Study of Loji Riverbed Change in Pekalongan City

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Abstract. Uncontrolled changes in river due to erosion and sedimentation will eventually reduce the capacity of the river and the sustainability of infrastructures along the river. Therefore, it is essential to understand the bed change pattern to unravel the mechanism of sediment transport in the river. Previous studies on Loji River in Pekalongan City are mainly related to flood control and have not elaborated on the river morphology. This study is aimed to analyse the riverbed change based on riverbed comparison and long-term prediction to provide insight into the river morphological problem, in order to reduce the impact of erosion and sedimentation. The riverbed data used for comparison is of 2018 and 2021, within 5 km from downstream. The long-term sediment transport simulation is conducted using HEC-RAS for eight years period. The results revealed that within 2018 to 2021 the erosion and sedimentation occur in the river, consisting of a maximum of 1.43 m thick deposition and -1.22 m of erosion from the initial bed. Long-term simulation results indicated that there is significant reduction of river capacity. Thus, future research direction is proposed to reduce the impacts of aggradation and degradation for the more resilient river infrastructures.
Keywords: river morphology, sedimentation, erosion

1. Introduction

Rivers are dynamic natural phenomena that can respond to changes by nature and man-made engineering in the river environment. The response in the form of changes in river morphology will have long-term implications for flood protection. Uncontrolled changes in river due to erosion and sedimentation will eventually reduce the capacity of the river and the sustainability of infrastructures along the river. Therefore, it is essential to understand the bed change pattern to unravel the mechanism of sediment transport in the river.

The City of Pekalongan, most of which is part of the Kupang watershed, experiences flooding every year, especially in the northern region, downstream of the Loji River. Pekalongan is one of the important cities in Central Java Province. Located on the northern coast of the island of Java, Pekalongan often experiences flooding. The floods inundated residential areas near the coastal zone and the extent of the affected area increases from year to year. Coastal area of Pekalongan becomes subject to flooding as a combined result of high rainfall, land use changes, changes in river cross-section, and unusually high tides (Rahmawati and Ardhiani, 2008). In the northern part, the surface is lower than sea level, so it is difficult for water to flow into the sea. Most of those areas are inundated during high tide (Wahyudi, S, Imam, 2010).

Loji River is one major river flowed through Pekalongan which has a significant contribution on flooding in the city. This river is the main river of Kupang Watershed, a part of Pemali Comal Watershed Management. With the upstream located at the foot of Mount Rogojembangan in Pekalongan City, the river passes through Pekalongan City to the Java Sea and influences the development of urban areas along the river.

Previous studies on Loji River in Pekalongan City are mainly related to flood control and have not elaborated on the river morphology. Based on previous studies, the capacity of the Loji river cannot accommodate flood discharge from upstream and is exacerbated by high tides, so that a floodway was built from Loji River to the Banger River. The floodway becomes one of the largest artificial rivers in Pekalongan City and is expected to be sufficient to drain the flow discharge. Flood discharge flowing from upstream part known as Kupang River. Banger River can reduce the water level in the Loji River so the flooding in Pekalongan city will be decreased. However, the increasing sedimentation in the river due to land use change in the basin area could reduce the capacity of the river. This study is aimed to analyse the riverbed change based on riverbed comparison and long-term prediction to provide insight into the river morphological problem, in order to reduce the impact of erosion and sedimentation.

2. Methodology

The methodology in this study consisted of two main stages:

- Comparison of 2018 and 2021 riverbed data
- Riverbed change prediction

2.1. Comparison of riverbed

The morphological changes were analysed using geographic survey data from Pusdataru Central Java Province (2018) and BBWS Pemali Juana (2021). Comparison of riverbed was obtained from the data of 2018 and 2021. The riverbed elevation was plotted within 5 km from the downstream. The output is the information of riverbed change in the form of aggradation and/or degradation at certain locations along the river.

2.2. Riverbed change prediction

Riverbed change prediction was performed by sediment transport simulation using HEC-RAS. The simulation was carried out using Quasi Unsteady Flow conditions with the input of daily discharge data as the upstream boundary condition and water level data as the downstream boundary condition. The geometric data used was obtained from measurements of the Loji River performed by Pusdataru Central Java Province in 2018 and computed in HEC-RAS to get new geometry data of 2021 by sediment transport simulation. The modeling results are validated with 2021 field data. The new geometry is used to simulate riverbed change for 2022-2029 period. The input data for sediment was from primary data taken in the field in the form of bed material and sediment rating curves as the boundary condition. The bed materials were taken in 6 locations (Fig. 1). The sediment rating curve was computed by sediment load analysis.

