Asian Journal of Water, Environment and Pollution, Vol. 10, No. 1 (2013), pp. 5–15.

History of Development and Attendant Environmental Changes in the Brantas River Basin, Java, Indonesia, since 1970

Seno Adi*, Ingo Jänen[1] and Tim C. Jennerjahn[1]

The Agency for the Assessment and Application Technology (BPPT), BPPT Building 2, Floor 18, Jl. M.H. Thamrin 8, Jakarta 10340, Indonesia

[1]Leibniz Center for Tropical Marine Ecology, Fahrenheitstrasse 6, 28359 Bremen, Germany

✉ seno1234@yahoo.com

Received November 5, 2012; revised and accepted November 16, 2012

Abstract: The Brantas River is the second largest river on the island of Java which has undergone major changes in the past decades because of the demands of an evergrowing population. Water management measures were mainly designed (i) to provide flood protection, (ii) to provide raw water for irrigation, households and industry, and (iii) to generate hydropower. The objective of this paper is to delineate the history of development and attendant environmental changes since 1970 as well as to address the effects of a mud volcano eruption in 2006. Data from three gauging stations representing the upstream, midstream and downstream portions of the Brantas River were chosen to display patterns in discharge (1970-2003) and in nutrients (1991-1997). Overall discharge decreased over time at all stations with the strongest decrease in the downstream portion. The amplitude of seasonal changes in discharge was highest in the downstream portion. Dissolved inorganic nutrient concentrations increased slightly downstream as a result of land use. An eruption of a mud volcano in 2006 added to the initially high sediment load of the river. A portion of the mud was directed into the river leading to extremely high suspended matter and low dissolved oxygen concentrations. As a large part of the high suspended sediment load, already settled in the river, dredging was initiated in order to avoid blocking of the river. The dredging material was used for land reclamation. The high nutrient and sediment loads of the Brantas River are to a large extent the result of intensive human activities in the catchment like hydrological alterations and land-use change. Extreme natural events like the mud volcano exacerbate the consequences of human alterations on the water quality and biogeochemistry of the river.

Key words: River, discharge, nutrient, mud volcano, land use change, Indonesia.

Introduction

The island of Java is the most populated area in Indonesia where about 60% of the population live. With a population density of approx. 1000 inhabitants per km^2 it is among the most densely-populated regions on the globe (BPS, 2010). Consequently, human activities such as intensive agriculture, urban and industrial development are strongly affecting the environment. The intensive agriculture is creating critical land and soil degradation leading to soil erosion and enhanced sedimentation in aquatic systems. The industrial and urban development besides having other effects generates effluents, especially wastewater. All these activities are affecting the water quality and integrity of river systems and coastal waters.

Currently, many river basins in Indonesia are degraded as a result of increasing land use and population growth and a lack of public awareness of environmental conservation. River basin degradation resulted in

*Corresponding Author

increasing fluctuations of river discharge between the rainy and dry seasons and an increase of the maximum to minimum river discharge ratio (Qmax/Qmin). The consequences are the occurrence of extreme floods in the rainy season as well as droughts in the dry season. In addition, the river and reservoir capacity decreases due to high rates of erosion and sedimentation, and the disposal of domestic, industrial, agricultural and mining waste decreased water quality. Currently, Indonesia's government makes every effort to restore water quality in some of its most degraded rivers many of which are located on the island of Java like the Citarum, the Ciliwung, the Cisadane, the Citanduy, the Progo, the Bengawan Solo and the Brantas. Among those rivers the Brantas is the most important one in terms of length and catchment area, management system, and water infrastructure.

The 320 km long Brantas is located in the East of Java and drains an area of approx. 11,050 km^2. It has its source in the mountainous region of Mt. Arjuno and is surrounded by volcanoes, some of them still active. It flows in a clockwise pattern around this area towards the Madura Strait in the East until it divides into two branches in the lowlands near the city of Mojokerto. From there the Porong River flows eastward and the Surabaya River flows in northeastern direction until it further divides into the northflowing Mas River which discharges into Surabaya Strait and the eastflowing Wonokromo which, like the Porong, discharges into Madura Strait. The Brantas River catchment has a population of about 14-15 million people from which about 2.6 million people live in the East Java capital Surabaya City. The main river also crosses some medium-sized towns of approx. 0.5 million inhabitants and municipalities such as Malang, Blitar, Tulungagung, Kediri, Nganjuk, Jombang and Mojokerto (Table 1, Figure 1; Jennerjahn et al., 2004; Aldrian et al., 2008).

Table 1: Population distribution in the Brantas River Basin in 2009

No	*Region name*	*Town*	*Regency*	*River segment*
1	Surabaya	2,631,305		Lower stream
2	Sidoarjo		1,802,948	Lower stream
3	Jombang		1,301,459	Downstream
4	Mojokerto	113,227	1,013,988	Downstream
5	Nganjuk		1,002,330	Midstream
6	Tulungagung		992,048	Midstream
7	Trenggalek		675,765	Midstream
8	Kediri	272,610	1,451,861	Midstream
9	Blitar	133,408	1,070,466	Upstream
10	Malang	820,857	2,452,411	Upstream
11	Batu	189,604		Upper stream

Data are from Badan Pusat Statistik (BPS, 2010).

