A study on nutrients enrichment in waterways as a trigger factor of harmful algal blooms in Lampung Bay, Indonesia

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Abstract. Harmful algal blooms (HABs) affect various coastal fisheries-related sectors leading to significant economic losses. Lampung Bay, Indonesia, is one of the regions regularly hit by HABs. A massive event of HABs first occurred in Lampung Bay in 2012. Afterward, HABs have continued to occur and have been associated with cultured fish's mass mortalities. Fertilizer runoff from nearby agricultural lands was suspected as one of the trigger factors of HABs in Lampung Bay. This paper investigated the potential trigger factors of HABs in the bay by combining spatial analysis through spatial assessment and water quality measurement. Spatial analysis was conducted using a high-resolution satellite image (WorldView-3) and a digital elevation model (DEM). Results of the land cover analysis were verified via ground truth survey. Water quality measurement was conducted at four sampling stations (two stations each in upstream and downstream). The sampling stations were selected based on the land cover analysis results. The water quality parameters consisted of pH, electrical conductivity (EC), NO_2 and NH_3. The water quality measurement was repeated 25 times from February 2020 to March 2021. A t-test statistical analysis was performed on the water quality data to examine fertilizer runoff possibility from upstream to downstream. The land cover analysis shows that most agricultural land areas are situated on steep hills along the Lampung Bay coastline. The measured values of EC, NO_2 and NH_3 downstream are significantly higher than that of upstream, with the p-value of EC, NO_2 and NH_3 are 1.89×10^{-3}, 1.89×10^{-4} and 2.25×10^{-6}, respectively. This study provides evidence that fertilizer runoff enriched the nutrient concentration in the bay and could be one of the trigger factors of HABs occurrence.

Key Words: fertilizer runoff, GIS, harmful algal blooms (HABs), hydrologic characteristics analysis, land cover analysis, remote sensing.

Introduction. Harmful algal blooms (HABs) generally occur when certain species of phytoplankton containing photosynthetic pigments grow out of control while producing toxic or harmful effects on fish, shellfish, marine mammals, birds and even human beings (Sellner et al 2003). When the algae bloom out of control in high concentrations, the water appears to be discolored or murky, varying in color from brown to red due to the pigments. Such kind of phenomenon is usually called red tide. HABs occurrence is commonly seen in coastal marine ecosystems, but it may also be found in freshwater ecosystems (Anderson et al 2012). The scale of HABs is variable, some are localized, in bays or estuaries, others are massive, covering hundreds of square km. According to previous studies (Anderson et al 2002; Sellner et al 2003; Flynn 2010; Flynn et al 2018) HABs are reportedly triggered by the presence of a high supply of nutrients, for instance, nitrogen (N) and phosphorus (P). The nutrients may be derived from both anthropogenic and natural sources. High supply of nutrient derived from agricultural fertilizer application (Glibert & Burkholder 2006), wastewater discharge to the river or sea (Moss et al 2013) and port digging activity that cause upwelling phenomenon (Riani et al 2013) are several examples of anthropogenic activity. On the other hand, the breakdown of organic material or atmospheric deposition are examples of natural sources of high nutrients (Anderson et al 2002; Roelke et al 2011).

The U.S. National Office for HABs (2016) reported that the global HABs occurrence has increased since 1970. In 1970 only 15 occurrences of HABs were found, yet in 2016 more than 100 occurrences were found globally. According to the same source, the causes behind the increase of global HABs occurrence are different in each location due to its characteristics. The causes are ranging from natural mechanisms of species dispersal, such as currents and storms, to human-related anthropogenic activity such as pollution, climate change and increased numbers of observers. The reasons behind the expansion of red tide are still being argued, but most coastal regions are now experiencing an unprecedented number and variety of HABs phenomena. In several places, HABs have occurred continuously. However, continuous HABs trigger in several places remains unclarified to this day.