Figure 1. Bed material sample locations

In estimating sediment load in the river, direct sediment load measurement would give better result. When there is not enough primary data of sediment in the river, the sediment load can be estimated by determining land erosion and sediment delivery ratio (SDR). Prediction of land erosion level was obtained from the USLE formula:

$$A = R \times K \times L \times S \times C \times P \qquad (1)$$

where:
A = computed soil loss per unit area
R = rainfall and runoff factor
K = soil erodibility factor
L = slope-length factor
S = the slope-steepness factor
C = the cover and management factor
P = the erosion-control practice factor

The parameter in the USLE formula could be determined from the topographic map data, land use, soil types, precipitation data, and land management data. The data was then processed using rasterbased GIS software to predict erosion levels. In this phase, the data used was a DEM (Digital Elevation Model) map to determine the LS factor, land cover to determine the C factor, land management for the P factor, regional rainfall for the R factor, and the soil type for the K factor.

The comparison of measured sediment in waterways or rivers and erosion in the land is called sediment transfer ratio, sedimentation potential, or sediment delivery ratio. USDA has issued guidelines on which SDR is highly dependent on watershed area, but there is no accurate method to estimate SDR [1]. The larger the watershed, the smaller the SDR as the large watershed provides more opportunities for the deposition of soil particles before reaching the river [2].

There are three SDR equations:
Vanoni (1975) $SDR = 0{,}4724\ A^{-0{,}125}$,
Boyce (1975) $SDR = 0{,}3750\ A^{-0{,}2382}$,
USDA SCS (1972) $SDR = 0{,}5656\ A^{-0{,}11}$.
Thus, one year of sediment production for the A km^2 watershed area can be formulated as:

$$S - pot = EA(SDR) \quad (2)$$

where:
S-pot = Yearly sediment production
SDR = Sediment Delivery Ratio
EA = Total erosion per unit area
A = Watershed area (km^2)

SDR can also be determined using a list from Ministry of Forestry giving SDR value based on watershed size. The list as in the table below.

Table 1. SDR value according to watershed size

Watershed area (ha)	SDR (%)
10	53
50	39
100	35
500	27
1,000	24
5,000	15
10,000	13
20,000	11
50,000	0.85
260,0000	0.49

3. Result and Discussion

3.1. *Riverbed Change (2018-2021)*

The riverbed data of 2018 and 2021 showed deposition and erosion along the river (Fig. 21). The sediment particles upstream have been transported downstream. Notably, a comparison of the 2018 and 2021 data indicates that aggradation came about in general except at the outer of the bends, consisting of a maximum of 1.43 m thick deposition from initial bed at 3,700 m from the river mouth (Fig. 4). In 2021, the riverbed at 3,600 m from downstream was lowered by about 0.9 m, owing to the erosion at the outer of the bend. A geographic survey in 2021 indicated a maximum erosion depth of about 1.22 m at a location 1,100 m upstream of the river mouth (Fig. 3). However, according to PPNP (2021) there was artificial dredging work that had been undertaken around the fish port at approximately 1,100 m from downstream to the river mouth for navigation purpose. The dredging volume was known to be around 14,000 m^3 per year but the authors could not find the exact dredging depth and range. Thus, the degradation around that location might be because of the dredging work.

