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Sediment Dynamics in the Brantas River Basin, Indonesia: Issues and Management Plans

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Abstract: Sediment issues in the Brantas River basin in Java Island, Indonesia have been important concerns since, prior to water resources development in the basin from 1950's and increasingly since that time. Volcanic activity, the growing human population, changing in land use, increasing water use, increasing prevalence of man-made structures and increasing of demand for sediment for construction purposes have caused complex technical and environmental challenges in relation to sediment management in the Brantas River basin. The main sediment issues in the Brantas River basin consist of debris flows from the eruptions of Mt. Kelut, sedimentation in reservoirs and degradation of riverbed. To cope with the sediment issues in the Brantas River basin, comprehensive basin-wide sediment management plans, consist of the Watershed Conservation Master Plan, Sabo Plan, Reservoir Sediment Management Plan and Riverbed Management Plan were formulated and implemented. The aim of this study is to discuss the sediment issues, related management plans and experience in basin scale sediment management in the Brantas River basin for sediment hazard mitigation and sustainable water resources.

Key words: Brantas River basin, reservoir sedimentation, sediment issues, sediment management plans, mitigation, water resources

INTRODUCTION

Sediment dynamics in river basins are affected by natural processes and anthropogenic influences. Sediment issues may arise from reduction of sediment inputs as well as from increases in sediment production and changes in sediment characteristics. Natural processes such as landslides and volcanic eruptions produce large volumes of sediment. Many anthropogenic activities on the land tend to increase rates of soil erosion and sediment delivery to river channels. On the other hand, in many river basins sediment fluxes in river channels have actually decreased in recent decades due to the construction of large dams and impoundments for water supply, hydroelectric power generation, irrigation and flood control. The trapping of sediment in reservoirs reduces their capacity to fulfil these functions and may also have detrimental effects on rivers through a reduction in downstream sediment fluxes which in turn impact aquatic habitats and cause channel downcutting and undermining of bridges and other infrastructures (Owens, 2008).

Sediment management at river basin scale is the most appropriate because the basin topography defines the area in which most sediment functions operate including human impacts and resource use. The Brantas River basin in East Java Province, Indonesia is one of the most developed river basins in Indonesia with water management works dating to the colonial period and earlier. There is long experience in basin scale sediment management due to the numerous and complex sediment related issues that occur there. In the 40 years between development of the Master Plan for the Brantas River basin in 1961 and 2001, eight large dams were constructed for flood control, irrigation, domestic and industrial water supply, power generation and recreation. These dams trap

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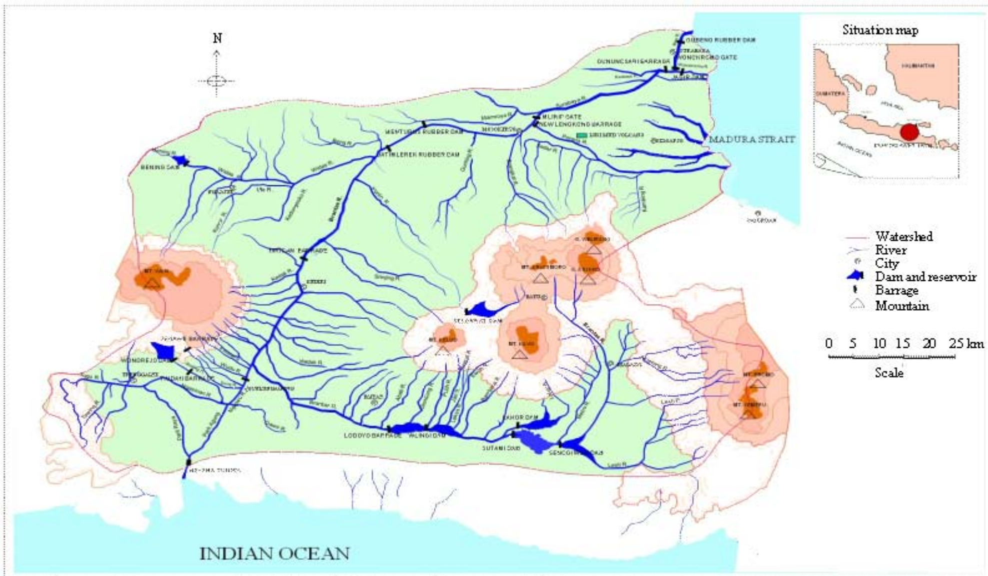

Fig. 1: Brantas River basin, showing channel planform morphology, topographic features and main reservoirs

sediment causing reservoir sedimentation and reducing sediment supply to downstream reaches. Concurrently, Mt. Kelut (1,724 m), one of the most active volcanoes on Java Island has impacted on the Brantas River sediment dynamics as the volcano produces large but episodic and unpredictable quantities of debris flow at each eruption causing temporary sediment storage in sub catchments, sediment accumulation in stream channels and frequent overbank flows and flooding during rainy seasons.

