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Volcanic Mud Contamination in the River Ecosystem: The Case Study of Lusi Mud Volcano, Indonesia

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ABSTRACT

The assessment of the impact of volcanic mud discharge into a river based on several quality indices including habitat quality index (HQI), water quality index (WQI) and fish biotic integrity (FIBI) using the case study of Lusi in Sidoarjo-Indonesia, was undertaken from January 2011 to February 2012. Compared to the data collected at the control station (HQI= 21; WQI= 59-75; FIBI=75), the siltation caused by the Lusi discharge adversely affected several factors. Firstly, the declining value of stream covers and aesthetics resulted in lower HQI (10-13); secondly, the increasing concentration of total suspended solids (TSS), biochemical and chemical oxygen demand (BOD and COD) resulted in low WQI, primarily in the dry season (22.3-49.3); and thirdly, the limited supporting habitat for cyprinids and the mud-intolerant native fish species lowered the FIBI score (60-65). The abundance of mud-tolerant species revealed that the downstream aquatic communities have the ability to adjust to the volcanic mud contamination. However, since there was a strong positive correlation between HQI and FIBI, the expected long term exposure to Lusi will be followed by more habitat degradation, thus limiting the life of fishes that are not tolerant to the mud and lowering of the quality indices permanently. Further investigations using *Mystus gulio* as the bioindicator for Lusi mud contamination is proposed, as follow-up research.

INTRODUCTION

The Sidoarjo mud volcano in Indonesia, also known as Lusi has been emitting mud nearly 90,000 m^3/day since 2006 (Istadi et al. 2009), and as estimated will continue for 26 more years (Davies et al. 2011). Lusi contains a high portion of very fine clay particles, which contain major metal Al, organic matter and a wide range of symbiotic bacteria (UNDAC 2006, Plumlee et al. 2008, Niemann & Boetius 2010, Jennerjahn et al. 2013, Hidayati et al. 2014). Lusi mud particle size of less than 10 µm (USGS 2008) could possibly have direct effect to the fishes by clogging onto the gill surfaces, and adhering to the spaces between the gill filaments (Muraoka et al. 2011). Previously, toxicity test in the laboratory found that Lusi lead the physical damage to gills (Hidayati 2010).

Lusi has been channeled to the adjacent river namely Porong river (the downstream of the biggest river in East Java, Brantas river). Porong river has an average depth of 1.6 m (Damar 2012) with average flow of 600 m^3 s^{-1} during wet season, while in dry season the flow commonly reduces to almost zero (Van der Linden 1989). The endurance of Lusi mud into Porong river, may result in the extreme suspended solids and increasing organic matter which is declining the water quality, as well as the siltation that buried the physical structure in river bed such as rocks, coarse woody debris (CWD) and macrophytes that are important to improve fish habitat quality (Kennedy & Johnston 1986, Roni & Quinn 2001, Thomaz & Ribeiro da Cunha 2010). Habitat quality is an essential measurement in any biological survey (Barbour et al. 1999). Zhang et al. (2014) reported that water quality and sediment pollution significantly affect the biotic integrity through direct effects on the fish community.

Hypothetically, the discharge of the Lusi effluent into the river for long periods will cause a decrease in the quality of water and habitat as well as adversely affect the life of aquatic organisms, included fish. Despite Indonesian freshwater has higher fish diversity than any other country (Dudgeon 2006), the environmental monitoring tools are not well developed in Indonesia (Pearce & Butler 2005). Generally, the study of environmental factors to the local riverine fish assemblages is carried out in temperate zones (compared to tropical ones), hence more studies in tropical rivers are required (Tejerina-Garro et al. 2005). Moreover, Boulton et al. (2008) reported that ecological process variables in the temperate region are similar to the tropical one. Ecological assessments using the physical and biotic indices had derived in temperate region, e.g. in western USA (Bryce et al. 2010), Texas (Pollack et al. 2009), Iowa (Wilton 2004) and North China (Zhang et al. 2014) as well as in tropical region, such as in West African river (Kamdem-Toham & Teugels 1999). This Lusi case study can be used to determine the impact of volcanic mud discharge on the river ecosystem from physical and biological indices (WQI, HQI and FIBI).

MATERIALS AND METHODS

Sampling sites: Description and duration: The Lusi mud volcano is located in the Sidoarjo district, East Java, Indonesia. To prevent the mud from flooding a nearby human settlement, the watery mud is collected initially in a settling pond from which it is channeled to the Porong River (Table 1 and Fig. 1).

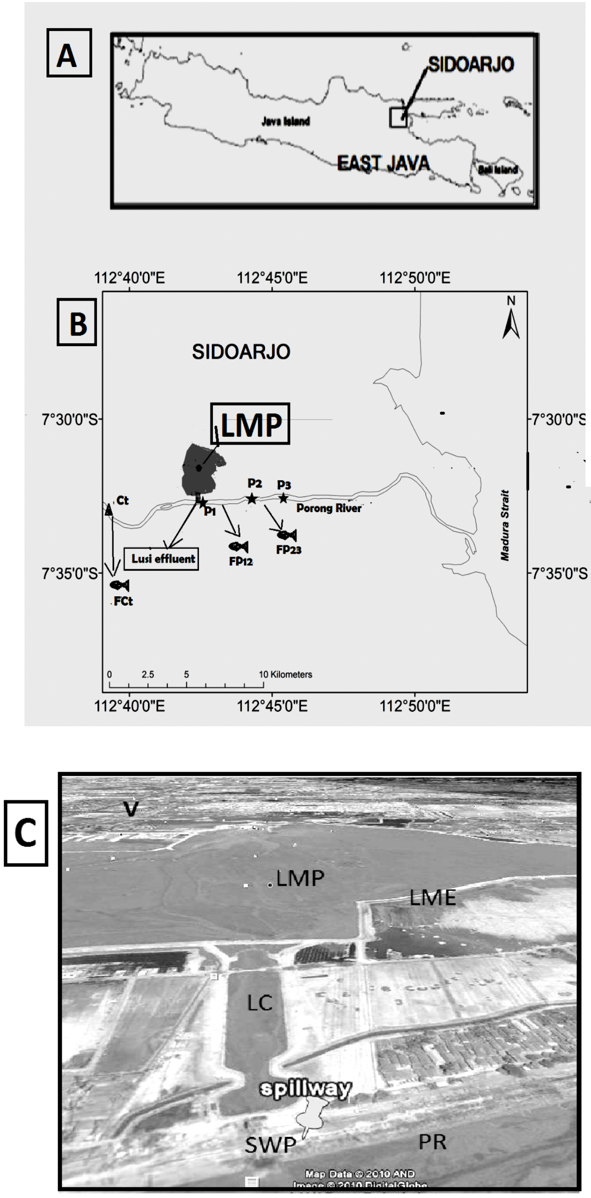
Water sampling during the survey period was carried out from January 2011 to February 2012, and coded S1, S4 and S5 for the wet season, while S2 and S3 represented the dry season. Meanwhile, the HQI observations and fish sampling activities were undertaken in the intermediate season between the wet and dry seasons (S1 - S2).

