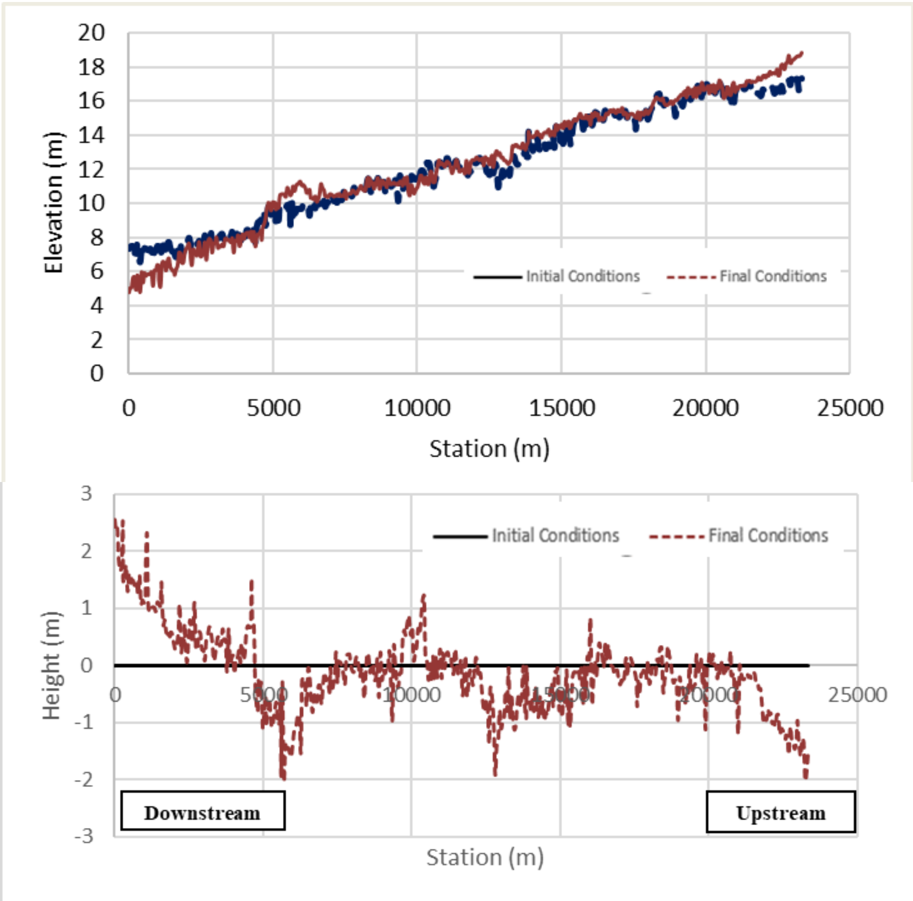

Figure 12. Change of riverbed with Bankfull Discharge

The total sediment transfer rate is 39,612 tons per year, based on modeling results with a bankfull discharge of 203.5 m^3/s for a year. The average height of upstream degradation is 1.5 meters, with a maximum height of 2 meters. With an average height of 1.45 m and a height of 1.55 m, aggradation (sedimentation) occurred downstream. The largest annual cumulative sedimentation along the Sadar river was 6,939 tons. The steep slope upstream of the river causes high flow velocity, which erodes the riverbed, resulting in dominant degradation from Sta 0 to Sta 3+600 with a total degradation of 10,577 tons/year. Meanwhile, sedimentation occurs primarily downstream of the river, from sta 18+750 to sta 23+000 (downstream of the river), due to the gentle slope of the river and sediment output from eight subwatersheds that flow into Sadar river, with a total sediment volume of 96,400 m^3 and a total sediment volume of 138,700 tons per year. The Sadar River deposits 1,324 tons of sediment every year downstream. The total sediment entering the river is 62,913,881 tons per year, while the total sediment leaving the river is 62,913,167 tons per year, resulting in a sedimentation rate of 713 tons per year. The river receives 95.60 percent of the total land sediment in the Sadar river watershed, which is 65,804,107 tons per year.

5.7 Result of Study

The largest aggradation and degradation results are obtained from the modeling results with Bankfull discharge. The solution that can be given is to maintain the river by dredging, where the total sedimentation volume along the river is 2,977 m^3, which needs to be dredged periodically every year to maintain the volume of the Sadar river storage capacity. In the Table 7 below, the points that need to be dredged are listed.

Table 7. Volume of sediment dredging for 1 year

Sta	Overflow height (m)	Volume sediment (m^3)
3+750	0.13	384
6+700	0.76	966
7+400	0.28	493
8+550	0.22	289
9+600	0.4	439
11+950	0.2	340
	Total	**2.911**

6. Conclusions

The following conclusions can be drawn from the findings of the various studies such as the bankfull discharge for the Sadar River capacity is 275 m^3/s, or the discharge of the 10-year return period. Flooding occurs in the upstream and middle of the channel because the cliffs are lower, and downstream areas are able to accommodate flood discharges for 25 and 50 year return periods, according to the results of the Hec-Ras 1D simulation for flood discharges for 25 and 50 year return periods. The flood distribution occurred in the upstream and middle of the river, with the highest occurring at sta 11+000 with a water level of 2.1 m. The maximum sediment size of the Sadar River from the modeling results is 6,939 tons/year with a total sediment transport rate of 39,612 tons/year. The total sediment deposited downstream of the river is 1,324 tons/year with a total sediment transport rate of 39,612 tons/year. The river receives 62,913,881 tons of material every year, accounting for 95.60 percent of the total sediment in the Sadar river watershed. Based on the modeling results, operations and maintenance in the form of dredging sediment on multiple parts with a total dredging of 2,911 m^3 must be performed on a regular basis.

7. References

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