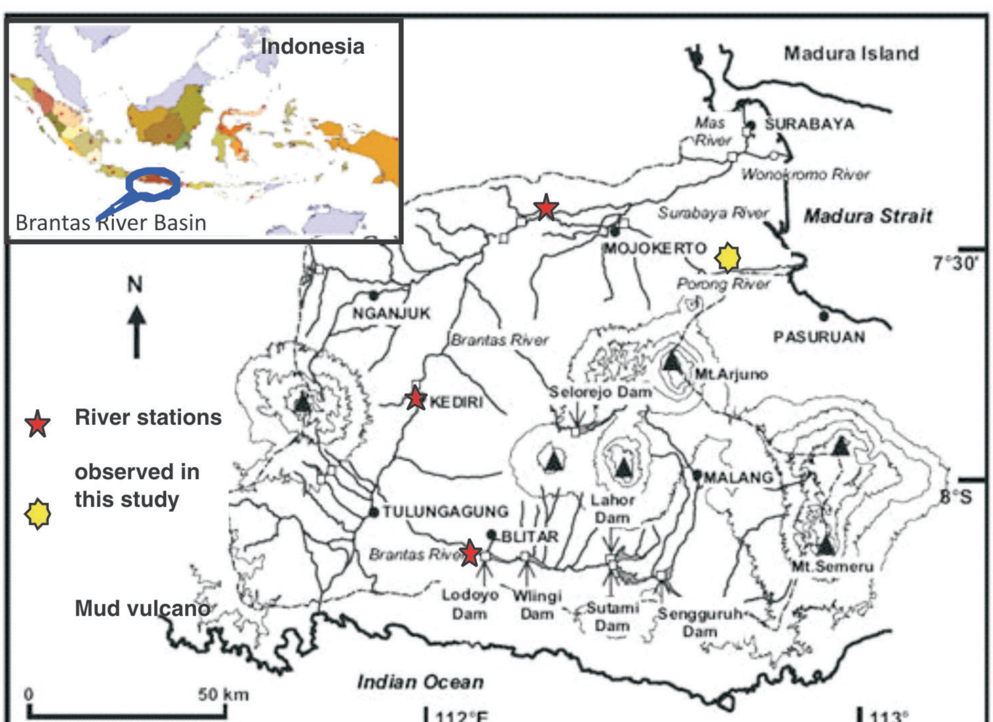

Figure 1: Brantas River basin, sampling stations and mud volcano site.

The river basin has a tropical monsoon climate with a rainy season from November to April and a dry season from May to October. The rainfall varies widely due to the topography varying from flat to mountainous. Average rainfall in the basin is approx. 2000 mm per year of which more than 80% occurs in the rainy season. In mountainous regions especially along the southern and western slopes of Mt. Kelud the average rainfall can amount to 3000-4000 mm per year. Topography of the Brantas River basin is determined by the mountainous complex of the volcanoes Mt Arjuno, Mt. Kawi, Mt. Kelud, and Mt. Semeru—the latter two of which are still active. Eruptions of Mt. Kelud and Mt. Semeru often result in volcanic debris flows into and deposition in the river that causes a rise of the river bed.

Additional sediment is introduced into the Porong River in the downstream region since a mud volcano erupted near the city of Sidoarjo on May 29, 2006. The mud volcano called "Lusi" (from "lumpur (= hot mud) Sidoarjo") started to emanate mud at a rate of 5000 m^3 d^{-1} which grew to a maximum of 180,000 m^3 d^{-1} (Davies et al., 2011) and still amounted to 10,000 m^3 d^{-1} in 2011 (Harsaputra, 2011). While part of the mud was directed into the Porong River major part of it remained on land and covered several villages and other infrastructure and approx. 30,000 people have been displaced.

The aquatic system of the Brantas River basin is strongly affected by human modifications and natural extreme events. This paper aims at delineating the history of river basin development and the attendant environmental changes as well as the effects of the mud volcano eruption. For this purpose results from several joint research projects are used.

Data Sources

Hydrological data series such as river discharge from 1970 to 2003 and river water quality of 1991-1997 were taken from the Jasatirta Corporation (Perum Jasa Tirta) which is the Brantas River water management authority. Physicochemical and biogeochemical data were obtained within the frame of the Indonesian-German SPICE (Science for the Protection of Indonesian Coastal Marine Ecosystems) programme and in cooperation with the Southeast Asia Regional Centre for START (SARCS). Analytical methods and part of the results displayed are given in Jennerjahn et al. (2004), Aldrian et al. (2008) and Jänen et al. (this issue).

History of Changes in the Brantas River Basin

Brantas River Basin Development

The development of the Brantas River basin was based on the approach "one river, one plan, one management". The river development started in 1961 under the assistance of the Japanese government firstly by tunnelling a tributary of the Brantas River, the Ngrowo River, to the south (to the Indian Ocean). This tunnel was constructed in order to redirect the water masses of the Ngrowo River that frequently caused floods in the Tulung Agung regency located in the southwestern Brantas catchment. In the following, many river structures were constructed such as large dams, rubber dams and barrages in order to regulate the Brantas River flow. A master plan for water management was then implemented in four phases as follows (JICA, 1998; Perum Jasa Tirta, 2001, 2007) (Table 2):

- Phase I (1962-1972): a flood control programme was initiated, dams were constructed and river channel capacity improved in the upper portion of the catchment;
- Phase II (1973-1984): an irrigation development programme was installed, reservoirs, barrages and technical irrigation systems were installed to support the "rice sufficiency" policy;
- Phase III (1985-1999): a water supply programme for domestic and industrial use was implemented;
- Phase IV (2000–2020): an Integrated Water Resource Management was implemented for water resources conservation.

Land-use Change and Water Structures Development

The land-use change on Java has caused significant changes of the hydrological regime (Pawitan, 2004). Between 1970 and 2004 the most dramatic change in land use was observed for plantations which increased from 5% in 1970 to more than 20% in 2004 (Figure 2). While rice (paddy) fields made up around one quarter between 1970 and 1993 it increased to about 38% in 2004. Forest cover increased from 15% to 25% between 1970 and 1993 and decreased to 10% in 2004. This is of particular importance as every regional administrative unit has to preserve at least 30% forest area according to Indonesian law.