Water quality was analysed according to the WQI of DOE Malaysia, which has been successfully applied to measure water quality for rivers in Malaysia as well as Indonesia (Susilo & Febrina 2011). The WQI serves as the basis for environmental assessment of a water course in relation to pollution load using the following variables: DO (Dissolved Oxygen), BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), AN (Ammonium Nitrogen), TSS (Total Suspended Solids) and pH. Then, all variables are combined into a single number which is used for categorization and designation of classes of beneficial uses (DOE Malaysia 2010, Susilo & Febrina 2011, Abassi & Abassi 2012).

The parameters namely DO, temperature, pH and ammonium nitrogen were measured at the sampling sites using the water quality tester, TROLL ® 9500. Platinum sensors were cleaned with a swab dipped in alcohol and gently rubbed (Geotech 2009). Salinity was measured by placing a drop of water sample onto the refractometer and reading the value.

Water samples were preserved in an icebox for 24 hours prior to analysis of TSS, BOD and COD in the laboratory in accordance to the methodology of the USEPA (1971, 1974, 1978). After analysis, classification of the water quality based on the WQI of the DOE Malaysia was as follows: Class I (< 92); Class II (76.5-92.7); Class III (51.9-76.5); Class IV (31.0-51.9); Class V (<31.0).

Assessment of the physical habitat quality was done in accordance to the standards of the Texas Commission on



LMP= Lusi Mud Pond; LME=Lusi Mud Embankment; V=Village; LC=Lusi Channel; SWP=Spillway pipe (effluent pipe); PR=Porong river

Fig. 1: Map showing the sampling stations.
Note: (A) The Lusi mud volcano is located in the Sidoarjo district-East Java Province. (B); (C): The mud flow is collected in the Lusi Mud Pond (LMP) from which it is channelled to the Porong River (Source of Lusi's satellite image, CRISP (2010)).

Environmental Quality (TCEQ 2004), which included parameters such as availability of in-stream cover, bottom substrate stability, number of riffles, dimensions of the largest pool and channel flow status, bank stability, channel sinuosity and aesthetics of reach (Table 2). Most of the physi-

Table 1: Description of sampling stations.

Parameter	Station	Site description and coordination
Water and habitat	P1	Located at the area of initial discharge (closest to the Lusi Effluent quality Pipe (LEP), coordinates: 7°32’41.8’S; 112°42’ 31.67’E
	P2	At an area about 3 km from the LEP, coordinates: 7°3242.91’S; 112°4349.53’E
	P3	At an area about 4 km from the LEP, coordinates: 7°32’36.57’S; 112°44’ 35.06’E
	Ct	Located about 6 km upstream, and it represented a Lusi-free station, coordinates: 7°33’ 10.42’S; 112°39’ 30.32’E
Fish integrity	F12	Located between P1 and P2
	F23	Located between P1 and P2
	FCt	Located at Ct station area

cal habitat data were obtained by visual observations, which were supported by photographs and when necessary enhanced with online satellite imaging. In addition, sediments and cover types on the riverbed such as cobbles, undercut banks and coarse woody debris, which were used to identify the substrates and in stream covers, were collected using a sediment grab sampler. Classification of substrates based on particle size was determined based on the Wentworth Grade Scale by sieving sediment samples through a series of sieve sizes ranging from 1.25 mm up to 63 mm (UNEP/WHO 1996).

The fish sampling methods adopted were of the Wilton (2004) and ARI (2011). Both the methods have several similarities with current research, i.e. sampling location of river, fish sampling technique that combines fishing gear and electric shock; measurement of biological integrity and physical habitat. Moreover, Wilton (2004) sampling methods are well proven and widely used across Iowa State since 1994. Fish were captured using fishing gear combined with electric shock. The fishing gear was a net with 2 mm mesh size, 2.5 m deep and 46 m length. The pulsed direct current (DC) was delivered in waveform to the water, by which the fish gets stunned and is easily collected with a gear. The fishing gear was hauled from a boat as well as walked onto the banks at approximate length area of 350 m passed through downstream to upstream.

The collected fish were placed in tanks of water, and then most fish species were identified in the field according to the reference of Fischer & Bianchi (1984) and Froese & Pauly (2011). Their total and standard length were measured prior to returning them to the water. However, unidentified fish species were preserved in 10% formalin solution prior to be identification in laboratory. In addition, the Fish Index for Biotic Integrity (FIBI) was calculated using the scoring system of component metrics (Table 3) from Moyle & Marchetty (1999). FIBI is a combination of several individual measures or metrics (Table 3), which have an ecologically relevant and quantifiable attribute of the aquatic biological community. The metrics response may be used to predict the environmental disturbances (Wilton 2004). Categories of fish metrices, whether they are native, carnivore or tolerant, were determined referring to the fish database that is listed by Froese & Pauly (2011).