The situation is deteriorating as East Java Province's economic growth is increasing infrastructure requirements in turn increasing demand for sand for construction materials leading to excessive sand mining activities in the middle reach of Brantas and Porong River. Sand mining activities in the rivers, trapping of sediment in the upstream reservoirs and the physical and economic difficulties of removing sediment from sabo dams on the slopes of Mt. Kelut have caused serious riverbed degradation. The continued riverbed degradation is causing bank collapse and destabilization, damage and destruction of the river channel and adjacent housing and infrastructure. This study provides an overview of the relevant physiographic characteristics of the Brantas River basin, the main sediment related issues in the basin, the management plans developed in response to the increasingly complex sediment dynamic of the basin and an evaluation of each of the main management plans.

Physiographic characteristics and description of the brantas river basin: The 11,800 km^2 Brantas River basin is located between 110°30' and 112°55'E and 7°01' and 8°15'S. The basin is largely comprised of agglomerate, tuff breccia, tuff, coral limestone and volcanic ashes of varying degrees of consolidation. The flat lowland terrain is composed of alluvial soils of loam, silt and clay. There are two active volcanoes in the basin, i.e., Mt. Semeru (3,676 m) to the East and Mt. Kelut (1,724 m) in the basin centre. Mt. Semeru is continuously active, although, its eruptions are not cataclysmic and most ash falls outside of the Brantas basin. Mt. Kelut has been very active over the last century, most recently in February, 2014 with an average interval of 19 years between eruptions. The eruptions have had catastrophic consequences on each occasion (Fig. 1).

The Brantas River is approximately 320 km in length with its source on the East slope of Mt. Anjasmoro, part of the Arjuno volcanic massif a major topographic feature dominating the Southeast-central portion of the basin. The river course is clockwise around the massif, first East then South across the Malang plateau (elevation 400 m), then West through the major dam and reservoir complex consisting of the Sengguruh, Sutami, Lahor, Wlingi and Lodoyo Reservoirs. At the confluence with the Ngrowo River in the South-Western portion of the basin, the Brantas River turns North through the agriculturally productive plains region and finally flows East again towards the delta where it bifurcates at Mojokerto City to the main distributary channels of the Porong River and the Surabaya River both of which discharge to Madura Strait in the Java Sea. The main tributaries above the delta include the Lesti River in the Southeast (catchment area of 625 km^2), the Ngrowo River in the Southwest (catchment area of 1,600 km^2), the Konto River in the central basin (catchment area of 687 km^2) and the Widas River in the Northwest (catchment area of 1,538 km^2). The Upper Brantas channel slopes are relatively steep (>0.005) and much more gentle lower in the system (<0.001).

The mean annual rainfall over the basin is around 2,000 mm of which more than 80% occurs in the November to April rainy season. Interannual rainfall variation is from about 1,400-2,900 mm. The mean annual rainfall in the high elevation areas is higher, reaching 3,000-4,000 mm, especially on the Southern and Western slopes of Mt. Kelut.

Population in the basin was 15.50 million in 2013. Population is concentrated in the lower basin in the major metropolis of Surabaya and surrounding communities where about half the populations live and in the upstream communities of Malang, Kediri and Blitar cities.

A significant sediment management issue in the Brantas River basin is the 2008 eruption of the Lusi mud volcano at Sidoarjo and adjacent to the Porong River (Abidin *et al*., 2009). The issues associated with this event are confined to a relatively small area of the Southern delta of the Brantas River and lie beyond the scope of this study with its focus on basin-wide sediment management issues and plans.

MATERIALS AND METHODS

Sediment related issues in the Brantas River basin

Debris flows from the eruptions of Mt. Kelut: Mt. Kelut (1,731 m), located at the center of the Brantas River basin is a very active volcano. More than 30 eruptions have been recorded in the historical period, since, 1000 AD with an average recurrence interval of about 33 years, resulting in extensive damage over the area of its Southern and Western slopes and sediment accumulation in the Brantas River. During the past century, eruptions occurred in 1919, 1951, 1966, 1990, 2007 and 2014. These recent eruptions were similar, characterized by very short durations and eruptive product volumes in the order of 30-200 million cubic meters (Mm^3). The eruptions produced devastating lahars, pyroclastic surges and flows and ash fall deposits.