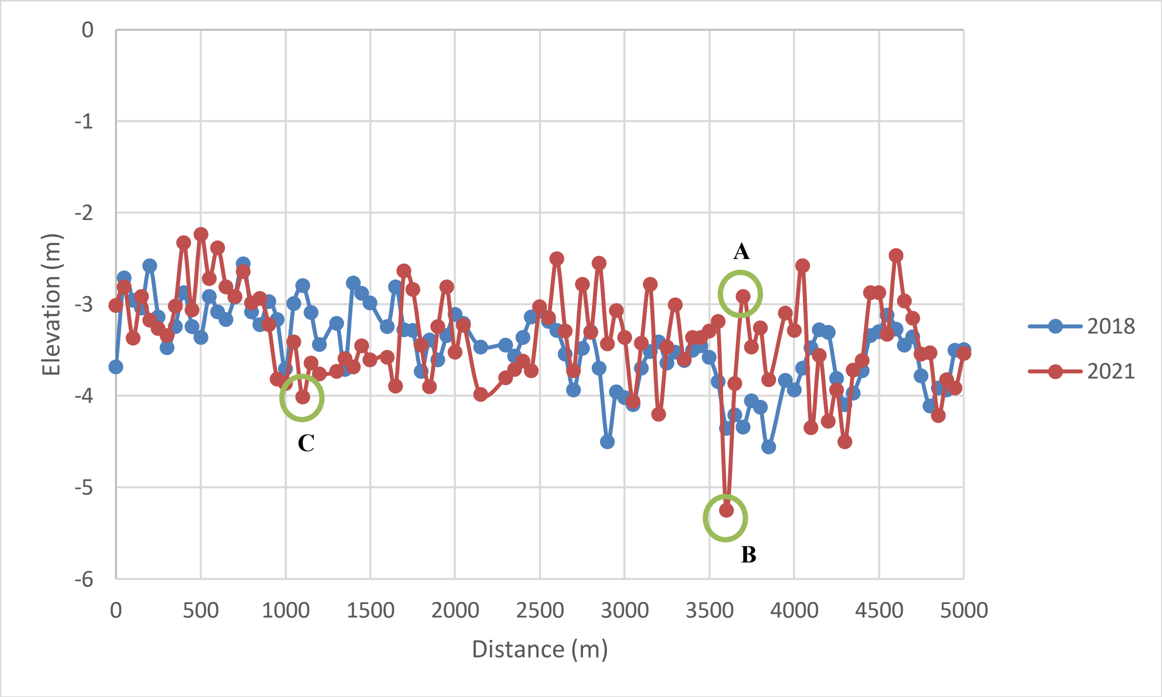

Figure 2. Loji River bed change from 2018 to 2021

Figure 3. Loji River layout

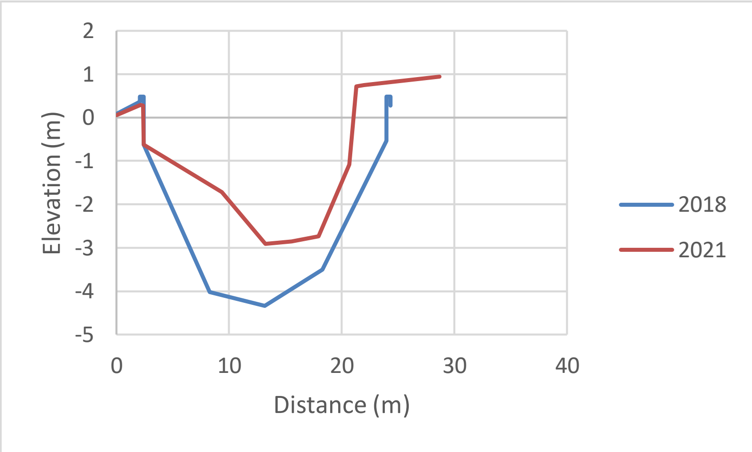

Figure 4. Aggradation at A (Sta. 3+700)

3.2. Riverbed Change Prediction (2022-2029)

Based on grain size analysis of bed material samples from the field, the results are as in the Figure 4. From these results, the sediment in Loji river is cohesive as most of the D50 size are less than 0,062 mm. Therefore, the sediment transport simulation in HEC-RAS has to be performed with cohesive option feature.

