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Environmental Science

Environmental Implications of the Sidoarjo Mud Flow in East Java, Indonesia

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Introduction

The mud volcano known as Lusi erupted on May 29, 2006, bringing tragedy to the area of Sidoarjo, East Java, Indonesia. According to Tingay et al. (2008), mud volcanoes are generally located in sedimentary basins and are a result of deep highly over-pressured shale, liquefaction of clays, shallow over-pressured gas, hydrate, or water-rich sequences. Prior to Lusi's eruption, this mixture of water and solids were gradually building up over time. This build up coupled with the ramifications of hydraulic fracturing have been hypothesized to be the catalyst of the mud volcano. The mud being projected from the volcano has permeated into local water sources. According to Purwaningsih & Notosiswoyo (2013), the hydro-chemical groundwater samples that were taken from wells in the study area showed that the major contaminates are sodium, calcium, chloride, and bicarbonate (Table 1). These pollutants pose several threats to the natural environment as well as human sustainability. The fish are involuntarily consuming the toxins, which puts them at risk for contamination. Indonesian diets consist largely of fish caught from their local waters. Because of this, Indonesian citizens are now susceptible to contracting different illnesses related to the toxins.

TABLE 1 SHOWS THE CONTAMINATES IN THE WATER.

Dissolved ions		Avarage dissolved ions				
		Well	Deep well	Bubble	Mudflow area	Porong river
Na^+	mg/l	**282.97**	**193.33**	**1906.67**	**7883.33**	**390.00**
Ca^{2+}	mg/l	**104.94**	**123.37**	**177.70**	**282.80**	32.10
Mg^{2+}	mg/l	83.47	72.40	181.80	398.61	11.50
K^+	mg/l	27.43	17.17	245.00	71.67	10.00
Fe^{3+}	mg/l	1.22	3.92	4.90	18.82	25.39
Mn^{2+}	mg/l	3.25	2.68	4.49	6.85	11.36
Cl^-	mg/l	**593.94**	**514.50**	**3702.57**	**14476.23**	**563.90**
SO_4^-	mg/l	21.25	12.27	**112.73**	85.67	49.00
HCO_3^-	mg/l	508.46	490.73	759.13	613.63	332.50
NH_4^+	mg/l	2.01	1.33	4.77	56.00	5.00
NO_3^-	mg/l	4.16	1.93	0.70	5.63	1.40
Li+	mg/l	**0.90**	**0.53**	**3.77**	**9.07**	0.40
Zn^{3+}	mg/l	0.09	0.02	0.16	0.69	1.01
Cu^{3+}	mg/l	0.00	0.00	0.01	0.27	0.39
Pb	mg/l	0.07	0.10	0.16	0.70	0.50
Cd	mg/l	0.01	0.01	0.02	0.06	0.02
Hg	µg/l	**2.44**	**1.12**	**2.68**	**1.81**	**4.09**

With these factors in mind, this research will discuss how Lusi's continuous and uncontainable eruption continues to impact the water quality and the socio-economic strength of Indonesia. In order to appropriately assess the impacts of Lusi's eruption, this paper will also address the controversy behind why Lusi erupted.

Water Quality

If the Indonesian government could implement water quality policies based on the United States as an example, then it would enable them to create better policies that deal with prospective negative environmental implications, which develop from natural disasters such as Lusi's eruption. In the United States according to the Environmental Protection Agency (EPA), the standards for water quality consist of three categories: water quality criteria, anti-degradation policy, and designated uses. The Clean Water Act specifies the principles for water quality in which States or Tribes are able to protect bodies of water by implementing the criteria under section 304(a). These stipulations also modify the guidelines to site-specific conditions and apply other methods of defense (EPA, 2014). The water quality principles also cover pollutant discharge by containing a list of 126 toxic pollutants that are utilized on a regular basis and considered high priority pollutants. The act also discusses how the toxins will interfere with the overall goals of section 101(a) of the Clean Water Act (40 CFR 131.11, 2001). According to section 101, "the objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters (40 CFR 101, 2001)." The focal point of the legislation is to maintain a specific standard of purity in water bodies throughout the Nation.

The Clean Water Act discusses the anti-degradation policy, which is defined as a process put in place to keep healthy water bodies clean and ensure protection to outstanding waters (in.gov, 2014). This policy is divided into three different sections, also known as tiers. Tier 1 of

the anti-degradation policy is devoted to maintaining and protecting any water bodies that stem from the need to protect the uses of water (40 CFR 131.12(a)(1), 2001). Tier 2 discusses water quality in bodies of waters whose quality is considered better than necessary in order to protect the uses of those water bodies (40 CFR 131.12(a)(2), 2001). Tier 3 is solely utilized to protect outstanding national resource waters, which are awarded the highest level of protection under this policy. This tier also covers extreme protection for waters of high biological diversity (40 CFR 131.12(a)(3), 2001).