The low percentage of forest in the Brantas River basin could negatively affect the soil and water conservation. While dryland farming decreased from more than 30%

Table 2: Master plan development in the Brantas River basin

No	Master plan	Objectives	Structures
1	Phase 1	Flood control Irrigation Hydropower	Sutami dam (1970) Selorejo dam (1973) New Lengkong dam (1973) Porong river improvement (1977) Lahor dam (1977)
2	Phase 2	Irrigation Flood control Hydropower Water supply (for domestic use and industry)	Brantas middle reaches river improvement (1977) Wlingi dam (1977) New Gunungsari dam (1981) Bening dam (1982) Lodoyo dam (1983) Tulungagung drainage (1987) Sengguruh dam (1989)
3	Phase 3	Water supply (for domestic use and industry) Irrigation Flood control Hydropower	Brantas middle reaches river rehabilitation (1990) Tulungagung hydropower (1990) Jatimlerek rubber dam (1992) Menturus rubber dam (1993) Wlingi dam rehabilitation (1993) Porong river rehabilitation (1993) Surabaya flood control (1995) Wonorejo dam (2000)
4	Phase 4	Water resources conservation and management	Established automatic water quality monitoring stations.

in 1970 to little more than 10% in 2004 the residential area stayed almost constant at 16-17% until 1993 and it then dropped to 10%. The high percentage of plantations and paddy fields indicates development of intensive agriculture potential consequences of which are increased soil erosion and release of agriculture effluents into water bodies.

Annual water utilization in this region is estimated to 2934 million m^3 which is 20-25% of the total available water. The current phase of integrated water resource management is designed to optimize the available water structures and hence the efficiency of water use. Major

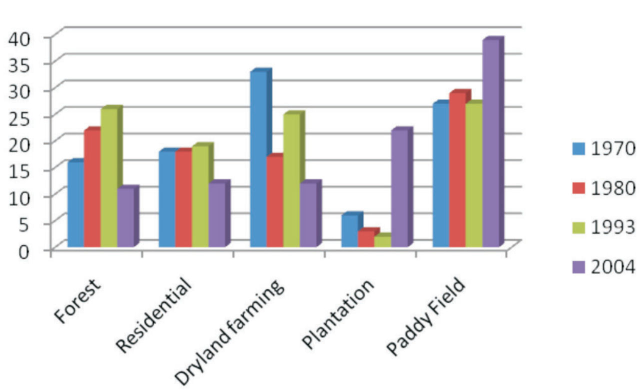

Figure 2: Land use change, 1970-2004.

benefits of the available water structures along the Brantas River are as follows (Ramu, 2004):

- Mitigation of flood discharge of 50 years return period of the main river;
- Generation of electric hydropower of the order of 233 MW per year;
- Supply of water for irrigation of 345,000 ha of paddy field;
- Supply of raw water for domestic and industrial use of the order of 300 million m^3 per year; and
- Supply of fresh water at a rate of 13.5 m^3 s^{-1} for an area of 11,000 ha of brackish aquaculture in the Brantas lowlands.

Currently, the main water structures in the Brantas River basin are seven concrete dams (four of which are cascade dams), three rubber dams, seven barrages, and irrigation systems. The reservoirs were constructed between 1970 and 2001 with initial gross and effective capacities of 647 million m^3 and 479 million m^3, respectively. Due to the upstream soil degradation and erosion the gross and effective capacities decreased to 405 million m^3 (62.6%), and 343 millon m^3 (71.6%), respectively (Ramu, 2004).

The strongest decrease of effective capacity down to 57% after 31 years of operation was observed in the largest reservoir (Sutami) located in the upstream portion of the catchment (Table 3). Apparently, intensive agriculture development there caused significant soil erosion leading to high sedimentation in the reservoirs. Moreover, ejected material from the active volcanoes Mt. Kelud and Mt. Semeru is deposited in the river. In 1990 Mt. Kelud ejected 100-300 million m^3 of volcanic material that reached the Brantas River and raised the river bed by about 2.5-7.5 m and filled the Wlingi reservoir with sediment (Toshikatsu, 2003).

River Discharge Trend and Pattern

The river discharge is not only controlled by the amount of rainfall, but also by soil type and properties, vegetation, river basin topography, and human activities. Records of monthly river discharge between 1970 and 2003 from three gauging stations in the upstream (Pundensari/ Blitar), midstream (Kediri) and downstream (Mojokerto) portions of the Brantas River catchment display seasonal and interannual variations. Discharge decreased over time and this decrease was most pronounced in the downstream portion of the river. Minima and maxima in the upstream, midstream and downstream portions occurred almost simultaneously. While minimum discharge was similarly low in all three sections the maximum discharge in the downstream portion was several times higher than in the upstream and midstream sections (Figure 3).

As a consequence of extreme rainfall events and hence river discharge peaks significant floods were reported, e.g. in March 1976, January 2002, February 2004 and January 2008, despite the fact that the Brantas River basin is the most developed in Indonesia with respect to flood protection (Toshikatsu, 2003; Ramu, 2004; Perum Jasa Tirta, 2007; Hidayat et al., 2009). Despite the dramatic shift in land use between the 1970s and the 2000s the magnitude and seasonal distribution of discharge did not

Table 3: Change of effective capacity in the reservoirs

No	*Reservoir*	*Catchment area*	*Purpose*	*Change of effective capacity (million m^3)*				
				Year	Capacity	Year	Capacity	%
1	Selorejo	90	I,H,F	1970	50.1	2003	41.5	83
2	Sutami	2050	I,H,F,Wd,Wi	1972	253.0	2003	145.2	57
3	Lahor	160	I,H,F,Wd,Wi	1977	29.4	2001	25.8	88
4	Bening	238	I,H,F	1982	28.4	1999	22.3	81
5	Wonorejo	126	I,H,F,Wd,Wi	2001	105.8	2001	105.8	100

Note: I = Irrigation; H = Hydropower; F = Flood control; Wd = Water supply for domestic; Wi = Water supply for industry. Data are from Trie et al. (2005).