In May 1919, Mt. Kelud erupted, ejected 38.5 Mm^3 of hot lahar and claimed 5,110 lives (Nippon, 1990). The August 1951 eruption produced only minor destruction with total volcanic product was estimated at 192 Mm^3 based on point depth surveys of the ash deposits. Mt. Kelut erupted again in April 1966, producing an estimated 90 Mm^3 of volcanic materials. The February 10, 1990 eruption resulted in large volumes of volcanic ash spreading over the South to West slopes of Mt. Kelut, depositing in villages, paddy fields and plantations within a 20-30 km radius. The total volcanic production of the 1990 eruption was estimated at 125 Mm^3. Subsequently, the potential lahar yield (the ash deposits which could form lahar flows) was estimated through field investigation as 57.3 Mm^3. The 2007 eruption of Mt. Kelut produced no significant volume of ejecta but created a lava dome which rose through the center of the crater lake atop the volcano. The lava dome expanded to 250 m diameter and 120 m high, cracked open and lava began oozing into the surrounding water (Fig. 1).

The eruption of February 13, 2014 sent an ash plume to 17,000 m which triggered ash and volcanic debris fall as far as 350 km away. This eruption caused ash fall to the Northeast, Northwest and West of the volcano and produced about 120-160 Mm^3 of volcanic material (Fig. 2). The ash deposit on the Northern slopes of Mt. Kelut became a debris flow to the Konto River a few days after the eruption occurred. The deposit on the Southern slopes is a potential future debris flow to the Brantas River through the Lekso, Jari, Semut and Putih Rivers.

Exessive riverbed sedimentation: A proportion of the large volumes of volcanic materials produced by the Mt. Kelut eruptions is mobilised by flood waters and transported to the Brantas River subsequently becoming riverbed sediment. Problems associated with riverbed sediment accumulation include reduced channel carrying capacity, resulting in more frequent overbank flows and greater flood damage to adjacent property. During the 1951-1970 period, the riverbed of the Brantas River aggraded by an average of about 1.5 m (OTCA., 1973). The channel capacity decreased and sediment was deposited around the intakes and canals of the irrigation systems. Thus difficulties arose in protecting the land from floods in the rainy season and in abstracting irrigation water in the dry season.

Aggradation was rapid for several years after the eruptions of 1951 and 1966. The volume of sediment deposits was measured at several sites in the middle reach of the Brantas River and in the Porong River from 1951-1970. The general tendency was for the river deposits to increase for about 5 years after the eruption and then gradually decrease. The total deposition in 1951-1970 was 48.3 Mm^3 or about 17% of the total volcanic product of the 1951 and 1966 eruptions of Mt. Kelut (JICA., 1998) (Fig. 2).

Reservoir sedimentation: It is well documented that the construction of dams and impoundments for hydroelectric power generation, irrigation, water supply and flood control, results in the trapping of a significant quantity of sediment in reservoirs and other features (Syvitski, 2003; Vorosmarty *et al*., 2003; Walling and Fang, 2003; Owens, 2008; Wang and Chunhong,

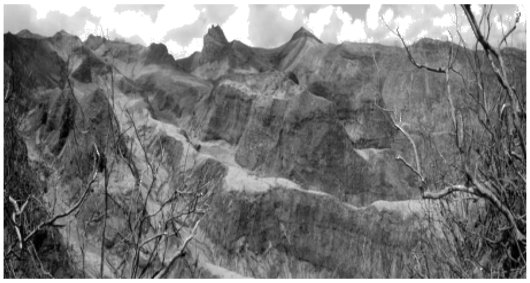

Fig. 2: Sediment deposits on the slopes of Mt. Kelut after the eruption of February 2014

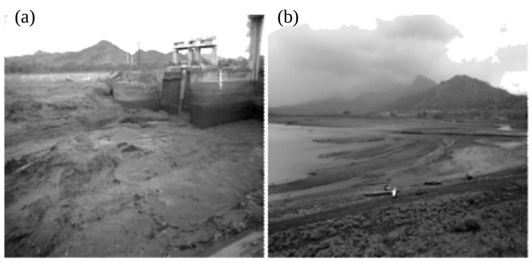

Fig. 3: a) Sedimentation in sengguruh reservoir and b) Selorejo reservoir

Fig. 4: Examples of check dams in the upper reach of the Brantas River

2010). Because of storage loss the functionality of the reservoir will decline as has occurred in reservoirs of the Brantas River basin.