RESULTS AND DISCUSSION

The bottom substrate analysis is important to determine the score of physical habitat quality (HQI) parameters such as in-stream cover and substrate stability. The substrate composition in the Lusi-receiving stations, i.e. P1, P2 and P3 lacked gravels (0%). The highest percentage of clay (77%) was found in the P1 stations, which were located at the initial discharge area of the Lusi effluent.

Substrate composition in the Lusi-receiving stations possibly occurred due to sedimentation and siltation, which were affected by the long period of the Lusi discharge that was rich in clay (particle size of 0.004-0.00024 mm) and dominated by fine particles less than approximately 10 micrometers (Plumlee et al. 2008). During the research, measured discharge of Porong river was in level of 16.7-81.4 $m^3 s^{-1}$ in dry season and 128-316.7 $m^3 s^{-1}$ in wet season. Volume of Lusi that moved to the Porong River was reported about 30.5-41.9 million m^3/year, while the density of particles was 2.19×10^3 kg/m^3 (BPLS 2011, Hidayati et al. 2014, Yanuar et al. 2009). This meant that the values of several habitat parameters including those available in the stream cover (HQI score=1-2), bottom stability (HQI score=1) and dimensions of the river pool (HQI score=1-3) in the Lusi-receiving stations, primarily at P1, were lower than those of the control station which was free from Lusi (Table 4).

Moreover, the fine particles in the Lusi discharge were considered the main factor for the high levels of TSS in the Lusi-receiving stations (Fig. 3) as they affected the water clarity and lowered the score of aesthetics parameter (HQI score=1). The HQI of the Lusi-receiving stations (P1=10; P2=12; P3= 13) was lower than that of the control station (Fig. 2). According to the results obtained for HQI, the sta-

Table 2: Scoring method for Habitat Quality Index (HQI) based on the method of the Texas Commission on Environmental Quality (TCEQ 2004)

Habitat Parameter	Scoring Category			
Available In-stream Cover	Abundant (score: 4) >50% of substrate favourable for colonization and fish cover; good mix of several stable (not new fall or transient) cover types such as snags, cobble, undercut banks, macrophytes	Common (score: 3) 30-50% of substrate supports stable habitat; adequate habitat for maintenance of populations; may be limited in the number of different habitat types	Rare (score: 2) 10-29.9% of substrate supports stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed	Absent (score: 1) <10% of substrate supports stable habitat; lack of habitat is obvious; substrate unstable or lacking
Bottom Substrate Stability	Stable (score: 4) >50% gravel or larger substrate; gravel, cobble, boulders; dominant substrate type is gravel or larger substrate.	Moderately Stable (score 3) 30-50% gravel or larger substrate; dominant substrate type is a mix of gravel with some finer sediments	Moderately Unstable (score:2) 10-29.9% gravel or larger substrate; dominant substrate type is finer than gravel, but may still be a mix of sizes	Unstable (score: 1) <10% gravel or larger substrate; substrate is uniform sand, silt, clay or bedrock
Number of Riffles	Abundant (score: 4) > 5 riffles	Common (score: 3) 2-4 riffles	Rare (score: 2) 1 riffle	Absent (score: 1) No riffles
Dimensions of Largest Pool	Large (score: 3) Pool covers more than 50% of the channel width; maximum depth is >1 m	Moderate (score: 2) Pool covers approximately 50% or slightly less of the channel width; maximum depth is 0.5-1 m	Small (score: 1) Pool covers approximately 25% of the channel width; maximum depth is <0.5 m	Absent (score: 0) No existing pools; only shallow auxiliary pockets
Channel Flow Status	High (score: 3) Water reaches the base of both lower banks; < 5% of channel substrate is exposed	Moderate (score: 2) Water fills >75% of the channel; or <25% of channel substrate is exposed	Low (score: 1) Water fills 25-75% of the available channel and/or riffle substrates are mostly exposed	No Flow (score: 3) Very little water in the channel and mostly present in standing pool
Bank Stability	Stable (score: 3) Little evidence (<10%) of erosion or bank failure; bank angles average <30°	Moderately Stable (score: 2) Some evidence (10-29.9%) of erosion or bank failure; small areas of erosion mostly healed over; bank angles average30-39.9	Moderately Unstable (score: 1) Evidence of erosion or bank failure is common (30-50%); high potential of erosion during flooding; bank angles average 40-60°	Unstable (score: 0) Large and frequent evidence (>50%) of erosion or bank failure; raw areas seen frequently along steep banks; bank angles average >60°
Channel Sinuosity	High (score: 3) > 2 well-defined bends with deep outside areas (cut banks) and shallow inside areas (point bars) present	Moderate (score: 2) 1 well-defined bend or > 3 moderately defined bends present	Low (score: 1) <3 moderately defined bends or only poorly-defined bends present	None (score: 0) Straight channel; may be channelized
Riparian Buffer Vegetation	Extensive (score: 3) Width of natural buffer is >20 m	Wide (score: 2) Width of natural buffer is 10.1-20m	Moderate (score: 1) Width of natural buffer is 5-10 m	Narrow (score: 0) Width of natural buffer is <5m
Aesthetics of Reach	Wilderness (score: 3) Outstanding natural beauty; usually wooded or unpastured area; water clarity is usually exceptional	Natural Area (score: 2) Trees and/or native vegetation are common; some development evident (from fields, pastures, dwellings); water clarity may be slightly turbid	Common (score: 1) Setting Not offensive; area is developed, but uncluttered such as in an urban park; water clarity may be turbid or discolored	Offensive (score: 0) Stream does not enhance the aesthetics of the area; cluttered highly developed; may be a dumping area; water clarity is usually turbid or discolored

Note: Status of Habitat Quality based on Total Score of HQI: 26 – 31 (Exceptional); 20 – 25 (High); 14 - 19 (Intermediate) and < 13 Limited

Table 3: Component metrics and scoring methods for the Index of Fish Biotic Integrity (FIBI) adopted from Moyle & Marchetty (1999).

