The development of sediment bypass channel for sediment management in the Brantas River Basin, Indonesia

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Abstract

Wlingi and Lodoyo reservoirs are major reservoirs on the mainstream of the Brantas River. Both reservoirs have problem on severe sedimentation due to eruption of Mount Kelud, one of the most active volcanoes in Indonesia. Countermeasures such as sediment bypassing, flushing are conducted to encounter the sedimentation in Wlingi and Lodoyo. Construction of sediment bypass channel is a long term countermeasure to prevent the lahar sediment inflow from entering Wlingi reservoir after eruption of Mount Kelud. To prevent the Putih River's lahar sediment from entering Wlingi reservoir, the sediment-laden flow of the Putih River was diverted to the Siwalan River by bypass channel of about 3.2 km length completed in 1991. The bypass channel reduced sedimentation in Wlingi reservoir but shifted it downstream to Lodoyo reservoir. An extension of the bypass channel from the Siwalan River to the Brantas River downstream of Lodoyo dam was completed in 2011. The completed bypass channel and lower extension is 7.2 km long. In the future, the extension of bypass channel to divert sediment from the Lekso and Jari River in the upstream of Wlingi reservoir needs to be developed. This paper will discuss the development of bypass channel in the Brantas River basin to manage sediment in the basin general and to promote sustainable use of Wlingi and Lodoyo reservoirs in particular.

Keywords: bypass channel, Lodoyo Reservoir, impact, lahar flow

1 Introduction

Wlingi and Lodoyo dam are located in Brantas River Basin, Indonesia. Both reservoir provide numerous benefits including reliable irrigation water supply, flood control, electricity generation, fisheries and particularly for flood control. Wlingi dam located in southern area of Mt. Kelud and has 2.890 km^2 catchment area. After it completion in 1977, the sedimentation rate rapidly increase with the annual sedimentation till 1988 reach to 1.3 million Cm. After Kelud eruption in 1990, about 57.3 million Cm volcanic material spread around the area surround. As a result, Wlingi storage capacity depleted till about 1.60 million Cm or 6.7% from its original capacity.

Lodoyo reservoir was constructed in 1983 with initial gross storage volume was 5.8 million Cm. the corresponding effective storage volume was 4.2 million Cm between the HWL 136.0 m and the LWL 130.5 m. Sedimentation in Lodoyo reservoir is mainly caused by sediment outflow from Wlingi, with additional sedimentation load from Siwalan river, and Putih river.

Kelud volcano is a small stratovolcano with summit elevation at 1731 m above sea level, located at about 27 km from Kediri City, lies between the volcanic massif of Gunung Wilis to the West and the complex of Kawi and Butak volcanoes to the East. The 1586 eruption produced one of the worst lahar in the historical record of volcanic eruptions. Since AD 1300, the periods of inactivity between eruptions range from 9 to 75 years (Kusumadinata 1979, Thour et al. 1998). All recent eruptions were very similar and were characterized by a very short duration (a few hours) and a low volume of eruptive products (0.1 – 0.2 km^3). Kelud eruption produced devastating lahars, pyroclastic surges and flows as well as ashfall deposits. Without debris control structures, up to 50 percent of the volcanic sediment is eventually carried into Brantas river. As a result, the bed level of the river has risen and severe flooding occurs during the rainy season.