Since, the basin development master plan for the Brantas River was the formulated in 1962, eight large reservoirs have been constructed in the basin-Sengguruh, Sutami, Lahor, Wlingi, Lodoyo, Selorejo, Bening and Wonorejo Reservoirs. The first five are located on the upstream reach of the Brantas River main stem and the remaining three are on the Konto River, Widas River and Ngrowo River basins, respectively.

The Sengguruh and Sutami Reservoirs on the Brantas mainstream and Selorejo Reservoir on the Konto River, have received very high sediment inflows from the highly erodible watersheds in the upper reaches of the Brantas, Lesti and Konto Rivers, respectively (Fig. 3 and 4). Since, its completion in 1988, sediment accumulation in Sengguruh Reservoir rapidly reduced its effective storage capacity to 25% of the initial capacity by 2014. Sedimentation in Sutami Reservoir, the largest reservoir in the basin, reduced its effective storage to 54% of initial capacity over the 37 years since its construction (Hidayat *et al*., 2012). Similarly, Wlingi and Lodoyo Reservoirs to the South of Mt. Kelut have effective storage capacities of about 39 and 47% of their initial capacities, respectively (Table 1). Forest cover in the Brantas River basin declined from 25% in 1993 to just 10% in 2004 (Adi *et al*., 2013). Most of this forest loss was upstream of the reservoirs in highly erodible steeplands with poor soil conservation measures a likely significant contributor to the high reservoir sedimentation rates (Table 1).

Riverbed degradation in the middle and lower reaches: The Brantas middle and lower reaches have experienced significant anthropogenic degradation of the riverbed since the late 1980's which increased markedly in the 1990's and continues to date. The riverbed degradation occurs due to the sediment trapping effects of the dams and weirs and excessive sand mining in the river with the annual sand mining volume estimated to be about 2 Mm^3. The rate of increase of the sand mining volume is estimated at 1% per annum, the growth rate of the construction sector in East Java Province (Nippon, 1990).

According to the surveys conducted in 1991, 1996 and 1997, serious degradation was observed in all reaches and the deepest degradation from 1996-1997 was about 4.5 m. The average heights of riverbed degradation of the Brantas and Porong Rivers in 1991 and 2004 were 2.27 and 1.95 m, respectively. Continued riverbed degradation has been the cause of serious bank collapse and destabilization, damage and destruction of facilities such as a rubber dam, bridge piers, weirs, ground sills, revetments, water intakes, etc. Riverbed degradation also reduces water surface elevation during dry periods, reducing the functionality of water abstraction intakes for irrigation, industrial and domestic water supplies.

Comprehensive basin-wide sediment management plans: In the post-independence period (from 1945) the Indonesian government prepared a series of the development plans which included flood mitigation measures (e.g., 1951-1953; 1956-1961; JICA., 1998). Recurrent major floods in the Brantas River basin through the 1950s prompted a further development planning initiative in 1961, the first Master Plan of Brantas

Table 1: Original and recently surveyed storage capacity of reservoirs in the Brantas River basin (PJT I)

Reservoir	Completion (years)	Original storage Capacity (Mm^3) Gross	Original storage Capacity (Mm^3) Effective	Survey (years)	Latest storage capacity (Mm^3) Gross	Latest storage capacity (Mm^3) Effective	Latest/original (%) Gross	Latest/original (%) Effective
Sengguruh	1988	21.50	2.50	2014	1.19	0.64	5.53	25.76
Sutami	1973	343.00	253.00	2014	158.56	135.43	46.23	53.53
Lahor	1977	36.11	29.43	2014	29.05	24.52	80.46	83.39
Wlingi	1977	24.00	5.20	2013	4.85	2.05	20.23	39.38
Lodoyo	1983	5.20	5.00	2013	2.72	2.37	52.25	47.44
Selorejo	1972	62.30	50.10	2014	34.82	33.32	55.88	66.51
Bening	1981	32.90	28.40	2012	27.86	25.44	84.67	89.58
Wonorejo	2000	122.00	106.00	2011	107.24	97.09	87.90	91.60

Table 2: Summary of sediment management planning in the Brantas River basin

Sediment management plan	Measures	Sediment flow
Watershed conservation	Planting works Hill side works Agro-forestry Teracing works Retaining walls	Reduce and control sediment yield and discharge Decrease sediment inflow into reservoirs
Sabo plan	Construction of check dams, consolidation dams, sand pockets, sediment settlement ponds, etc Construction of sand bypass channels Construction of open type dams (slit type and conduit type dams)	Debris flow occurrence control Debris flow control Decrease sediment inflow into reservoir Release sediment to downstream
Reservoir sediment management	Sediment removal works by dredging and flushing	Restore storage capacity Ensure sediment supply to downstream section
Riverbed management plan and sand mining control	Construction of ground sills Control of illegal sand mining Enhance stakeholder awareness	Stabilize riverbed Stabilize river and relevant structures Decrease sand mining volume in river

River basin development with the objective of controlling flooding by construction of two large dams in the upstream reaches, the Sutami Dam on the Brantas River and the Selorejo Dam on the Konto River. Initially focussed on flood control, Water Management Master Plans in the Brantas basin evolved through irrigation in 1973, domestic and industrial water supply in 1985 and management and conservation of water resources in 1998 (Hidayat, 2009). Sediment management planning in the Brantas River basin occurs in the context of and in some cases within this history and framework.