Section 101(a)(2) of the Clean Water Act classifies and discusses fitness of water bodies specifically regarding their physical, chemical, and biological characteristics. In part it also correlates water bodies to the geographical setting, as well as the socioeconomic and cultural characteristics of the surrounding area. Any water bodies that are inconsistent with these standards need to be reexamined every three years to see if revisions need to be created (EPA, 2014).

Information found in the Environmental Assessment: Hot Mud Flow in East Java, Indonesia and Purwaningsih & Notosiswoyo's research suggest that the metal and mercury concentrations in East Java's local water sources are low. However, both reports suggest that the standard only takes specific causes of pollutants into account. There is one variable that is unaccounted for in the standard; hydraulic fracturing (United Nations, 2006).

Hydraulic Fracturing

Indonesia is considering a policy change in terms of environmental regulations. The Mud Flow has been hypothesized to be a result of two correlative catalysts. There are certain individuals who believe a 6.3 magnitude earthquake was the primary cause of Lusi's eruption where as others believe it was the fracturing being conducted in the zone (Smithsonian

Magazine, 2011). In 2008, at the International Conference of Petroleum Geologists, 55 out of 74 attendees agreed that the drilling played a major part in the disaster (Smithsonian Magazine, 2011). Tingay (2008) verifies the belief that the cause of the mudflow was a result of hydraulic fracturing considering their research states, "…Lusi was triggered by a blowout in the Banjar Panji- 1 gas exploration well 200 m from the eruption (Tingay et al., 2008)."

If the failure of the fracturing equipment used by PT Lapindo Brantas is taken into account, then it is safe to say that fracturing along a fault line could have been the major catalyst of the eruption. PT Lapindo Brantas built the hydraulic fracturing site in East Java, Indonesia on the Watukosek fault (Figure 1). Indonesia should use the events of Lusi as a lesson that enables them to develop more precautionary measures. Even though the Watukosek fault was inactive at the time that the site was designed, it should have never been developed along a fault line. It has been known that an earthquake of greater magnitude can reactivate a fault line.

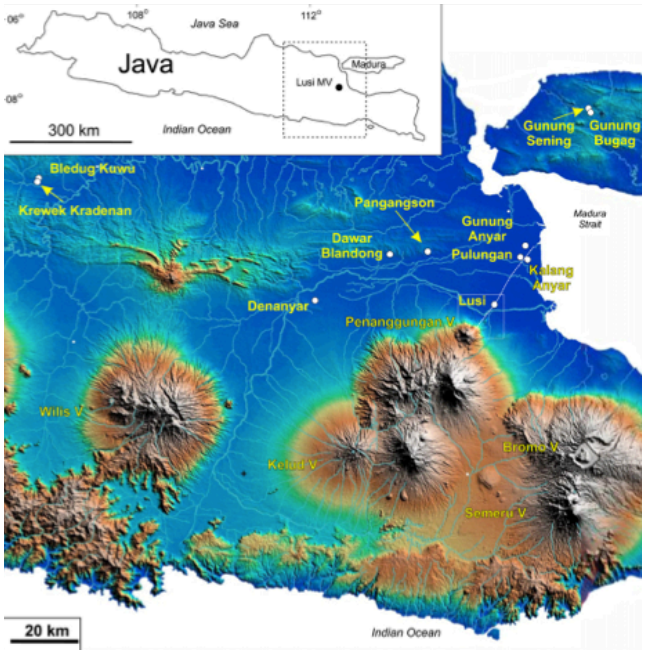

FIGURE 1 SHOWS THE WATUKOSEK FAULT AND LUSI

It is important to discuss the scientific processes of fracturing in order to better visualize the significance of the impact. Hydraulic fracturing is a process used when extracting natural gas, such as methane. This type of fracturing is used when other extraction methods may not be used because the depth at which the gas is located within the ground. During the extraction method, over a million gallons of water mixed with additional chemicals are pumped deep underground, which in turn creates new or enlarges already existing fissures (Hubbert & Willis 1972). These injected chemicals total 750 products that are continuously being used throughout the fracturing method. As these products are introduced into the ground they begin to significantly impact the quality of the groundwater. The chemicals eventually leach into the surrounding aquifer thus entering the hydrologic cycle causing widespread contamination (Waxman et al., 2011).