	Component Metrics	Score 1	3	5
I	Percentage native fish species	<20%	20-80%	>80%
II	Number of native species present	0-1	2-4	>4
III	Number of age classes, cyprinids	0-1	2	3+
IV	Total number of fish species	<5	5-7	>7
V	Total fish abundance	low number present	common, small numbers captured without difficulty	abundant, easy to capture in large numbers
VI	Percentage top carnivores	<1%	1-5%	>5%
VII	Percentage tolerant species	>20%	5-20%	<5%
VIII	Percentage introduced species	>40%	10-40%	<10%

Notes: IBI Score = [Total points/Number of metrics] × 20
Status of aquatic communities
80-100 Aquatic communities in very good to excellent condition
60-79 Aquatic communities in good condition
40-59 Aquatic communities in fair condition
<40 Aquatic communities in poor condition

Table 4: Habitat Quality Index (HQI) in the control area and in Lusi-receiving stations.

Station	Score of HQI parameter										
	I	II	III	IV	V	VI	VII	VIII	IX	HQI	Status
Ct	3	3	1	4	3	1	2	2	2	21	High
P1	1	1	2	1	1	3	0	0	1	10	Limited
P2	1	1	1	3	2	3	0	0	1	12	Limited
P3	2	1	1	3	2	3	0	0	1	13	Limited

Notes: I = available in stream cover; II = bottom substrate stability; III = number of riffles; IV = dimensions of largest pool; V = channel flow status; VI = bank stability; VII = channel sinuosity; VIII = riparian buffer vegetation; IX = aesthetics of reach

tus of habitat quality at the Lusi-receiving stations was rated as “limited”, while at the control station the rating was “high”.

As previously described, the Lusi discharge was responsible for the high concentration of TSS in the Lusi-receiving stations ([P1=676-4176]; [P2=459-1146]; [P3= 493-1013] mg/L). These concentrations were found to be significantly higher ($p<0.05$) than the TSS concentration at the control station (Ct=40-380.5 mg/L) primarily in the dry season. Furthermore, the Pearson analysis indicated that the TSS was positively correlated to the BOD ($r=0.80$) and this explains why the highest concentrations of TSS (4176 mg/L) as well as BOD (120.5 mg/L) occurred at the same station and time as seen at P1, S2 (Fig. 3). Hydrocarbon content in the sediments of the mud volcano supports chemosynthesis in various bacteria (Niemann & Boetius 2010, Yang et al. 2012). Moreover, Jennerjahn et al. (2013) reported that the Lusi input increased the concentration of suspended matter and the load of particulate organic carbon (POC), which have the potential to increase BOD as well as COD levels (Quayle 2009). Consequently, the high levels of TSS, BOD and COD contributed to the low WQI level (Fig. 4).

The multivariate and Tukey test indicated that WQI at all stations receiving Lusi were significantly lower ($p<0.05$) than that of the control stations. Compared to the range of the WQI in the control site (59-75), the station P1, located at the site of the initial discharge of Lusi exhibited the lowest WQI (19-63) and was most often categorized in class IV. Meanwhile, the WQI at P2 (35-69) and P3 (31-62), generally categorized in Class III, was significantly higher ($p<0.05$) than that of P1. Overall the WQ1 at the Lusi-receiving stations, during the dry season was significantly lower than wet season ($p<0.05$). This declining trend in WQI (22.3-49.3) resulted in the lowering of the water class (Fig. 4).

The presence of rocks and coarse woody debris (CWD) in the river bed increases the riffle areas that increase the dissolved oxygen, enhancement of habitat diversity, hence improving fish habitat quality primarily for juvenile and followed by increasing the fish communities (Kennedy & Johnston 1986, Roni & Quinn 2001). Macrophytes provide the physical structure for fish nursery, improve the complexity and diversity of habitats that can increase the diversity of life for animals such as invertebrates, fish and water birds (Thomaz & Ribeiro da Cunha 2010) as well as in-

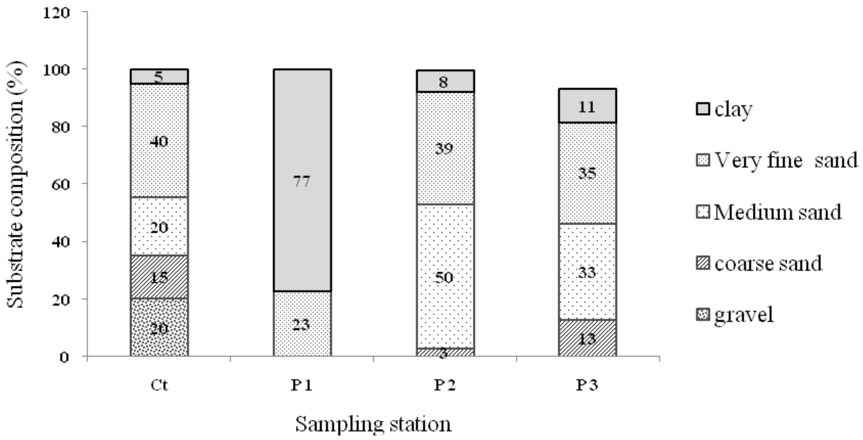


Fig. 2: Comparison of the substrate composition in the Lusi-receiving stations (P1, P2 and P3) and the Control (Ct) station.