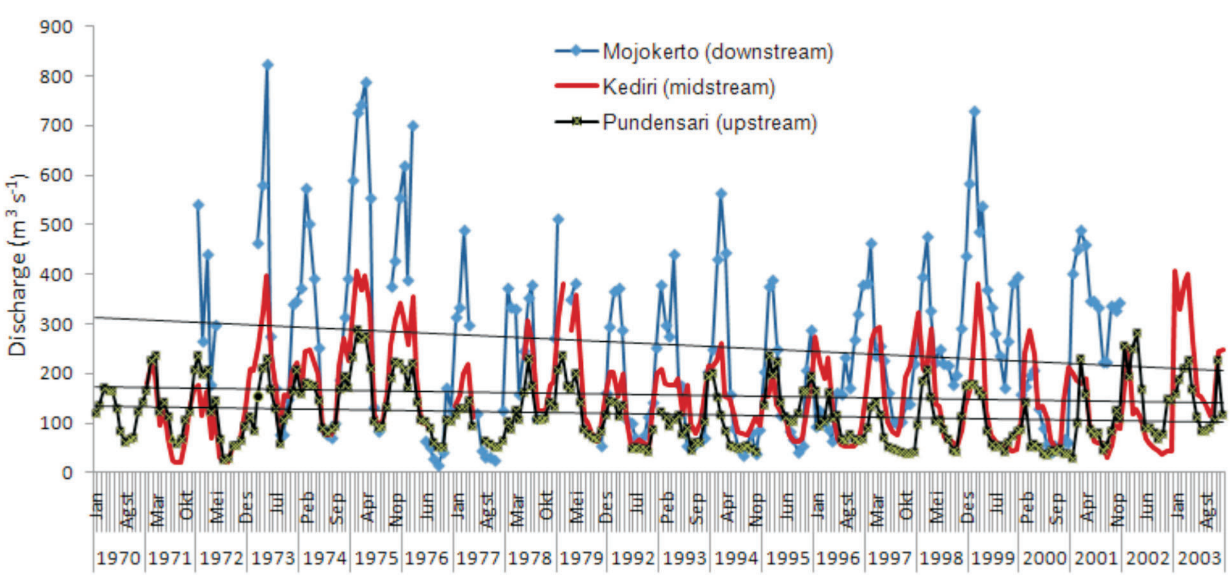

Figure 3: River discharge pattern and trend in upstream, midstream and downstream: portions between 1970 and 2003.

change that much. It indicates that the available water structures are generally able to mitigate the consequences of high rainfall events except for the abovementioned floods.

Nutrient Concentrations and Trophic Status

Land-use change and hydrological alterations usually affect nutrient load and composition and the trophic status of rivers and coastal waters (e.g. Smith et al., 1999; Smith et al., 2003; Seitzinger et al., 2010). Time series data (1991-1997) of dissolved inorganic nutrients from the abovementioned stations display concentrations and distribution patterns which result from seasonal variations in rainfall in combination with human activities in the catchment. Ammonium concentrations were mostly fairly low in the upstream and midstream portions of the river, but increased over time with significant peaks of more than 55 µM in 1997. In the downstream portion of the river maximum ammonium concentrations were around 80 µM and an absolute maximum of 120 µM was recorded in 1997. These much higher maximum concentrations were observed during times of low discharge, i.e. the dry season, and probably result from domestic waste input while lower concentrations in the rainy season are also the result of dilution by high discharge.

In general, dissolved inorganic nutrient concentrations in the Brantas River were high, especially the dissolved inorganic nitrogen (DIN) mainly consisting of nitrate (Jennerjahn et al., 2004). Nitrate concentrations displayed significant seasonal variations on a generally high level throughout the whole catchment. While nitrate varied between 40 and 100 µM in the upstream portion of the river it was much higher in the mid- and downstream portions (Figure 4). Concentrations were much higher than in the Indonesian Citanduy River and in the same range as in other world rivers impacted by human activities (Jennerjahn et al., 2009). These high nitrate concentration and the associated high N/P ratio in the Brantas River probably result mainly from the intensive fertilizer use in agriculture (Jennerjahn et al., 2004).

Like nitrogen, phosphate is a limiting nutrient required for primary production by terrestrial and aquatic plants and it is commonly used in fertilizers to enhance the growth of crop plants. Additionally, wastewater released into the environment, that has not been properly treated, can contain abundant phosphates from detergents and in combination with increased concentrations of other essential nutrients cause algal blooms in water bodies. With a few exceptions phosphate levels <0.5 µM throughout the whole catchment, but displayed an increase to 1-2 µM, in an exceptional month to 4.4 µM, in 1996 and 1997 (Figure 5) which is at the lower end of the range observed in polluted world rivers (Jennerjahn et al., 2009).

Excess nitrogen and phosphorus inputs from agriculture activities lead to significant water quality problems including harmful algal blooms, hypoxia and declines in flora and fauna. In order to assess the trophic status of the Brantas River with regard to nutrient pollution we chose the criteria applied by Smith et al. (1999). As threshold values displayed for the oligo-, meso- and eutrophic conditions shown in Figure 6 are for total nitrogen and total phosphorus our nitrate and

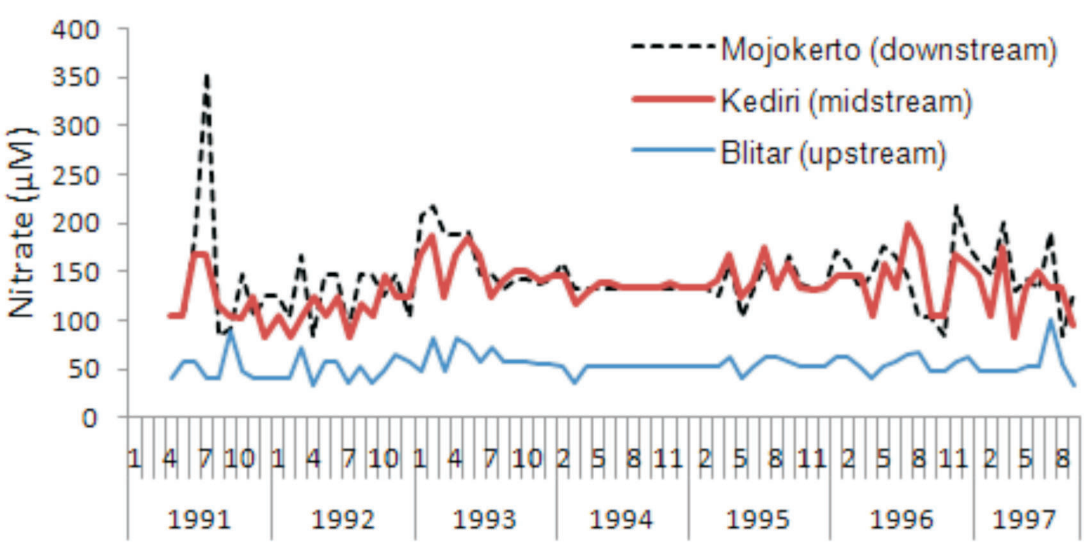

Figure 4: Nitrate concentration in upstream, midstream and downstream portions between 1991 and 1997.