The sediment issues in the Brantas River basin have been induced by a spatially and temporally complex mix of natural and anthropogenic processes and interventions in the system. These include the ejecta from Mt. Kelut, erosion and sediment yield from the degraded watershed, trapping of sediment flow by the sabo facilities and dams and sand mining in the river. To cope with these issues, comprehensive basin-wide sediment management planning in the Brantas River basin was proposed as a suite of integrated sediment management plans consisting of the Watershed Conservation Master Plan, Sabo Plan (Debris Flow and Volcanic Disaster Mitigation Plan), Reservoir Sediment Management Plan and Riverbed Management Plan. Each of these plans is described below and summarised in Table 2.

Watershed conservation master plan: The Watershed Conservation Master Plan for the Brantas River basin was formulated to reduce and control soil erosion and sediment discharge to the Brantas River and its tributaries. The target watersheds for planning are the Upper Brantas, Brangka Lekso, and Konto Rivers. These are the high sediment yield areas in the Brantas River basin.

The main objectives of the plan are reduction of sediment yield and discharge to enhance the safety and progressive socio-economic development of inhabitants of the watershed area, installation of effective disaster mitigation facilities in areas of unstable sediment and land conservation measures in the devastated land areas for promotion of regional industry, agro-forestry and improvement of the environment in the watershed; reduction of reservoir sedimentation to ensure the required water storage volumes for reservoir operations and the target areas would be a model for management interventions in other areas suffering similar types of disasters and the plan formulation would provide guidance for formulation of effective conservation plans in other areas. The target year for completion of the Watershed Conservation Master Plan is 2025 (Table 3).

The second part of the Sabo Plan in the Brantas River basin is the Mt. Kelut Volcanic Disaster Mitigation Plan

Table 3: Implementation phases of comprehensive basin-wide sediment management planning in the Brantas River basin

Plan phase	Target (years)	Sediment management plan	Remarks
Urgent plan	2008	Sabo Plan (Urgent Sabo works) riverbed management plan	Implemented
Mid term plan	2025	Watershed Conservation Master Plan Sabo Plan (Priority Sabo works)	Upper Brantas, Brangkal, Lekso, Upper Konto River watersheds
Long term plan	2050	Sabo Plan (Long term Sabo works)	Sabo facilities on Rank A harmful rivers Sabo facilities on Rank B and C harmful rivers
Continuous management plan		Reservoir Sediment Management Plan	Target reservoirs Sengguruh, Sutami, Wlingi, Lodoyo. Sediment removal works by dredging and flushing
		Control of sand mining in rivers	Joint inspection, enhance the awareness, etc.
		Alternative sand sources	Excavation of sediment in Sabo facilities
		Monitoring Plan	

comprising: volcanic sediment control plan against rainfall: secondary lahar (debris flow and mudflow) and volcanic sediment control plan against volcanic eruption: primary lahar (nuee ardante, pyroclastic flow, volcanic ash-fall, primary lahar with crater water). The Mt. Kelut Volcanic Disaster Mitigation Plan proposes construction of 145 sediment control facilities consisting of 49 check dams (11 open-type check dams and 38 closed-type check dams), 76 consolidation dams (16 open-type consolidation dams and 60 closed-type consolidation dams) and 20 sand pockets. Urgent works included the rehabilitation of one consolidation dam on the Semut River and two check dams on the Badak River, the construction of three check dams and two consolidation dams on the Lekso Riverm and the construction of a bypass channel. These urgent works were completed in 2011 (Nippon, 1990). The target year for completion of long term works under the Sabo Plan is 2050 (Table 2 and 3).