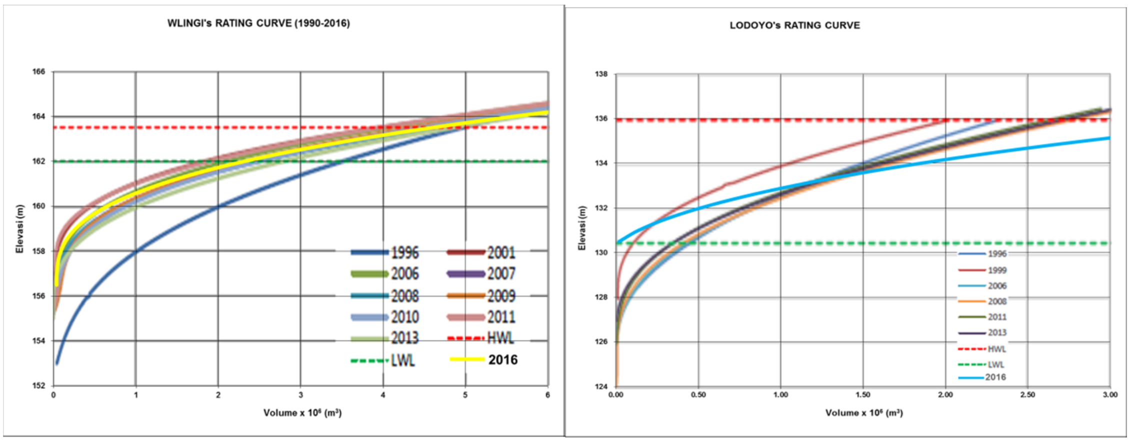

Fig. 1: Historical rating curve of Wlingi reservoir (left) and Lodoyo reservoir (right)

2 Sedimentation due to Kelud eruption in 2014

In the past, sedimentation in Wlingi reservoir is mainly caused by sediment-laden flood from the major tributaries to Brantas River, i.e the Putih, Jari, Lekso and Semut Rivers, which drain the southern slopes of Mt. Kelud. After the completion of sediment bypass channel 1^{st} stage in 1991, the water and sediment flows from Kali Putih river no longer contribute to Wlingi reservoir.

On 13 February 2014, one and a half hour after the government rose the danger level of volcanic activity, at 22:50 (local time), a Plinian eruption took place. Ash fell in the region in all direction from the vent. This eruption created an eruption column that reached ~ 25 km and that was distributed almost on half of Java island. After the 2014 eruption, about

50×10^6 m^3 of material was deposited on the upper slope of Kelud Volcano. This material has then been remobilized by rainfalls and generated lahar along the river under Kelud Volcano. In 18 February 2014, first lahar after Kelud eruption 2014 was occurred in several rivers (Kali Ngobo, Mangli (Kediri), Kali Bladak (Blitar), and Kali Konto (Kediri-Malang)). Then it followed by secondary lahar which observed in Kali Icir, and Kali Lekso.

Table 1: Sedimentation in Wlingi reservoir

Survey Years	Total Storage		Sediment Deposit
	Million m³	%	Million m³ year-1
1977	24.00		
1982	18.32	76.33%	1.14
1985	14.44	60.17%	1.29
1988	9.50	39.58%	1.65
1990	4.60	19.17%	2.45
Mt. Kelud Eruption in 1990			
1990	1.60	6.67%	18.00
1991	4.77	19.88%	-3.17
1992	2.51	10.46%	2.26
1993	1.98	8.25%	0.53
1995 Pre Flushing	4.63	19.29%	-1.33
1995 Post Flushing	4.94	20.58%	-0.53
1996 Pre Flushing	5.33	22.21%	-1.17
1996 Pre Flushing	5.75	23.96%	-1.68
2001	3.97	16.54%	0.36
2004	4.41	18.38%	-0.15
2006	4.00	16.67%	0.21
2011	4.42	18.42%	-0.08
2016	4.59	19.11%	-0.03

Table 2: Sedimentation in Lodoyo reservoir

Survey Years	Total Storage		Sediment Deposit
	Million m³	%	Million m³ year-1
1983	5.20		
1990	3.69	70.96%	0.22
1993	2.84	54.62%	0.28
1996	2.35	45.19%	0.16
2003	2.03	39.04%	0.05
2008	2.78	53.46%	-0.15
2009	2.67	51.35%	0.11
2010	2.67	51.35%	0.00
2011	2.65	50.96%	0.02
2016	4.11	79.08%	-0.29

3 Sedimentation countermeasures in Wlingi and Lodoyo reservoir

Sedimentation management was implemented till today can be categorized as:

- Watershed management through conservation activities.
- River bed management activities to reduce sediment inflow in reservoir, i.e. check dam construction and sabo dam rehabilitation. Besides that activities, sediment

diversion also developed to reduce sedimentation. Bypass channel construction is one of those countermeasures.

- Reservoir sedimentation management through dredging and flushing activities.