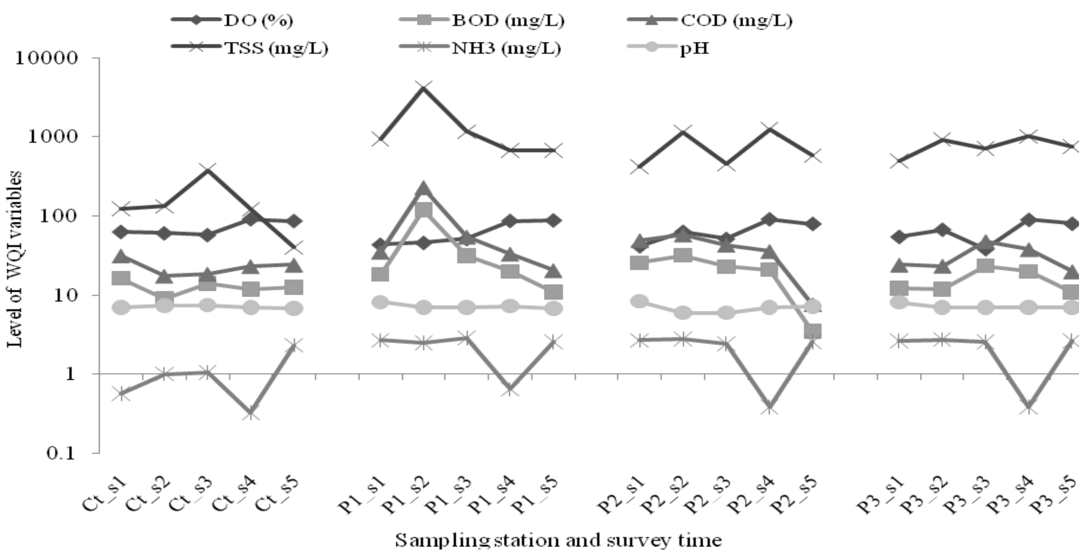


Fig. 3: Comparison of the values of the WQI-variables (TSS, DO, BOD, COD, NH_3 and pH) among sampling stations and time of survey (S1, S2, S3, S4 and S5).

crease the level of dissolved oxygen (Hunt & Christiansen 2000). The siltation of the Porong river by the Lusi discharge contributed to the lack of in-stream covers (Fig. 2 and Table 4) including gravel, buried CWD and aquatic macrophytes (Chen et al. 2014) thus causing adverse effects on the fish population.

With reference to the composition of fish species (Table 6), it was observed that the percentage of the fish species *Mystus gulio* (Hamilton) at (44%) and *Saurida tumbil* (Bloch) at (39%) occurred in abundance at the Lusi-receiving stations (FP12 and FP23) despite being exposed to Lusi contamination. The study on effect of Lusi exposure to the milkfish (Hidayati 2010) indicated that Lusi caused gill alteration. The fine Lusi particles were possibly attached to the surface of the gills and filled the space between the gill filaments that causes the oxygen deficiency as a result of changes in gill respiratory surface area (Plumlee et al. 2008, Muraoka et al. 2011). Visually, the gill surface of M. *Gulio*, which caught in Lusi effluent area (P1), was physically covered by mud (Fig. 5). The survival of M. *gulio* is likely to be related to its behavioural characteristic of facultative air breathing (Veerasamy 2012). Concentrations of Al and Fe in all sediment samples of Lusi-receiving stations (Hidayati 2014) did not exceed the reference level of soil and clay (UNDAC 2006, Hidayati 2014). The observed pH level in all sampling stations was in safe level (pH=7-7.24) according to the National Recommended Water Quality Criteria (USEPA WQC 2009), that is stipulated in the range of 6.5-

9.0. The Al toxicity relatively depended on the ambient pH (Jezierska & Witeska 2006); since the water showed near-neutral pH, Lusi effect to the fish might be related to its particle size rather than Al as the major metal.

Rusch & Oesterheld (1997) suggested that it is important to use the dominant species as the bioindicator of water pollution. *M. gulio* is the potential candidate for use as the bioindicator of the Lusi contaminated river due to its dominance at the Lusi-receiving stations. In addition, its presence in a previous investigation by Herlina et al. (2005) suggested that M. *gulio* could adapt to extreme changes in the concentration of suspended solids and through modification of substrates. Moreover, its body size range of 5.2 to 20.4 cm, indicated that all growth phases of M. *gulio* may have adapted well to the Lusi exposure.

The finding, based on the composition and identification of fish biotic integrity (FIBI) criteria (Table 5 and Table 6), resulted in the FIBI order, of FCt (75) > FP23 (65) > FP12 (60). The lowest FIBI score was that exhibited at station FP12 and this was seemingly attributed to the absence of cyprinids (Table 3 and Table 4), which were limited because of the low HQI and WQI scores (Beamish et al. 2006).

Table 7 shows that the FIBI showed positive strong correlation with the HQI (r= 0.99) and was moderately correlated to the WQI (r= 0.62). A previous investigation by Herlina et al. (2005) recorded that Cyprinidae (genus *Barbodes/Puntius*) were present in the study area. Cyprinids possibly live in fast flowing rivers that are supported by gravel and rock substrates (Rachmatika et al. 2005). Lack of gravel in FP12 lowered the HQI score due to changes in the bottom substrates ability (Table 2), could possibly be responsible for the absence of cyprinids (Table 3).

With reference to the status of aquatic community (Table 6), it was indicated that integrity of the fish community at the Lusi-receiving stations was in a good condition as that found at the control station. Results revealed that the river was able to adjust the extreme mud contamination and maintain its community by the survival of mud-tolerant native species such as M. *gulio* and S. *tumbil* (Table 5). However, reference to Table 4 indicated that the volcanic mud caused decrease in habitat quality that could support cyprinids and mud-intolerant native fish species. Further adverse impact on fish assemblage could possibly occur due to the predicted long period of the mud volcano eruptions (Davies et al. 2011), and this could probably cause the lowering of the indices permanently. Further investigations using M. *gulio* as the bioindicator for Lusi mud contamination is proposed, as a follow up research.

Table 6: FIBI scoring according to Moyle & Marchetty (1999).