Sabo Plan: Sabo is a Japanese term referring to intensive erosion and sediment control works, particularly in mountainous landscapes. The Sabo Plan in the Brantas River basin was formulated to control sediment and debris flows caused by mobilisation of volcanic ash and mud by intensive rains in order to prevent and mitigate disasters. The Sabo Plan targets mountain slope and river channel areas at high risk of debris flows and volcanic hazards. It was formulated by assessing both natural phenomena and socio-economic conditions in order to ensure safety, quality of life and socio-economic development. The Sabo Plan in the Brantas River basin consists of two parts, i.e., the Sediment Control Plan and the Mt. Kelut Volcanic Disaster Mitigation Plan.

The Sediment Control Plan for control of debris flows was formulated using a combination of structural measures and non-structural measures. The structural measures proposed include construction of 142 sediment control facilities (Fig. 4) consisting of 134 check dams (61 open-type check dams and 73 closed-type check dams) and 8 closed-type consolidation dams. The urgent works including construction of 5 check dams on the upper reach of the Brantas River, one sediment settlement pond upstream of Sengguruh Reservoir, 1 check dam and 2 consolidation dams on the Lesti River were completed in 2008 (Nippon, 1990). Non-structural measures, including monitoring and forecasting of debris flows, disaster warning systems, adequate evacuation systems and communication and information for disaster prevention, were proposed as priority works in the mid term planning phase.

Reservoir Sediment Management Plan: The Reservoir Sediment Management Plan in the Brantas River basin was formulated to achieve sustainable utilization of the reservoirs. The Sengguruh, Sutami, Wlingi and Lodoyo Reservoirs on the Brantas River were selected for sediment management works. These are the reservoirs with the greatest loss of effective capacity (Table 1). The reservoir sediment management includes both dredging and spoil placement on the adjacent land and the much cheaper technique of sediment flushing by opening spillway gates. The planned works are as follows.

Sengguruh reservoir: Dredging of 100,000 m^3 and flushing of 400,000 m^3 of sediment.

Sutami reservoir: Dredging of 300,000 m^3 is recommended with consideration of the available spoil bank capacity (for approximately 5 years).

Wlingi reservoir: Dredging of 200,000 m^3 and flushing of 400,000 m^3 by fully opening the spillway gates to empty the reservoir.

Lodoyo reservoir: Dredging of 200,000 m^3 is recommended to gradually restore the storage capacity. Coordinated sediment flushing with the Wlingi reservoir is regarded as an effective measure to reduce sedimentation economically.

Riverbed management plan and sand mining control: The Riverbed Management Plan in the Brantas River basin was formulated to reduce the impact of riverbed degradation in the Brantas middle reaches and the Porong River. The plan consists of structural measures using ground sill construction to stabilize the riverbed. Thirteen ground sills with heights of 0.5-3.5 m from the local average riverbed elevation were proposed. Construction of three ground sills on the Porong River and rehabilitation of one ground sill on the Brantas middle reach were completed as urgent works in 2009.

To control illegal and excessive extraction of sand from the river channel in the Brantas middle reaches and the Porong River, two measures were recommended to mitigate the sand mining issue in the river: intensive control of sand mining activities including removal of illegal sand mining facilities by the joint inspection team and enhancing stakeholder awareness of the implications of illegal mining. The execution of comprehensive basin-wide sediment management plans in the Brantas River basin is to be conducted based on the phased implementation plan and continuous management plan as summarized in Table 3.

RESULTS AND DISCUSSION

Natural and anthropogenic disturbance of the Brantas River basin occurs at high frequency, magnitude and duration. While the system has evolved with a high natural disturbance regime (intermittent volcanic ejecta input, intense seasonal rainfall and sediment transport regimes), there is a pressing need to stabilise the anthropogenic disturbance to facilitate the ecological recovery and socio-economic viability and sustainability of the basin. In this situation sediment management has been designed to acomplished the objectives for protect human lifes from environmental disturbance and natural disturbance. Other study stated that sediment management has to fulfill objectives particularly to secure human activities and will be subject to different legal requirements. In order to balance all this Sediment Management Plans should be developed. Therefore, the institutional provisions of the management plans can provide the necessary platform and instruments. Management plans, guidance and frameworks have to consider the high natural variability of sediment dynamics. An adaptive management which allows for environmental variations in a given range will be needed. Base on this situation, the management plans has to be site specific. It has been acknowledged that acting in often highly dynamic systems will contain an element of uncertainty (Netzband, 2007).

The development of a basin use plan have to considered balances the Conceptual Basin Model and the basin-scale objectives and should then result in a site prioritisation for further management that best meets the objectives of all stakeholders. On the other hand, site-specific assessment and management is characterised by tiered assessment and the determination of site-specific risk. Management options are driven by site-specific impact on basin-scale objectives, site-specific risk, technical and economic feasibility and regulations (Apitz and White, 2003).