Sediment inflow reduction involve several activities in upstream areas such as soil conservation, erosion control on farm, and consolidation dam construction. Sediment bypassing which connected Putih river to Glongdong river was completed in 1991 and the lower extension which connect to downstream Lodoyo reservoir was completed in 2011. So, this bypass channel also help reduce the sedimentation in Wlingi and Lodoyo reservoir. The dredging and flushing activities in Wlingi and Lodoyo reservoir can be seen in the table below.

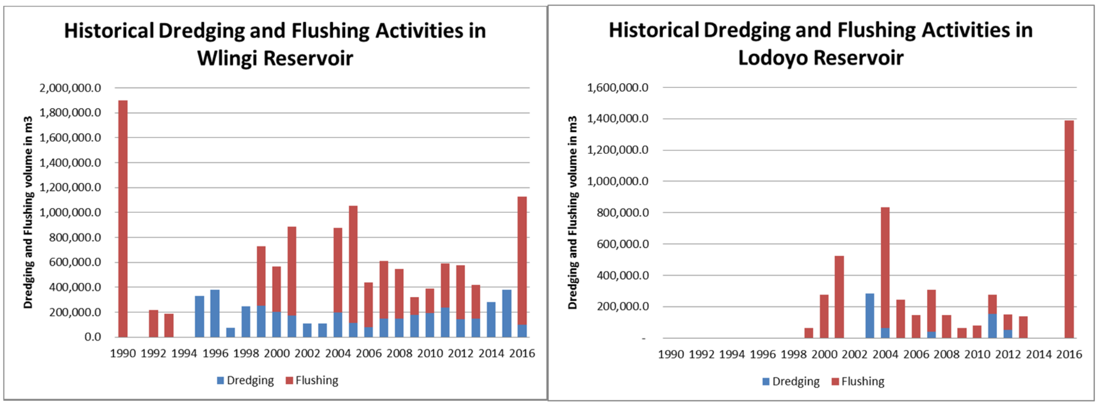

Fig. 2: Historical dredging and flushing activities in Wlingi reservoir (left) and Lodoyo reservoir (right)

The strategy to reduce the sediment inflow from upstream of Wlingi and Lodoyo reservoirs by debris control facilities has been implemented very effectively. Flushing activities which was conducted from 1990-2016 has been resulted on 2,413,882 m^3 sediment flushed from Wlingi and Lodoyo reservoir.

4 Sediment bypass channel to prevent lahar sediment inflow

Bypass channel development is one of measures to control river bed slope in the sediment production areas, control lahar flow direction, localize the spread flow direction, stabilize the bed level of rivers on the lahar plain, and restrict the amount of sediment that may enter the Brantas River. Sediment carried by Kelud streams has caused the bed level of the Brantas to rise by as much as 1.5 metres per year (Nippon Koei 1978). As a result, severe flooding occurs and low-lying areas near the river are constantly waterlogged during the rainy season. The debris control structures along the Kali Putih River help reduce the sediment load carried into the Brantas River.