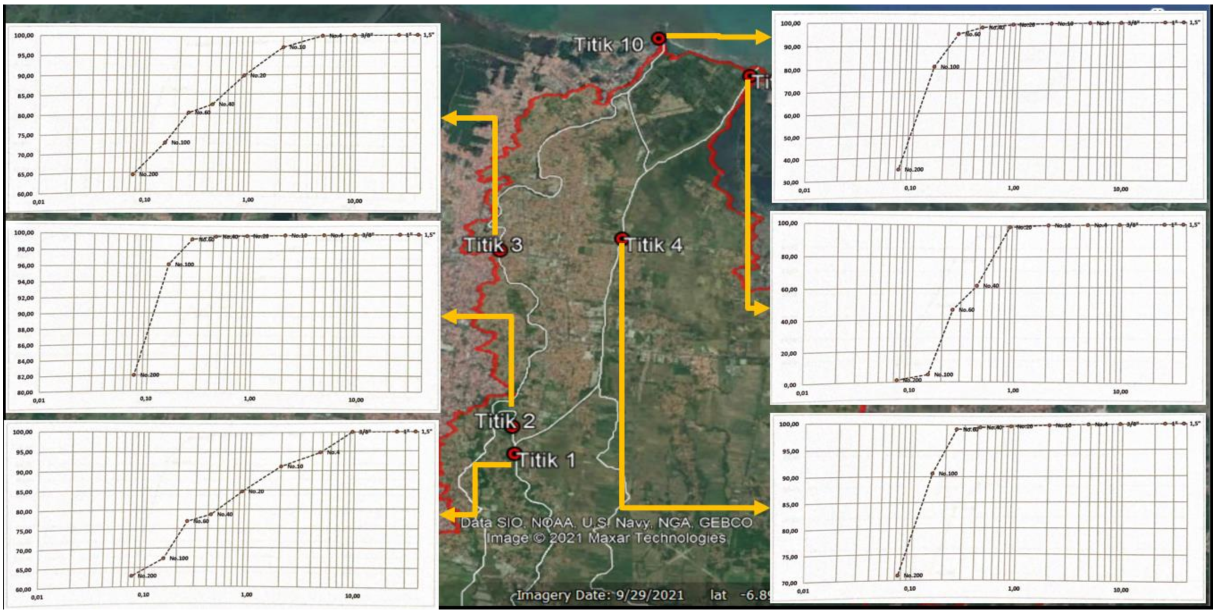

Figure 4. Bed material grain size distribution

For sediment load analysis, the SDR is 12% as the watershed area is between 10,000 and 20,000 ha. The sediment rating curve obtained by computed mean discharge of 2002-2019 and sediment load can be seen in Figure 5. The sediment transport simulation in HEC-RAS was performed with cohesive option feature by inputting shear threshold and erodibility rate. These values should have been obtained by laboratory test but as it was not carried out in this study, the value was assumed according to relevant studies.

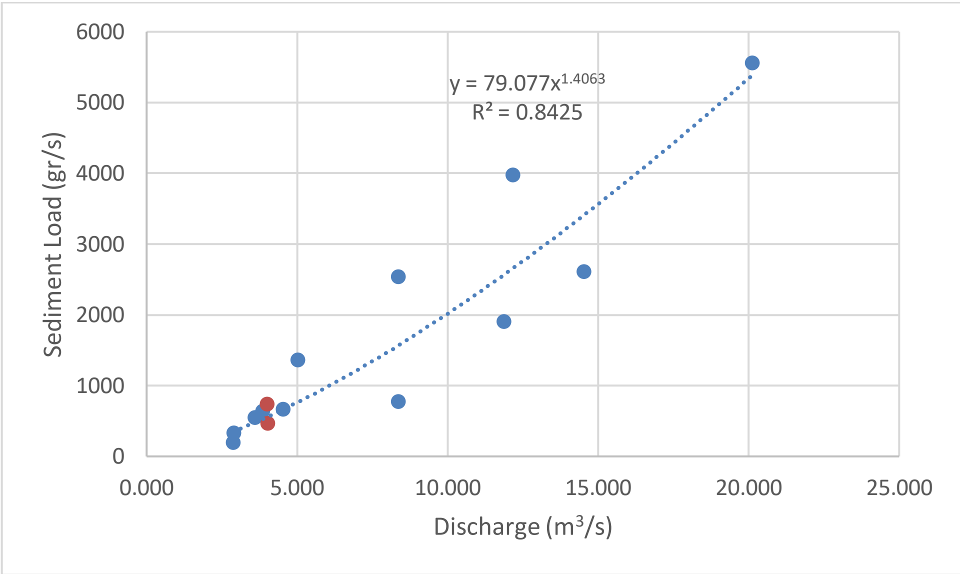

Figure 5. Sediment rating curve

The simulation result as in Figure 6 was validated by 2021 field data. The bed change obtained from the model was similar to the field data but the aggradation along 2,000 km from the river mouth was underestimated as HEC-RAS could not computed flocculation phenomenon.