Currently, Indonesia is incredibly influenced by the United States' policies that allow for hydraulic fracturing. This is problematic considering the recent impact of Lusi (Franco et al., 2013). According to the US-Indonesian Energy Investment Roundtable,

> Indonesia stands poised to benefit from a global market that increasingly looks to natural gas for many uses, including as the bridge fuel technology to a lower carbon energy future. Through engagement with our private sector, through dialogues such as today's, and programs such as the Unconventional Gas Technical Engagement Program, we look forward to advancing our strategic partnership for energy security into a long and fruitful future (p. 6)

In an effort to reduce the pollutants released into the water bodies and in turn all areas of East Java, it would be advisable to push toward the end of the advancement and openness of hydraulic fracturing on Indonesian soil. In order to prevent future incidents a complete stop to all fracturing must take place. Instead of following in the footsteps of the United States regarding the acceptance of hydraulic fracturing, the funds utilized for fracturing should be placed in research for alternative natural gas extraction methods. Natural gases are considered a potential solution

to our global energy crisis. It is important that research be conducted to find ways to extract gas without using the harmful methods of hydraulic fracturing. The decrease of water resources due to pollution, heavy agriculture, water user behavior, global climate change, or hydraulic fracturing (The Water Dialogues Indonesia, 2013). For example, the potential impact of a fracking well failing and causing environmental damage and contamination is possible (Figure 2). If the pipeline malfunctions the chemicals will begin to increase the size of the fissures. This then increases the potential for earthquakes to happen in the affected zones. There is also a possibility for the fissures to reach the aquifer zone thus contaminating the water supply.

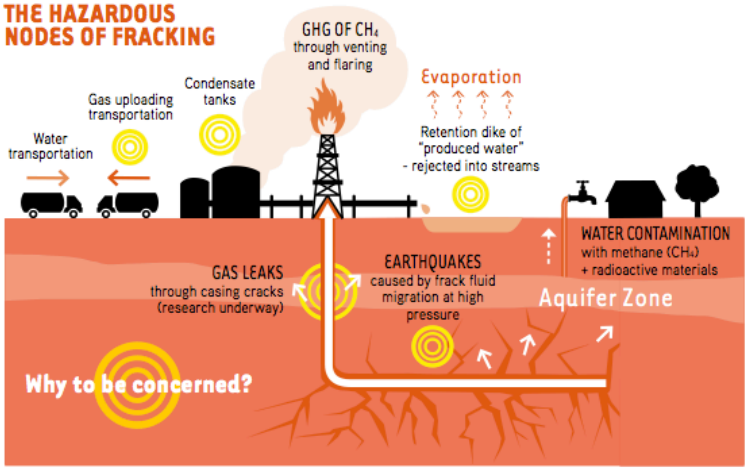

FIGURE 2 SHOWS THE FRACTURING PROCESS

Social and Economic Impacts

The initial pollutants not only impact both the groundwater and surface water, but they also have an overall negative effect on Indonesian citizens. The public should be updated on the continuous progress of the research and chemical usage. One of the primary catalysts for concern is how the continuous mudflow has caused the areas of East Java to go from a very prosperous fishing village to an agricultural village.

Presently, Lusi has cost the Indonesian government 500 million dollars, a number that continues to rise as time progresses. This figure is substantial considering Indonesia has a GDP of only 878 billion dollars. In a country like Indonesia, 500 million dollars holds a large amount of weight (Smithsonian Magazine, 2011). The cost of damages coupled with the inevitable shift in their driving economic forces has proven to be very significant.

By 2011, fisheries contributed to 20 percent of Indonesia's GDP, which calculates to 175.6 billion dollars of the GDP. Over 60 percent of the nations protein comes from these fisheries, even though the coastal fishers has increased by over 40 percent in the past 10 years. This means that they are unable to help their GDP grow while still feeding their population. This further indicates that the catch has decreased, which is significant because Indonesia is the richest biological fishery (Michigan State University, 2012).

According to The Water Dialogues, "The Indonesia's 1945 Constitution article 33 states that [The land, the waters and the natural resources within shall be under the powers of the State and shall be used to the greatest benefit of the people]. The statement "under the control" does not mean all activities should only be implemented by the government (The Water Dialogues Indonesia, 2013)." This document is suggesting that private entities should have the ability to produce accurate standards when thinking about water quality. The document also states that, "This includes land and water having economic value and social functions. Utilization should be based on sustainable manner and for the maximum prosperity of Indonesian people" (The Water Dialogues Indonesia, 2013). Even though the Indonesian constitution references water quality it does not have a rigorous testing schedule. This is evident because 64 of the 470 watersheds in Indonesia are considered to be in critical condition, and 26 are in the Java area alone (The Water Dialogues Indonesia, 2013).

However, just because the government sets standards does not mean that they are accurate for the situation. Based on the content of the Environmental Assessment: Hot Mud Flow in East Java, Lusi's mud flow is causing damages to the marine and aquatic environment, as well as the surrounding agricultural lands (Tables 2-4).