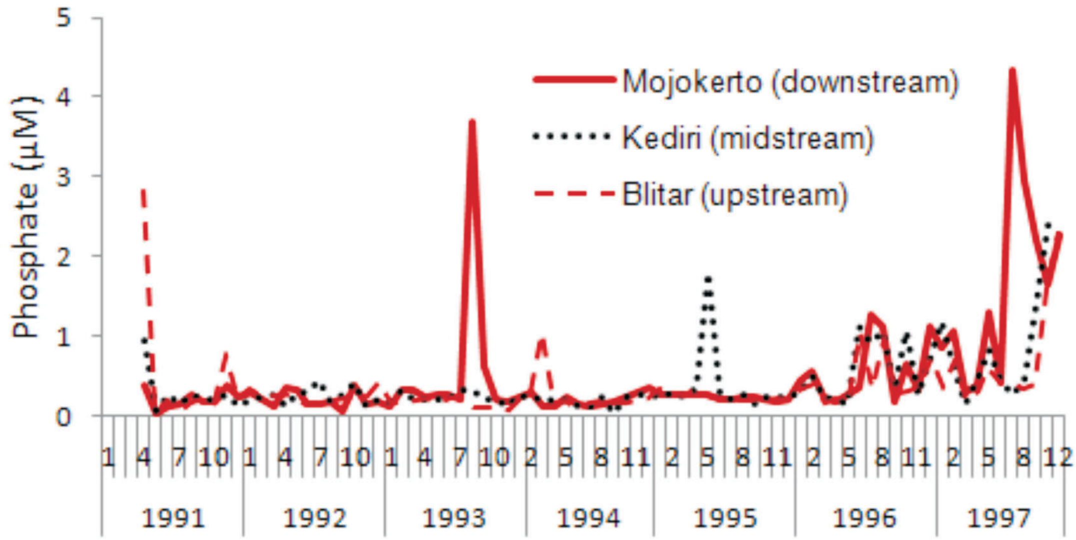

Figure 5: Phosphate concentration in upstream, midstream and downstream portions between 1991 and 1997.

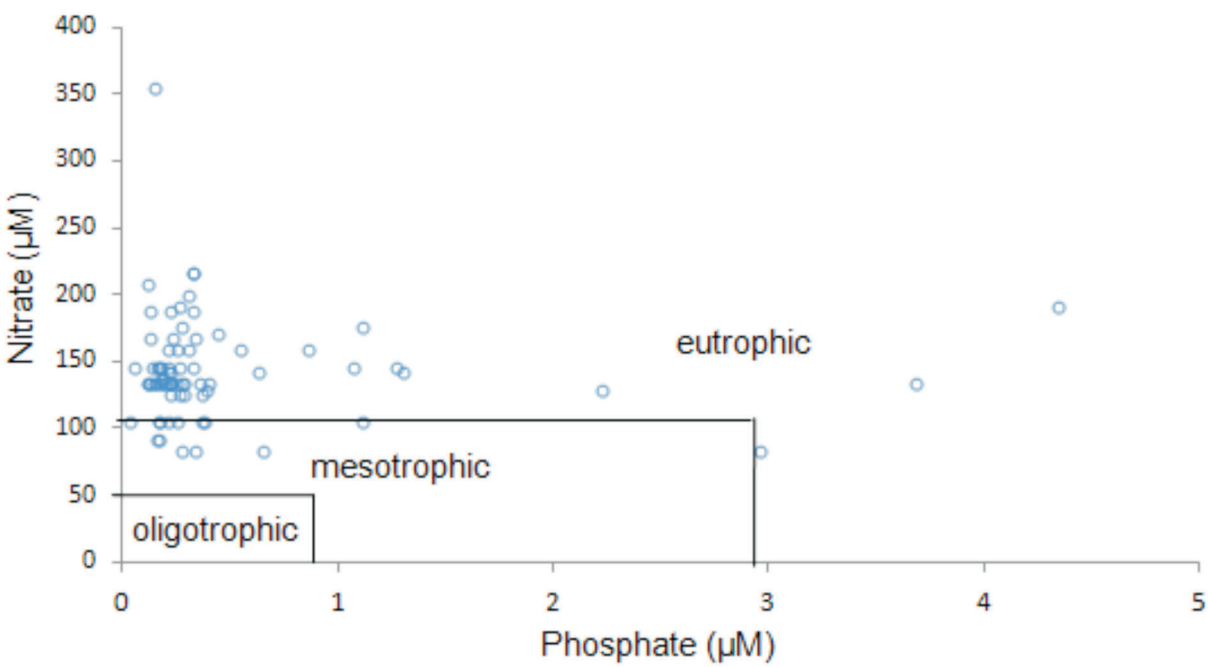

Figure 6: Trophic status in the downstream portion of the Brantas River. Thresholds used are taken from Smith et al. (1999).

phosphate data shown have to be considered underestimates of the total nitrogen and phosphorus load of the Brantas. However, even when taking this into account it becomes clear that the Brantas River is heavily eutrophied with respect to nitrogen while its phosphorus load appears to be moderate for the period 1991-1997 (Figure 6). With regard to its trophic state the Brantas River is comparable to the Citanduy River in central Java while many polluted world rivers are eutrophic (Jennerjahn et al., 2009).