Metrics	Precentage (%) or number of species			Score (1-3-5)		
No.	FCt	FP12	FP23	FCt	FP12	FP23
I	100%	100%	71%	5	5	3
II	5	3	5	5	3	5
III	2	0	2	3	1	3
IV	5	3	7	3	1	3
V	Common	Common	Common	3	3	3
VI	20%	67%	43%	5	5	5
VII	40%	100%	86%	1	1	1
VIII	0%	0%	29%	5	5	3
Total Score				30	24	26
IBI				75	60	65
Status of Aquatic Communities				Good	Good	Good

Table 7: The Pearson correlation analysis between quality assessment indexes.

		Correlations			
		Station	IBI	HQI	WQI
Station	Pearson Correlation	1.00	0.92**	0.91**	0.56**
	Sig. (2-tailed)		0.00	0.00	0.00
IBI	Pearson Correlation		1.00	0.99**	0.62**
	Sig. (2-tailed)			0.00	0.00
HQI	Pearson Correlation			1.00	0.59**
	Sig. (2-tailed)				0.00
WQI	Pearson Correlation				1.00

** Correlation is significant at the 0.01 level (2-tailed), N=60

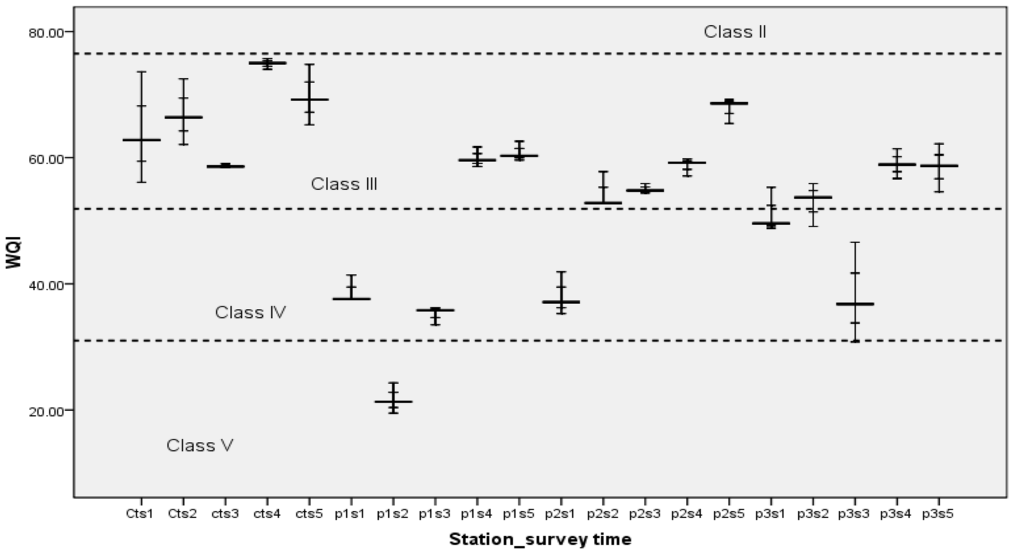


Fig. 4: Comparison of the levels of WQI and water classification among sampling stations and time of survey (S1, S2, S3, S4 and S5).

Table 5: Composition and identification of fish biotic integrity criteria

Station	Name of Species	Family	Carnivore No. of Caught	Native or Intermediate	Tolerance	Feeding habit	Total species	Number of native species	Number of cyprinids	Number of tolerant species	Number of Carnivores
FCt	*Anabas testudineus*	Anabantidae	3	Nat	v	Om					
	Barbonymus altus	Cyprinidae	3	Nat	X	Om					
	Lutjanus griseus	Lutjanidae	1	Nat	v	Car	5	5	2	3	1
	Puntius binotatus	Cyprinidae	2	Nat	X	Om					
	Trichopodus tricopterus	Osphronemidae	1	Nat	v	Om					
FP12	*Mugil cephalus*	Mugilidae	8	Nat	v	Om					
	Mystus gulio	Bagridae	25	Nat	v	Car	3	3	0	3	2
	Saurida tumbil	Synodontidae	8	Nat	v	Car					
FP23	*Barbonymus altus*	Cyprinidae	2	Nat	X	Om					
	Mugil cephalus	Mugilidae	4	Nat	v	Om					
	Mystus gulio	Bagridae	20	Nat	v	Car					
	Oreochromis niloticus	Cichlidae	2	Int	v	Om	7	5	2	6	3
	Rasbora argyrotaenia	Cyprinidae	1	Int	v	Her					
	Saurida tumbil	Synodontidae	32	Nat	v	Car					
	Terapon theraps	Terapontidae	1	Nat	v	Car					

Notes: Nat = Native; Om = omnivore; Car = carnivore; Her = herbivore

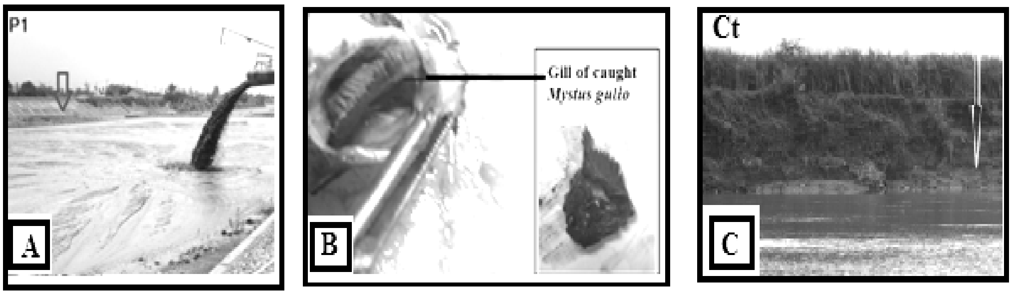


Fig. 5: Site sampling condition: A. Lusi-receiving station (P1); B. Performance of M. *gulio* gill that caught in P1; C. Control station (Ct). Arrow shows water body performance, where Lusi-receiving station exhibit highly siltation.