TABLE 2: SHOWS THE IMPACT ON THE MARINE ENVIRONMENT WHEN EXPOSED TO MUD

Component	Critical parameter	Impact	Quantity/Concentration	Hazard- to the receptor	Exposure of ecosystem	Exposure of humans
Mud	Heavy metals	MEDIUM	MEDIUM Local elevation of heavy metals and especially mercury. Exceeding of Dutch and Indonesian water quality standards. Long term effects expected	HIGH High Toxic solids (mercury).	Possible fate of pollutants not assessed	MEDIUM Through bioaccumulation and bio concentration humans will be exposed by consumption of seafood.
Mud	Organic compounds, including Phenols	LOW	LOW Normal background concentrations detected.	HIGH Toxic	LOW Not applicable	LOW Not applicable
Mud	Salinity	LOW	HIGH Concentrations expected to be high	LOW Concentrations do not differ from sea water	LOW Not applicable	LOW Not applicable
Mud	Suspended solids	HIGH	HIGH The suspended solids are composed of more than 90% of clay	HIGH Suspended solids are dangerous for benthic organism and fishes (creation of anaerobic condition on the sea floor and clogging of fish gills)	HIGH Mud flow dilution is not expected to take place at the discharge point because of the difference of density between the mud and the sea water. The mud will rapidly cover the sea bottom and eradicate the existing benthic organisms and disturb the whole food chain	Not applicable

TABLE 3: SHOWS THE IMPACT ON THE AQUATIC ENVIRONMENT WHEN EXPOSED TO MUD

Component	Critical parameter	Impact	Quantity/Concentration	Hazard- to the receptor	Exposure of ecosystem	Exposure of humans
Mud	Heavy metals	MEDIUM	MEDIUM Local elevation of heavy metals and especially mercury. Exceeding of Dutch and Indonesian water quality standards. Long term effects expected	HIGH Highly toxic solids (mercury).	Possible fate of pollutants not assessed	MEDIUM Through bioaccumulation and bio concentration humans will be possibly exposed by consumption of fishes
Mud	Organic compounds, including Phenols	LOW	LOW Normal background concentrations detected.	HIGH Toxic	LOW Not relevant	LOW Not applicable
Mud	Salinity	HIGH	HIGH Concentrations expected to be high	HIGH The fresh water body ecosystem are extremely sensitive to change in salinity	HIGH Fresh water living organisms will be eradicated by the discharge of a huge volume of salty water in their environment	Not applicable
Mud	Suspended solids	HIGH	HIGH The suspended solids is composed of more than 90% clay	HIGH Suspended solids are dangerous for benthic organism and fishes. (Creation of anaerobic condition on the river bed and clogging of fish gills)	HIGH	Not applicable

TABLE 4: SHOWS THE IMPACT ON AGRICULTURAL LANDS WHEN EXPOSED TO MUD

Component	Critical parameter	Impact	Quantity/Concentration	Hazard- to the receptor	Exposure of ecosystem	Exposure of humans
Mud	Heavy metals	MEDIUM	MEDIUM Local elevation of mercury slightly exceeding the Dutch sludge standards for agricultural use as organic fertilizer. Also slightly exceeding the Dutch ecological and human risk standards of soil quality.	HIGH Highly toxic solids (mercury).	LOW Slightly exceeding the ecological standards for the disposal of 2 tons of mud per ha and per year	MEDIUM Through bioaccumulation and bio concentration humans can be exposed by consumption of rice and vegetables
Mud	Organic compounds, including Phenols	LOW	LOW Normal background concentrations detected.	HIGH Toxic	LOW Not relevant	LOW No adverse effects expected
Mud	Salinity	HIGH	HIGH Concentrations expected to be high	HIGH Concentrations expected to be high	HIGH The crop will be severely affected by the salinity because the concentration of Na will exceed the coping capacity of the vegetation	Not applicable

The citizens of Indonesia rely heavily on the aquatic life and surround water bodies for nutrition but as Lusi's mud flow and hydraulic fracturing continues their nutrient sources decline. *Plastic: A toxic love story* by Susan Freinkel is the perfect example of how using plastic impacts not necessarily the generation that uses them but future generations. The same can be said for Lusi, because even though there is a minimal immediate impact on the citizens who live in East Java currently, as time continues it will be hard to track how the toxins used in hydraulic fracturing and those released during Lusi's eruption have affected future generations.

Conclusion

Lusi's eruption was incredibly damaging to the surrounding environment as well as the very damaging citizens of Indonesia. Since Lusi's eruption in 2006, there has been a significant impact that continues to test the socio-economic strength of Indonesia, as well as a large amount of degradation on the environment through its impacts on the water quality and in turn the aquatic environment. The Indonesian government must create policies that reflect the United State's in order to improve the degrading water quality and protect future health of citizens who are reliant on aquatic life for nutrition. This would be affective considering that Indonesia's

current policies are not successful in promoting the protection of water bodies and their ecosystems.

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