Coastal Progradation

The Porong River also serves as a flood canal. The flood discharge is usually associated with high suspended sediment flux to coastal waters leading to sediment deposition and delta progradation there. A study of

Porong delta growth by Hoekstra (1989) based on aerial photographs and morphology analysis identified sediment deposition on the amount of 12.4 million m^3 yr^{-1} (19.7 million t yr^{-1}) or approximately 40 ha yr^{-1} until 1981 (Table 4). Furthermore, he described a regular sediment distribution in delta-lobe shape to Madura strait via the Alo River and the Semblingan River. In 1979 an artificial channel was cut in the SE side of the Porong delta which at present is the most important channel with respect to sediment transport (Figure 7).

Impact of the Mud Volcano

In the year 2006 a mud volcano erupted near the city of Sidoarjo and the Porong River. The centre of eruption was initially close to villages, paddy fields, fish ponds and mangrove areas and the mud covered large areas in the surroundings leading to the displacement of thousands of people. The temperature of the mud varying between 28°C and 68°C and the high chloride content between 14,000 mg l^{-1} and 25,000 mg l^{-1} indicates that the mud is probably old marine sediments. In the year 2008 the mud volcano ejected up to 180,000 m^3 mud per day with an average 100,000 m^3 per day (Davies et al., 2011). In order to prevent flooding of the whole area earth dikes were built and part of the mud stored in the artificial mud ponds. An additional measure was to direct part of the mud into the nearby Porong River assuming that the river would transport the mud to coastal waters of Madura Strait during the wet season. However, the high load of total suspended matter and particulate organic carbon led to environmental degradation in the river, for example, by causing severe oxygen depletion in the river particularly during the dry season. To manage the water flow of the Porong the Mud Volcano Sidoarjo Authority (BPLS, 2011) started dredging the estuary which produced about 2.9 million m^3 of mud part of which was used for coastal reclamation (40 ha). Additionally, a jetty of 5.2 km length was built in order to direct the mud seaward to the deeper parts of Madura Strait (Figure 8).

A United Nations rapid assessment study on the mud volcano eruption reported that major threats to the aquatic environment could be high turbidity and possibly creation

Table 4: Characteristics of the Porong delta development

Period	*Length (m)*	*Length increase ($m\ y^{-1}$)*	*Area ($10^6\ m^2$)*	*Area increase ($10^6\ m^2\ y^{-1}$)*	*Volume ($10^6\ m^3$)*	*Volume increase ($10^6\ m^3\ y^{-1}$)*
1886-1910	1690	70.4	25.4	1.1	184.5	7.7
1910-1935	193	7.7	2.9	0.1	59.3	2.4
1935-1981	1296	28.2	19.4	0.4	570.6	12.4
Total					811.4	19.7

Data are from Hoekstra (1989).

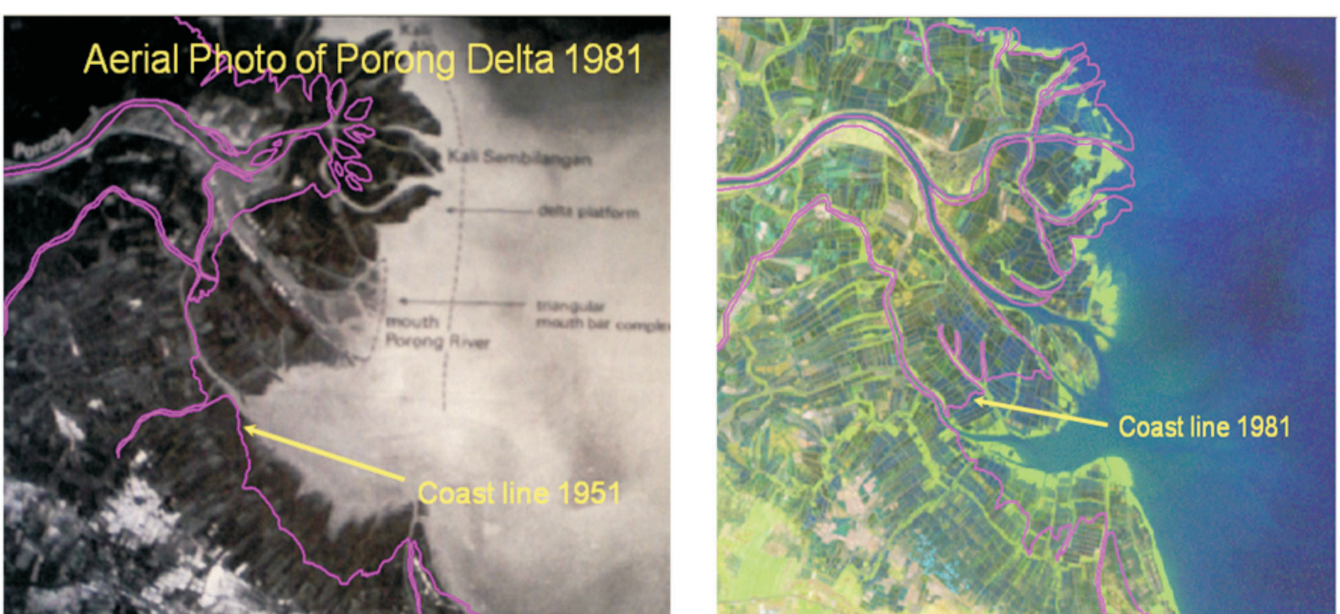

Figure 7: Porong River delta development on a aerial photo (left) and a Landsat TM Image 2002 (right).

Figure 8: Jetty of 5.2 km length (left) and coastal reclamation area of 40 ha where dredged mud was deposited (right; BPLS, 2011).

of anaerobic conditions (UNEP/OCHA Environment Unit, 2006). Indeed, our own studies revealed a dramatic drop of oxygen concentrations in the Porong after the mud volcano input during the dry season in 2008. Because of high discharge during the rainy season this effect was much less pronounced. Nevertheless, oxygen concentrations went down to 5-6 mg l^{-1}, i.e. <80% saturation (Figure 9; Jennerjahn et al., subm.). The mud volcano input also increased the total suspended matter (TSM) concentration of the Porong significantly. Because of very low input from the hinterland, TSM increased by orders of magnitude after the mud volcano input during the dry season. In the rainy season the TSM load coming from the hinterland was much higher. Nevertheless, the TSM concentration doubled after the mud volcano input (Figure 9).