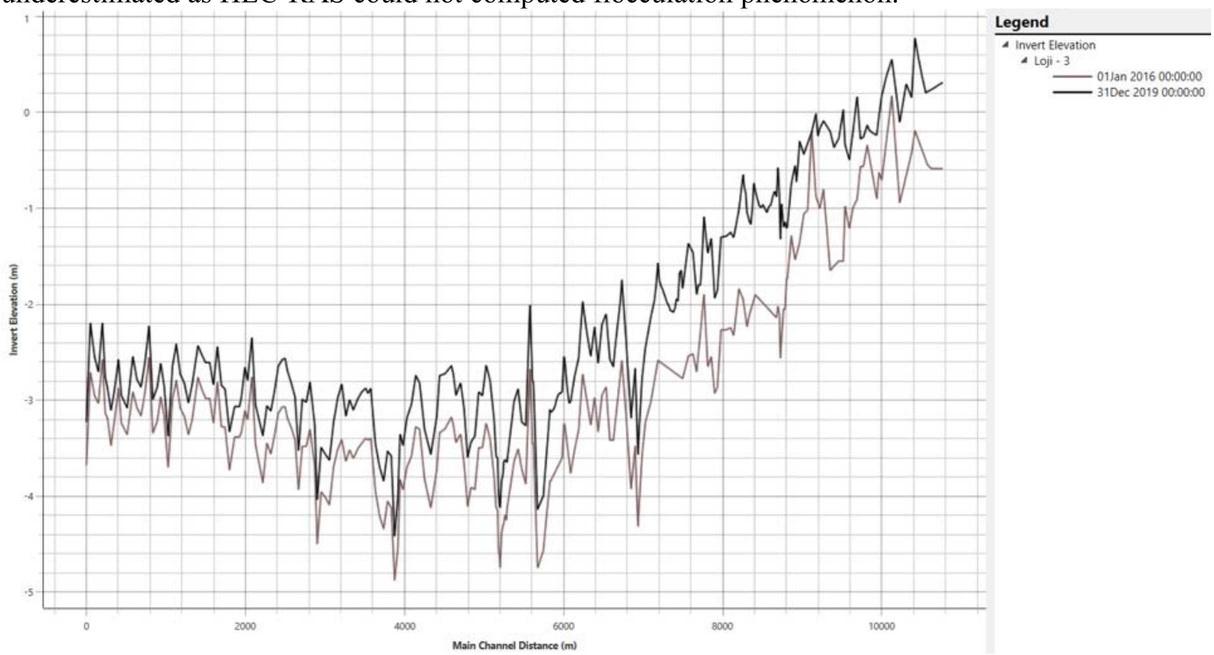

Figure 6. Riverbed change of 2016 - 2019 simulation result

The new riverbed was created from those results and used to simulate sediment transport for the period of 2022 to 2029. The daily discharge for 2022 to 2029 was assumed to be the same as previous years. The riverbed change result can be seen in Figure 7 and Figure 8. Aggradation occurred with the maximum of 1.85 m thick deposition, reducing the river capacity that could increase the risk of flood in Loji River.