CONCLUSION

Based on the Lusi case, there has been an indication that the volcanic mud discharge into the river has resulted in the degradation of the habitat and water quality, resulting in the lowering of the class of water, and subsequently lower FIBI scores. However, the river has adjusted to the volcanic mud contamination and with the survival of mud-tolerant species.

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REFERENCES

Abassi, T. and Abassi, S.A. 2012. Water Quality Indices. Elsevier, Oxford UK, pp. 384.

ARI 2011. Documenting fish assemblages in the Anglesea river estuary following acidification events. Anglesea River Fish Survey Report. The Arthur Rylah Institutes, DSE.

Barbour, M.T., Gerritsen, J., Snyder, B.D. and Stribling, J.B. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. 2nd edition, EPA/841-B-99-002. U.S., Environmental Protection Agency, Office of Water, Assessment and Watershed Protection Division, Washington D.C.

Beamish, F.W.H., Saardrit, P. and Tongnunui, S. 2006. Habitat characteristics of the Cyprinidae in small rivers in central Thailand. Environmental Biology of Fishes, 76: 237-253.

Boulton, A.J., Boyero, L, Covich, A.P., Dobson, M., Lake, S. and Pearson, R. 2008. Are tropical streams ecologically different from temperate streams? In: Tropical Stream Ecology. Elsevier Inc. 256-257.

BPLS 2011. Badan Penanggulangan Lumpur Sidoarjo Review Rencana-strategis 2010-2014. Badan Pelaksana BPLS (Strategic plan Review of Sidoarjo Mud Management Agency) http://www.bpls.go.id/penanganan-luapan-ke-kali-porong. Accessed 14th of July 2014.

Bryce, S.A., Lomnicky G.A. and Kaufmann, P.R. 2010. Protecting sediment-sensitive aquatic species in mountain streams through the application of biologically based streambed sediment criteria. Journal of the North American Benthological Society, 29(2): 657-672.

Chen, X., Deng, Z., Xie, Y., Feng, Li., Hou, Z., Xu, L. and Li, Y.F. 2014. Effects of sediment burial disturbance on the vegetative propagation of *Phalaris arundinacea* with different shoot statuses. Aquatic Ecology, 48(4): 409-416.

CRISP 2010. Centre for Remote Imaging, Sensing and Processing National University of Singapore. https://crisp.nus.edu.sg/coverages/EJmudflow/index20101117.html. Accessed on 7th December 2010.

Damar, A. 2012. Net phytoplankton community structure and biomass dinamics in the Brantas River estuary, Java, Indonesia. In: Subramanian. V. (Ed.) Coastal Environment Focus Asian Coastal Region, pp. 173

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

DOE (Department of Environment) Malaysia. 2010. Malaysia Environmental Quality Report. Edited by Publication Section Strategic Communications Division Department of Environment Malaysia. Kuala Lumpur: Ministry of Natural Resources and Environment Malaysia, pp. 78.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawataba, Z.I., Knowler, D.J., Leveque, C., Naiman, R.J. et al. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. Biological Reviews, 81: 163-182.

Fischer, W. and Bianchi, G. 1984. FAO Species Identification Sheets for Fishery Purposes. Western Indian Ocean (Fishing Area 51). Prepared and printed with the support of the Danish International Development Agency (DANIDA). Rome, Food and Agricultural Organization of the United Nations, Vol. I.

Froese, R. and Pauly. D. 2011. Fish Base. World Wide Web Electronic Publication. www.fishbase.org.

Geotech 2009. Multi Parameter TROLL 9500 Operator's Manual. www.geotechenv.com.

Herlina, E., Kusumaningrum, N.S., Rahmawati, N.Z. 2005. Ancaman penurunan kualitas air Sungai Brantas terhadap kelestarian diversitas dan perilaku makan ikan lokal. Laporan Program Kreativitas Mahasiswa Penelitian. Direktorat P2M Dikti, LPPM Universitas Brawijaya Malang, Indonesia.

Hidayati, D. 2010. An evaluative study on Sidoarjo mud flow after phytoremediation treatment in milk fish (*Chanoschanos*) liver. IPTEK- The Journal for Technology and Science, 21: 28-31.

Hidayati, D., Norela, S., Ismail, B.S. and Shuhaimi-Othman, M. 2014.

Impact of mud volcano lava to the aquatic life using the fish biological study case in Lusimud volcano Indonesia. Research Journal of Environmental Toxicology, 8: 1-24.

Hunt, R.J. and Christiansen, I.H. 2000. Dissolved Oxygen Information Kit. A CRC Sugar Technical Publication, CRC for Sustainable Sugar Production, Townsville, pp. 27.

Istadi, B., Pramono, G.H., Sumintadireja, P. and Alam, S. 2009. Modeling study of growth and potential geohazard for Lusi mud volcano East Java, Indonesia. Marine and Petroleum Geology, 26: 1724-1739.

Jennerjahn, T.C., Janen, I., Propp, C., Adi, S. and Nugroho, S.P. 2013. Environmental impact of mud volcano inputs on the anthropogenically altered Porong River and Madura Strait coastal waters, Java, Indonesia. Estuarine, Coastal and Shelf Science, 130: 152-160.

Jezierska, B. and Witeska, M. 2006. The metal uptake and accumulation in fish living in polluted waters. In: Twardowska, I., Allen, H.E., M.M., Haggblom, M.M. and Stefaniak, S. (Eds.) Soil and Water Pollution Monitoring. Protection and Remediation, Springer, New York, pp. 107-114.

Kamdem-Toham, A. and Teugels, G.G. 1999. First data on an index of biotic integrity (IBI) based on fish assemblages for the assessment of the impact of deforestation in a tropical West African river system. Hydrobiologia, 397: 29-38.