Summary and Conclusions

The Brantas is the second largest river on Java and plays an important role in the supply of drinking water, energy and irrigation in its catchment. The regional development in terms of urbanization, population growth, intensive agriculture and industrial growth increased the risks of floods and droughts, land degradation, water deterioration and coastal change. To cope with this situation, the Brantas River Authority (Perum Jasa Tirta corporation (PJT)) developed a master plan consisting of four phases that included establishing water quality laboratories and automated water quality monitoring and the construction of water structures such as concrete dams, rubber dams, barrages, flood canals and a dyke system. However, effective storage capacity of reservoirs was rapidly reduced to 57-88% due to the anthropogenic activities such as intensive agriculture and urban development. As a result extreme rainfalls caused flooding in some areas again. Between 1991 and 1997, the dissolved inorganic nutrients concentration nitrate, ammonium and phosphate increased slightly downstream also as a result of intensive land use in the mid- and downstream regions. Ammonium concentrations oscillated strongly with high concentrations during times of low discharge indicating high organic matter decomposition.

A strongly prograding delta at the mouth of the Porong River is the result of an initially high sediment load from the hinterland which even increased due to land use change. The eruption of a mud volcano that ejected about 100,000 m^3 per day in 2008 added to the sediment load of the river. A portion of the mud was directed into the Porong leading to high suspended matter and low dissolved oxygen concentrations in the river. As a large part of the high suspended sediment load was already settled in the river, dredging was initiated in order to avoid blocking of the Porong. These activities resulted in 2.9 million m^3 of material which was then used for coastal reclamation. The high nutrient and sediment loads of the Brantas River are to a large extent the result of intensive human activities in the catchment like hydrological alterations and land-use change. Extreme natural events like the mud volcano exacerbate the consequences of human alterations on the water quality and biogeochemistry of the river.

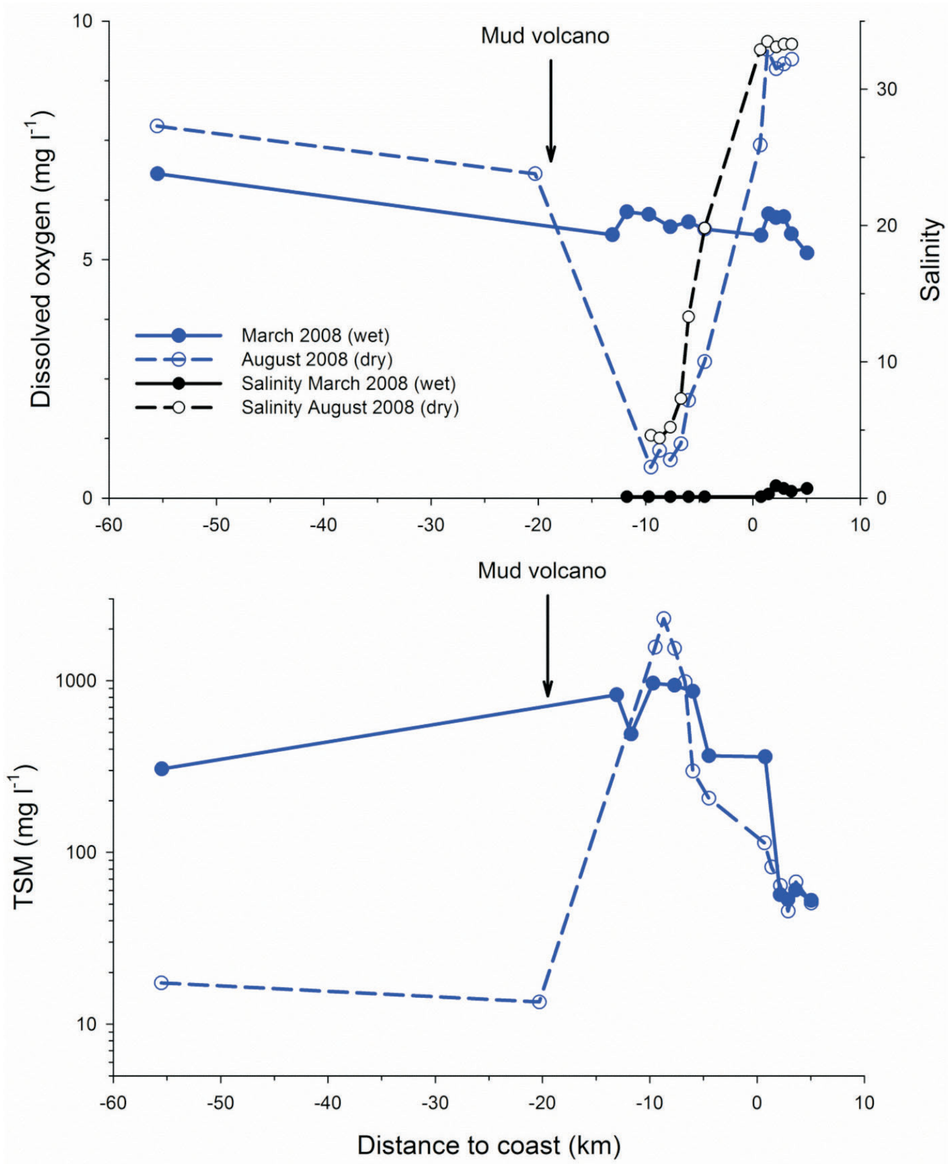

Figure 9: Physicochemical characteristics and total suspended matter (TSM) concentration in the Porong before and after the mud volcano input during the wet and dry seasons of 2008: Upper panel—dissolved oxygen and salinity, lower panel—TSM concentration.

Acknowledgements

Financial support by the German Federal Ministry of Education and Research is gratefully acknowledged (Grant Nos. 03F0301A and 03F0456C). We also thank Perum Jasa Tirta 1 for the data support.