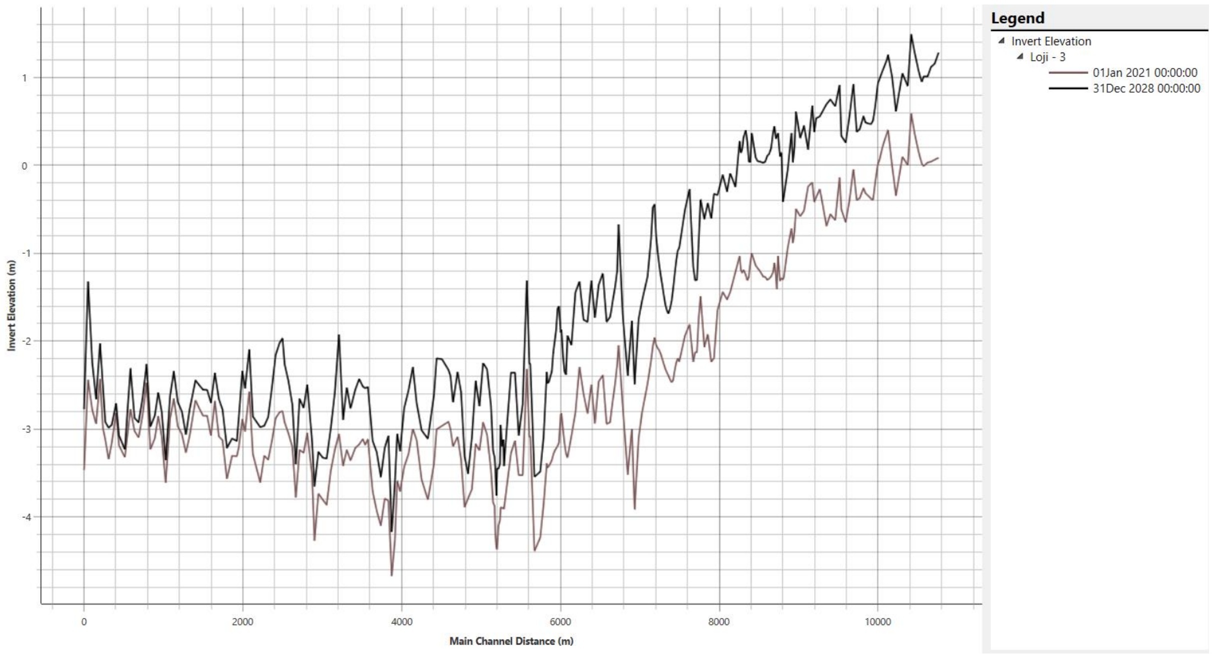

Figure 7. Riverbed change of 2022 - 2029 simulation result

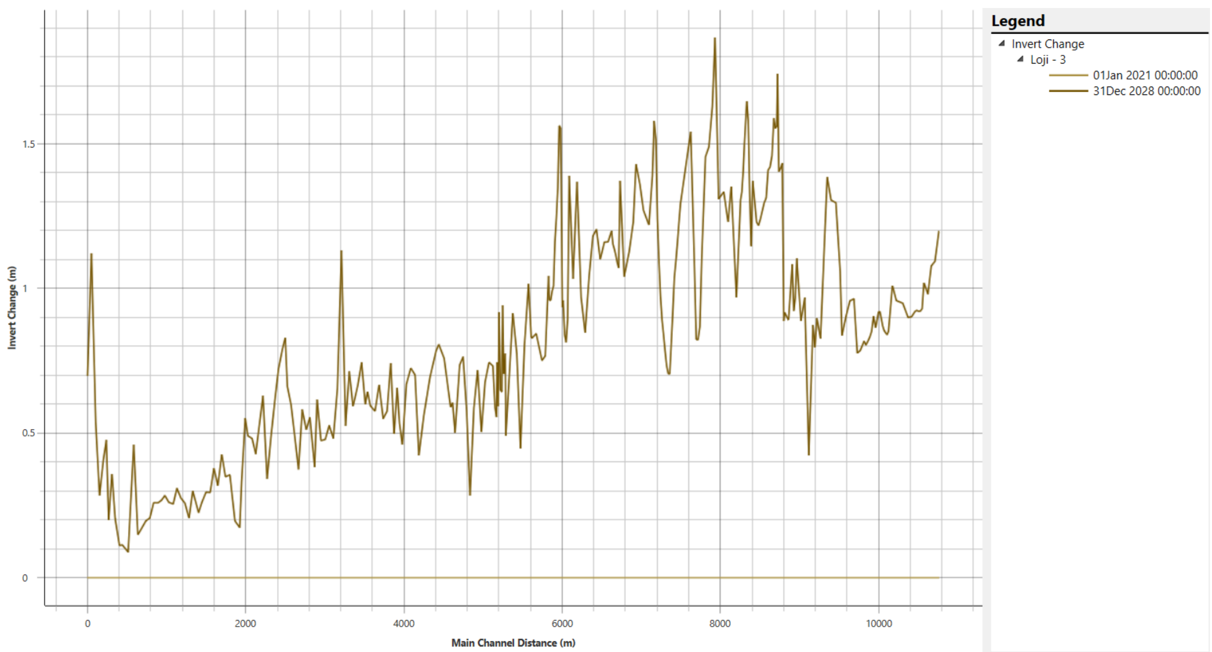

Figure 8. Riverbed change of 2022 - 2029 simulation result

4. Conclusion and Recommendation

Based on the comparison of 2018 and 2021 riverbed data, in general, aggradation occurred along the river due to sedimentation, consisting of a maximum of 1.43 m thick deposition. Degradation came about at the outer of the bends with a maximum erosion depth of about 1.22 m from the initial bed. Long-term simulation results indicated that the aggradation increased to maximum of 1.85 thick deposition, reducing the river capacity. Thus, future research direction is proposed to reduce the impacts of aggradation and degradation for the more resilient river infrastructures.

For improving the precision of cohesive sediment transport modelling, it is recommended to take more sample data of bed material, analyse the fine grain size distribution using hydrometer and also investigate the sediment properties by performing shear stress test. The data sampling of sediment load should also be conducted using standardized tools and taken in both rain and dry season to obtain more accurate result of sediment rating curve.

References

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