Soil erosion and sediment delivery cause many environmental problems pose considerable human life burden on society. Therefore, policy makers are looking for strategies to reduce their impact. Spatial properties of soil erosion and sediment delivery as well as a variety of possible soil conservation and sediment control measures, requiring an integrated approach to the management and conservation of water catchment areas. Soil conservation measures taken in the areas are effective in reducing the loss of soil at the site and reducing sediment. Interestingly, off-site sediment control measures appear to be less effective in reducing sediment than previously thought (Verstraeten *et al*., 2002).

Implementations of the measures for comprehensive basin-wide sediment management in the Brantas River basin are under progressive implementation. In order to improve the effectiveness of the Watershed Conservation Master Plan, Sabo Plan, Reservoir Sediment Management Plan and Riverbed Management Plan and Sand Mining Control, evaluations are needed based on field observations. Summary evaluations of each plan follow.

Measures of the Watershed Conservation Master Plan have been implemented by many authorities in the Brantas River basin. They are involved in watershed conservation from upper administration services at government level to farmer groups at the field level. However, the administrative powers, scope and responsibility of each authority and their interrelationships are not clearly established or regulated. Each agency conducts its activities based on its sectoral program and there is no unified coordinating body for overall watershed conservation and management. Several supporting programs under national policies, i.e., the National Movement on Forest and Land Rehabilitation (Gerakan Nasional Rehabilitasi Hutan dan Lahan-GNRHL), the National Partnership Movement for Saving Water Resources (Gerakan Nasional Kemitraan Penyelamatan Air-GNKPA) and One Billion Indonesian Trees (OBIT) program are also conducted in the Brantas River basin. Despite these programs, intensive agricultural operations without adequate soil conservation measures continue in the upper reach of the Brantas River basin. More effort is needed to educate and raise the awareness of farmers in order to reduce sediment loads. Community participation or bottom-up approaches and measures for changing farmer's attitudes such as demonstration activities through pilot projects are needed for immediate implementation in watershed conservation projects. A new coordination body is recommended, composed of the full spectrum of stakeholders from top levels of administration to farmer groups at the field level in order to promote effective inter-agency cooperation and to develop community participation and bottom-up approaches. It should be established as a high priority for developing integrated long-term policy, strategy and management of conservation activities (Table 3).

February 2014 eruption of Mt. Kelud mainly affected areas Northeast, Northwest and West of the volcano. Urgent and priority works of the Mt. Kelut Volcanic Disaster Mitigation Plan need to be implemented in these areas. The debris flow in the Konto River has caused damage to check dams, irrigation intakes, revetments, etc. Furthermore, the sediment flux in the Konto River has caused problems for hydroelectric power generation at the Mendalan and Siman Hydropower Stations as their reservoirs have silted up and coarse material is entering the turbines. Non-structural measures such as monitoring/forecasting of debris flows, providing information and warnings of disasters to inhabitants and adequate evacuation systems should be developed in the Konto River as a priority in order to save human lives and mitigate against sediment related disasters. A flexible strategy that provides a rapid response to sediment-related issues arising from Kelut eruptions in whichever area is affected is needed.

Dredging activities in the reservoirs of the Brantas River basin face serious contraints due to operational costs, low performance of the aged dredgers and limited availability of land for spoil dumps (disposal sites). Therefore, it is difficult for management agencies to comply with the recommendations of the Reservoir Sediment Management Plan in the Brantas River basin in terms of the dredging volume. In the Wlingi and Selorejo Reservoirs, dredging is conducted by discharging sediment to the river channel below the dams. Sediment flushing in the Wlingi and Lodoyo Reservoirs, the technique planned to remove most of the sediment from these reservoirs can not be conducted regularly due to limited water availability (sediment flushing in the Wlingi and Lodoyo Reservoirs uses additional water from the Sutami Reservoir) and the environmental problems, it causes downstream. Based on observations during the flushing operations in 2004 and 2009, the impacts on water quality and aquatic organisms are significant, causing extremely high SSC, turbidity, BOD and COD. The degraded water quality, together with low DO, causes secondary impacts on aquatic organisms. There is inadequate knowledge of the physical, ecological and socio-economic impacts of these management processes. Accordingly further study on the impact of dredging with riverine disposal in the Brantas River and Konto River is needed.

Illegal and excessive sand mining activities continue in the Brantas middle and lower reaches. It is very difficult to completely stop sand mining activities in the river channels and to move sand mining activities to the Mt. Kelut area due to the social and economic problems that creates including the large number of households reliant on sand mining as their primary income source and the higher cost of sand sourced from Sabo Dams because of the higher transport costs. The number of inspections carried out by joint teams including police and other agencies responsible for controlling and supervising sand mining activities, remains limited because of financial and other resource constraints.