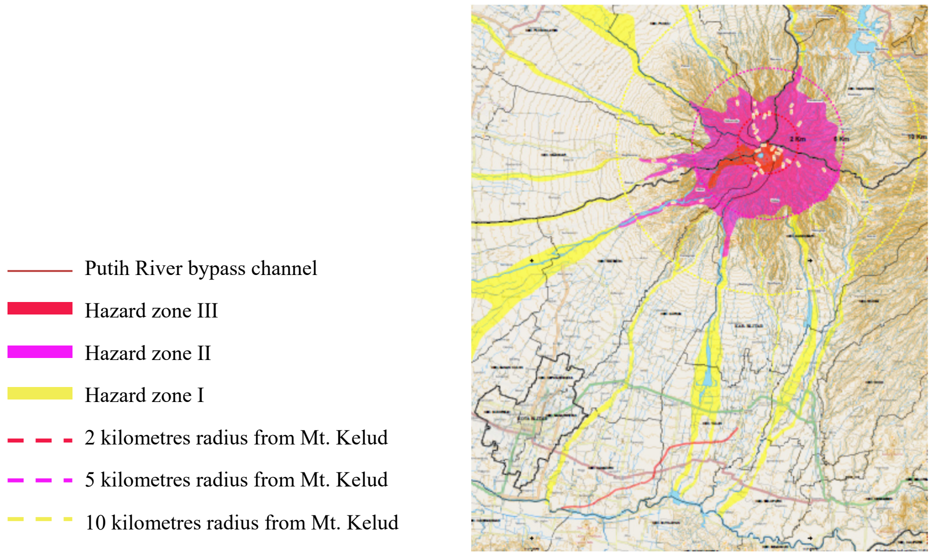

Fig. 3: Mt Kelud eruption hazard map

Through the development of this sediment bypass channel, the sedimentation from Kali Putih and Kali Ganggangan would flow to Wlingi and Lodoyo reservoir. Lahar from Mt Kelud, which resulted from any eruption in the future, also can be diverted to Lodoyo's downstream area so it can't severe the sediment load in both reservoir.

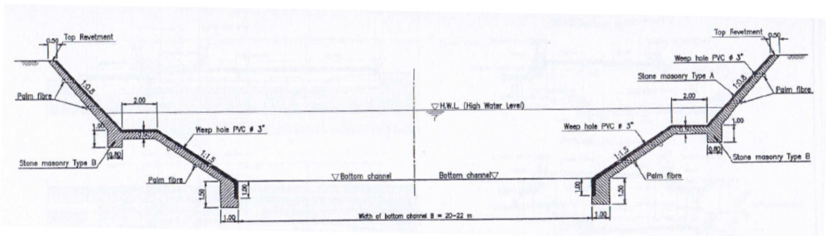

Fig. 4: Typical cross section of Kali Putih sediment bypass channel

5 Material and method

In May 2015, we collected bed sediments from Wlingi and Lodoyo reservoirs. Grab samplers used to collect surface sediments in both reservoirs. Inflow recording, rainfall observation, and field surveys also carried out in Jari River, Lekso River and Putih River, in March 2014, April 2015, February 2016, and February 2017, to observe debris flows and sediment transport. Some water samples also took in Lekso River to collect the total suspended solids (TSS) by using filtration method in PJT-I's Water Quality Laboratory. We estimate the sediment inflow to Wlingi and Lodoyo reservoir as a result from three lahar tributaries by following relations between water and sediment discharges as:

$Q_s = 0.06Q^{2.60}$ ………………(1) for Lekso/Semut River tributaries

$Q_s = 2Q^{2.49}$ ……………………(2) for Jari River tributaries

$$Q_s = 22Q^{2.52} \text{ ………………..……(3) for Ganggangan River tributaries}$$

6 Result

As countermeasure against lahars originating from Mt. Kelud, extensive debris control facilities were constructed in the affected area of Mt. Kelud. About 70.8 Mm^3 sediment discharge control facilities was planned by Ministry of Public Works in 1970 to improve the mitigation on secondary lahars originating from Mt. Kelud. The installed capacities of the facilities until today still reach about 34% from its initial plan or about 24.4 Mm^3 which includes a comprehensive network of sediment detention facilities, numerous sabo dam, and sediment bypass channel development.

The completion of 10.52 km length sediment bypass channel in 2011 gave significant effects on reducing sedimentation in Wlingi and Lodoyo reservoir. From the Wlingi and Lodoyo bathymetric data in 2010 and 2011, Wlingi and Lodoyo's storage capacity in 2011 were 4.42 Mm^3 (increased about 0.084 Mm^3 from 2010's capacities) and 2.65 Mm^3 (increased about 0.020 Mm^3 from 2010's capacities).

Mt. Kelud eruption in 2014 has significant effects on Wlingi and Lodoyo reservoir which showed by a significant change of the grain size distribution of the river bed stream in Wlingi reservoir and Lodoyo reservoir as shown in figures below. Coarse sediment (Kelud eruption product) has been transported further to downstream. This is also emphasized by the data from Total Suspended Solid (TSS) in Lekso River from late February 2014's observation that reach about 1,199 mg/L (in February 25th) and 5,594 mg/L (in March 4th).