Kennedy, G.J.A. and Johnston, P.M.A. 1986. Review of salmon (*Salmosalar* L.) research on the river Bush. In: Crozier, W.W., Johnson, P.M (eds.) Proceedings of the 17th Annual Study Course, Institute of Fisheries, pp. 49-69.

Moyle, P.B. and Marchetti, M. 1999. Application of indices of biotic integrity to California streams and watersheds. In: Simon, T.P. (ed.) Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC Press, Boca Raton, Florida, pp. 367-379.

Muraoka, K., Amano, K. and Miwa, J. 2011. Effects of suspended solids concentration and particle size on survival and gill structure in fish. Proceedings of the 34th World Congress of the International Association for Hydro-Environment Engineering and Research, June 26-July 1, 2011, Brisbane Convention and Exhibition Centre, Brisbane, Australia, pp. 2893-2900.

Niemann, H. and Boetius, A. 2010. Mud volcanoes. In: Timmis K.N. (ed.) Handbook of Hydrocarbon and Lipid Microbiology, Springer-Verlag, Berlin Heidelberg, pp. 205-214.

Pearce, D.G. and Butler, R.W. 2005. Contemporary Issues in Tourism Development. Taylor and Francis E-library, pp. 249.

Plumlee, G.S., Casadevall, T.J., Wibowo, H.T., Rosenbauer, R.J., Johnson, C.A., Breit, G.N. and Lowers, H.A. et al. 2008. Preliminary analytical results for a mud sample collected from the Lusi mud volcano, Sidoarjo, East Java, Indonesia. U.S. Geological Survey Open-File Report.

Pollack, J.B., Kinsey, A.P. and Montagna, A. 2009. Freshwater inflow biotic index (FIBI) for the Lavacea-Colorado Estuary Texas. Environmental Bioindicator, (4): 153-169.

Quayle, W.C., Fattore, A., Zandona, R., Christen, E.W. and Arienzo, M. 2009. Evaluation of organic matter concentration in winery wastewater: a case study from Australia. Water Science and Technology, 60(10): 2521-2528.

Rachmatika, I., Nasi, R., Sheil, D. and Wan, M.A. 2005. First look at the fish species of the middle Malinau. Center for International Forestry Research (CIFOR), Bogor, Indonesia, pp. 34-35.

Roni, P. and Quinn, T.P. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences, 58(2): 282-292.

Rusch, G.M. and Oesterheld, M. 1997. Relationship between productivity and species and functional group diversity in grazed and non-grazed pampas grassland. Oikos, 78: 519-526.

Susilo, G.E. and Febrina, R. 2011. The siplification of DOE water quality index calculation procedures using graphical analysis. Australian Journal of Basic and Applied Sciences, 5(2): 207-214.

TCEQ 2004. Texas Commission on Environmental Quality TCEQ-20156-C (Rev. 04-15-2004). Surface water quality monitoring program. Habitat Assessment Worksheet-Part III Habitat Quality Index.

Tejerina-Garro, F.L., Maldonado, M., Ibañez, C., Pont, D., Roset, N. and Oberdorff, T. 2005. Effects of natural and anthropogenic environmental changes on riverine fish assemblages: A framework for ecological assessment of rivers. Brazilian Archives of Biology and Technology, (48): 1.

Thomaz, S.M. and Ribeiro da Cunha, E. 2010. The role of macrophytes in habitat structuring in aquatic ecosystems: methods of measurement, causes and consequences on animal assemblages composition and biodiversity. Acta Limnologica Brasiliensia, 22(2): 218-236.

USGS (U.S. Geological Survey) 2008. Volcano Hazards Program (VHP) Photo Glossary: Mud Volcano. http://volcanoes.usgs.gov/about/pglossary/MudVolcano.php.

UNDAC (United Nation Disaster Assesment and Coordination) 2006. Environmental assessment hot mud flow East Java Indonesia. Published in Switzerland by the Joint UNEP/OCHA Environment Unit, 1-56, Final Technical Report, July 2006.

UNEP/WHO 1996. Water quality monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes. In: Bartram J. and R. Ballance (eds.) Sediment Measurements, UNESCO, WHO and UNEP, London, UK, pp. 1-15.

USEPA 1971. Method 160.2, Residue, Non-filterable (gravimetric, dried at 103-105°C).

USEPA 1974. Method 405.1. Biochemical Oxygen Demand (5 Days, 20°C).

USEPA 1978. Method 410.1. Chemical Oxygen Demand (Titrimetric, Mid-Level). Approved for National Pollutant Discharge Elimination System (NPDES). Editorial Revision.

USEPA, WQC 2009. National Recommended Water Quality Criteria. https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

Van der Linden, W.J.M., Cloetingh, S.A.P.L., Kaasschieter, J.P.H., Jef Vandenberghe, Van de Graaff, W.J.E. and Van der Gun, J.A.M. 1989. Coastal Lowlands: Geology and Geotechnology. Kluwer Academic Publishers. Springer.

Veerasamy, M.A. 2012. Study of impact distillery waste on the catfish *Mystus gulio* (Hamilton). Department Zoology, Barathidasan University, India.

Wilton, T. F. 2004. Iowa Biological Assessment of Iowa's Wadeable Stream. Iowa Department of Natural Resources.

Yang, H.M., Lou, K., Sun, J., Zhang, T. and Ma, X.L. 2012. Prokaryotic diversity of an active mud volcano in the Usu City of Xinjiang, China. Journal of Basic Microbiology, 52(1): 79-85.

Yanuar, R., Budiarso and Koestoer, R.A. 2009. Hydraulics convances of mud slurry by a spiral pipe. Journal of Mechanical Science and Technology, 23(7): 1835-1839.

Zhang, H., Shan, B. and Liang, A.O. 2014. Application of fish index of biological integrity (FIBI) in the Sanmenxia Wetland with water quality implications. Journal of Environmental Sciences, 26(8): 1597-1603.