CONCLUSION

The Brantas River basin is the most intensively developed river basin in Indonesia. The basin has supported not only the economic development of East Java Province but also National Economic Development. Water resources development and management in the Brantas River basin provides benefits in flood control, irrigation, water supply for domestic and industrial use, power generation, etc. Concurrently, a complex suite of sediment-related issues continue to threaten ecological processes, water resources, hydro-electric power generation and socio-economic sustainability in the basin. The sediment issues in the Brantas River basin have been induced by clearing of erodible steeplands without effective soil conservation measures, input of erupted volcanic materials largely from Mt. Kelut, trapping of sediment flow by the large dams and sabo facilities and sand mining in the river. In order to address these issues, sediment management in the Brantas River basin is considered as a central component of integrated river basin management. Thus sediment management is a necessary and integral part of Brantas River basin management.

Sediment management in the Brantas River basin is based on comprehensive basin-wide sediment management plans which consist of the Watershed Conservation Master Plan, Sabo Plan, Reservoir Sediment Management Plan and Riverbed Management Plan and Sand Mining Control. Comprehensive basin-wide sediment management in the Brantas River basin is based on phased implementation plans. The involvement of all stakeholders with strong government support is essential to achieve the objectives of each plan. The evaluation of each plan based on the current situation reveals the need for clearer definition of agency roles, better agency and stakeholder coordination, urgent remedial interventions and continuing issues and limitations in relation to management of reservoir sedimentation and illegal sand mining. There is an underlying need for continued improvement of the plans with a focus on the effectiveness of their implementation.

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REFERENCES

Abidin, H.Z., R.J. Davies, M.A. Kusuma, H. Andreas and T. Deguchi, 2009. Subsidence and uplift of Sidoarjo (East Java) due to the eruption of the Lusi mud volcano (2006-present). Environ. Geol., 57: 833-844.

Adi, S., I. Janen and T.C. Jennerjahn, 2013. History of development and attendant environmental changes in the Brantas River Basin, Java, Indonesia, since 1970. Asian J. Water Environ. Pollut., 10: 5-15.

Apitz, S. and S. White, 2003. A conceptual framework for river-basin-scale sediment management. J. Soils Sediments, 3: 132-138.

Hidayat, F., 2009. The Planning Spiral of Brantas River Basin. CRBOM Small Publication, Surakarta, Indonesia,.

Hidayat, F.H., E. Subagyo, A. Rianto, M. Taufiqurrachman and A. Nugrahany, 2012. Management of reservoir sedimentation in the Brantas River Basin Indonesia. Proceedings of the International Symposium and 80th ICOLD Annual Meeting and 24th Congress on Dam for a Changing World, June 2-8, 2012, CIGB ICOLD, Kyoto, Japan, pp: 1-3.

JICA., 1998. Development of the Brantas River Basin. Japan International Cooperation Agency, Tokyo, Japan.

Netzband, A., 2007. Sediment management: An essential element of river basin management plans. J. Soils Sediments, 7: 117-132.

Nippon, K., 1990. Recommendation on formulation of Sabo master plan for G. Kelud. Nippon Koei, Co. Ltd, Tokyo, Japan.

OTCA., 1973. Report on the Brantas River Basin development. Overseas Technical Cooperation Agency, Tokyo, Japan.

Owens, P.N., 2008. Sustainable Management of Sediment Resources: Sediment Management in the Basin Scale. Vol. 4, Elsevier, Amsterdam, Netherlands, ISBN: 9780444519610, Pages: 265.

Syvitski, J.P., 2003. Supply and flux of sediment along hydrological pathways: Research for the 21st century. Global Planet. Change, 39: 1-11.

Verstraeten, G., K. Oost, A. Rompaey, J. Poesen and G. Govers, 2002. Evaluating an integrated approach to catchment management to reduce soil loss and sediment pollution through modelling. Soil Use Manage., 18: 386-394.

Vorosmarty, C.J., M. Meybeck, B. Fekete, K. Sharma, P. Green and J.P.M. Syvitski, 2003. Anthropogenic sediment retention: major global impact from registered river impoundments. Global Planetary Change, 39: 169-190.

Walling, D.E. and D. Fang, 2003. Recent trends in the suspended sediment loads of the world's rivers. Global Planet. Change, 39: 111-126.

Wang, Z.Y. and H.U. Chunhong, 2010. Strategies for managing reservoir sedimentation. Int. J. Sediment Res., 24: 369-384.