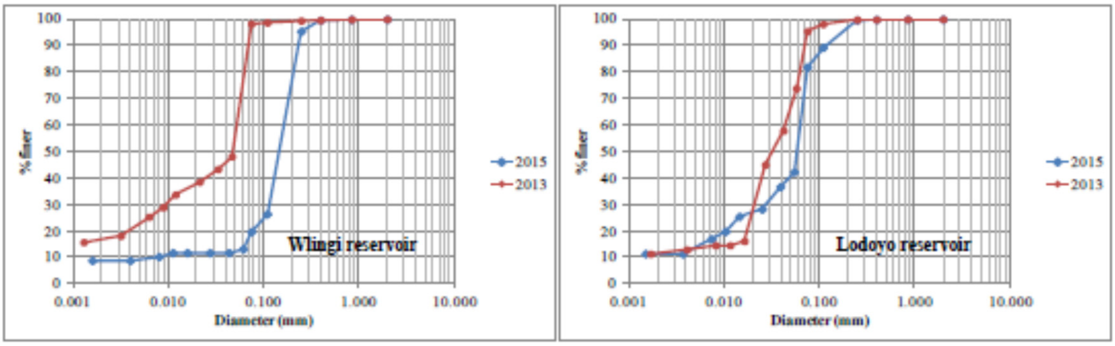

Fig. 5: Grain size distribution of sediment sample in Wlingi reservoir (CRB 128) and Lodoyo reservoir (LD 4) in March 2013 and May 2015, before and after the eruption of Mt. Kelud in February 2014

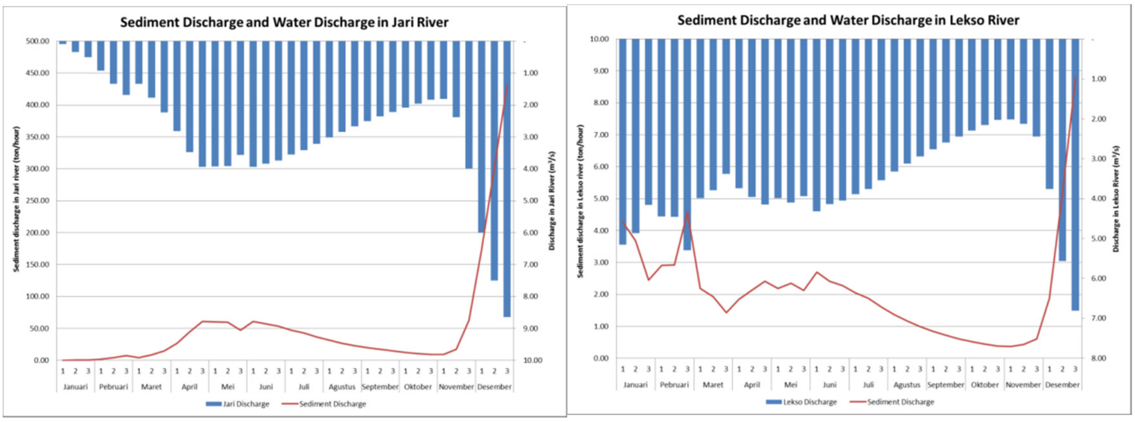

Fig. 6: Sediment and water discharge that recorded in Jari River and Lekso River after Mt Kelud eruption

Based on our data monitoring in Jari River and Lekso River show significant sediment discharge in Lekso River after the eruption. The residual volcanic ash which can't be transported in Lekso River on February-March then transported in the next rainy season. At least, about 18,311.63 tons and 432,193.73 lahar material was transported after eruption until the end of 2014 from Kali Jari and Kali Lekso respectively.

Fig. 7: Sediment laden flood in upstream of Putih River in November 2016 (left) and condition of existing Putih River sediment bypass channel in February 2017 (right)

7 Conclusion

Due to Mt. Kelud eruption in 2014, Wlingi and Lodoyo reservoir gain additional sediment load from volcanic ash which transferred from Jari River, Putih River and Lekso River. The development of sediment bypass channel which connect Putih River to the downstream of Lodoyo was reduce the lahar sediment load which transported to Putih River although lahar sediment which flows from Lekso and Jari River still give significant impact on Wlingi and Lodoyo's storage capacities. Routine maintenance activities which held by PJT-I, i.e., flushing and dredging, help to reduce sedimentation in both reservoir, but the full development of sediment bypass channel to connect the Jari River and Lekso

River which also have significant impact on Wlingi and Lodoyo storage capacities still need to be implemented. Beside that, regarding to the Mt. Kelud eruption risk in the future, the long term program to construct 145 sediment control facilities also need to be implemented.

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