References

Aldrian, E., Chen, C.-T.A., Adi, S., Prihartanto, Sudiana, N. and S.P. Nugroho (2008). Spatial and seasonal dynamics of riverine carbon fluxes of the Brantas catchment in East Java. *Journal of Geophysical Research*, **113:** JG000626.

Badan Pusat Statistik (BPS) Provinsi Jawa Timur (2010). Provinsi Jawa Timur Dalam Angka, Surabaya. www.bps.go.id.

Badan Penanggulangan Lumpur Sidoarjo/Agency for the Sidoarjo Mud volcano Reduction (BPLS) (2011). Kegiatan Penanganan Endapan Lumpur di Muara Kali Porong. www.bpls.go.id.

Davies, R.J., Mathias, S.A., Swarbrick, R.E. and M.J. Tingay (2011). Probabilistic longevity estimate for the LUSI mud volcano, East Java. *Journal of the Geological Society*, **168:** 517-523.

Harsaputra, I. (2011). Porong turnpike safe to use during exodus. *The Jakarta Post*, August 13, 2011.

Aldrian, E., Nugroho, S.P., Adi, S., Prihartanto and N. Sudiana (2006). The Final Project Report: The Brantas Catchment Water and Carbon Cycle. The Southeast Asia Regional Center for START (SARCS) – BPPT, Jakarta.

Hidayat, F., Sungguh, H.M. and Hatrianto (2009). Impact of Climate Change on Floods in Bengawan Sola and Brantas River Basins, Indonesia.

Hoekstra, P. (1989). River Outflow, Depositional Processes and Coastal Morphodynamics in a Monsoon-Dominated Deltaic Environment, East Java, Indonesia. Netherland Geographical Studies 87, Amsterdam.

Jänen, I., Seno Adi and T.C. Jennerjahn (2012). Spatio-temporal variations in nutrient supply of the Brantas River to Madura Strait coastal waters, Java, Indonesia, related to human alterations in the catchment and a mud volcano. *Asian Journal of Water, Environment and Pollution*, this issue.

Jennerjahn, T.C., Ittekkot, V., Klöpper, S., Adi, S., Nugroho, S.P., Sudiana, N., Yusmal, A., Prihartanto and B. Gaye-Haake (2004). Biogeochemistry of a tropical river affected by human activities in its catchment: Brantas River estuary and coastal waters of Madura Strait, Java, Indonesia. *Estuarine, Coastal and Shelf Science*, **60:** 503-514.

Jennerjahn, T.C., Nasir, B. and I. Pohlenga (2009). Spatio-temporal variation of dissolved inorganic nutrients related to hydrodynamics and land use in the mangrove-fringed Segara Anakan Lagoon, Java, Indonesia. *In:* Jennerjahn, T.C. and Yuwono, E. (eds.), Segara Anakan, Java, Indonesia: A mangrove-fringed coastal lagoon affected by human activities. Special issue. *Regional Environmental Change*, **9:** 259-274.

Jennerjahn, T.C., Jänen, I., Propp, C., Adi, S. and S.P. Nugroho. Environmental impact of mud volcano inputs on the anthropogenically altered Porong River and Madura Strait coastal waters, Java, Indonesia. *In:* Jennerjahn, T.C. and Mitchell, S. (eds.), Pressures, Stresses, Shocks and Trends in estuarine Ecosystems. Special issue. *Estuarine Coastal and Shelf Science* (submitted).

JICA (1998). The study on comprehensive management plan for the water resources of the Brantas River Basin in the Republic of Indonesia. Final Report, Main Report. The Republic of Indonesia, Ministry of Public Works, Directorate General of Water Resources Development.

Pawitan, H. (2004). Perubahan Penggunaan Lahan dan Pengaruhnya terhadap Hidrologi Daerah Aliran Sungai (Land use change and its impact on watershed hydrology). Laboratorium Hidrometeorology, FMIPA-IPB, Bogor.

Perum Jasa Tirta I (2001). Pedoman Operasi dan Pemeliharaan di DAS Kali Brantas – Cetakan III, Malang.

Perum Jasa Tirta I (2007). Management for water related disaster (flood) and water demand: Case study in the Brantas River. Symposium on River Environment and Water Resources Management, Japan.

Ramu, K. (2004). Brantas River basin case study Indonesia. Background paper. *In:* "Integrated River Basin and the Principle of Managing Water Resources at the Lowest Appropriate Level – When and Why does It (Not) Work in Practice? World Bank.

Seitzinger, S.P., Mayorga, E., Bouwman, A.F., Kroeze, C., Beusen, A.H.W., Billen, G., Van Drecht, G., Dumont, E., Fekete, B.M., Garnier, J. and J.A. Harrison (2010). Global river nutrient export: A scenario analysis of past and future trends. *Global Biogeochemical Cycles*, **24:** GB0A08, doi:10.1029/2009GB003587.

Smith, S.V., Swaney, D.P., Talaue-McManus, L., Bartley, J.D., Sandhei, P.T., McLaughlin, C.J., Dupra, V.C., Crossland, C.J., Buddemeier, R.W., Maxwell, B.A. and F. Wulff (2003). Humans, Hydrology, and the Distribution of Inorganic Nutrient Loading to the Ocean. *BioScience*, **53:** 235-245.

Smith, V.H., Tilman, G.D. and J.C. Nekola (1999). Eutrophication: Impacts of excess nutrient input on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution*, **100:** 179-196.

Toshikatsu, O. and K. Musiake (2003). Changes of runoff mechanism of the Brantas River over the past 30 years. Perum Jasa Tirta I and JICA.

Trie, M.S., Tjoek, W.S. and A. Harnanto (2005). Pengelolaan Sumberdaya Air. Bayumedia, Malang.

UNEP/OCHA Environment Unit (2006). Environmental assessment: Hot mud flow, East Java, Indonesia. Geneva.

Asian Journal of Water, Environment and Pollution

Volume 8 Number 2 **April – June, 2011**

Contents