Lampung Bay, an area located in southernmost Sumatra Island is also one of the areas that are severely damaged by HABs. Lampung Province is known as one of the centers for aquaculture in Indonesia, marked by the existence of one of the fifteen marine aquaculture (also known as mariculture) development centers in Indonesia (MMAF 2019). According to the provincial government of Lampung (2015) a large part of mariculture facilities is located in western part of Lampung Bay and the fish cultured commodities are among high economic value fishes, such as, milkfish (*Chanos chanos*), snapper (*Lutjanus* sp.), pompano (*Trachinotus blochii*) and grouper (*Epinephelus* sp.). A vast HABs occurrence in Lampung Bay was first reported in 2012 (Riani et al 2013; Furuya et al 2018). Afterward, HABs continue to occur almost every year and have been associated with cultured fish's mass mortalities in the bay, especially in the western part of the bay (Sidabutar et al 2021). Specifically, approximately 150 mariculture facilities existed in the western part of Lampung Bay in 2010. However, because of the massive economic loss caused by HABs fish mass mortality, only 26 survived in 2018 (Saville et al 2019). It means that a trigger that causes HABs to appear periodically certainly exists. Therefore, the investigation of the trigger that causes periodic HABs is necessary in order to understand the phenomenon as well as to find a strategy for sustainable mariculture in Lampung Bay.

On the other hand, the government of Lampung Province (2020) stated that agriculture sector has been their priority of economic foundation for decades. This is indicated by the fact that Lampung is known as one of the largest food contributors in Indonesia for the last few decades (Ministry of Agriculture 2020). Statistics Indonesia (2021) also reported that the area of agricultural lands (including paddy, farm and estates) in Lampung Province had also increased to approximately 1.5 times since 1990 to 2019. Moreover, farmers in Lampung Province tend to use excessive amounts of fertilizer believing in crop yield improvement due to a lack of information even though soil includes diverse nutrients essential for agricultural yield growth (Asnawi 2013; Astuti et al 2013). Although these fertilizers might boost crop production in the farm, their excessive use does not increase crop yield in the same proportion (Huang et al 2010).

In many parts of the world, fertilizer runoff from agriculture sector has become a major contributor to eutrophication and eventually to HABs (Glibert 2014; Misra et al 2016; Chakraborty et al 2017). Different fertilizers containing N and P are being used in farming to increase the crop yield in order to meet the increasing food demand. However, less than half of the nutrients in fertilizer are consumed by plants, which means half of them remain as residue in the soil surrounding the plants (Widowati et al 2011; Misra et al 2016). According to Chakraborty et al (2017) these fertilizer residues erode into surrounding water bodies, such as drain, river and eventually ended in lakes or sea, where they enhance the water with nutrients. The high nitrogen load makes the water body more fertile, which encourages algae bloom. Given the fact that agriculture sector in Lampung Province is expanding and agriculture is one of the major causes for HABs occurrence, this study suspects fertilizer runoff from nearby agricultural lands as one of the trigger factors of HABs in Lampung Bay. Therefore, an investigation of agricultural land spatial analysis and water quality in Lampung Bay are necessary to clarify continuous HABs trigger occurrence for the future of mariculture in Lampung Bay as well as for the balance and synchronization of the fisheries and agricultural sectors.

In our previous research (Saville et al 2019), we presented the first attempt to investigate the suspicion of fertilizer runoff primarily via spatial analysis of a high-resolution satellite image and a digital elevation model (DEM). The previous study has examined that several agricultural land areas are situated on steep hills along the Lampung Bay coastline in which there is a possibility of fertilizer runoff during the rain. However, the evidence and analysis of the previous study were not enough to conclude the suspicion of fertilizer runoff because the previous analysis was conducted mainly by mapping land cover classification with a limited one-day ground truth survey without water quality measurement. This study is a continuation of the previous research to investigate the potential trigger factors of HABs in the Bay by combining land cover analysis through a more extensive spatial assessment and water quality measurement through in-situ water sampling.

Material and Method

Spatial analysis. This study divided the spatial analysis into land cover classification and hydrologic characteristics analysis. Spatial analysis was conducted using a high-resolution satellite image (WorldView-3) which was shot in June 2018 and a 2011 DEM data from ASTER (NASA) in order to grasp land use in the target area along western Lampung Bay coastline. In this study, we conducted a 5-day extensive ground truth survey in area along Lampung Bay from 16th to 20th of February 2020. We confirmed location data using highly precise and stable positioning services Quasi-Zenith Satellite System (QZSS)-equipped Casio WSD F-30 during extensive ground truth survey. The spatial analysis in this study was conducted using ArcGIS (ESRI) software. To begin with, this study separated land and sea by normalized difference vegetation index (NDVI). Then, the result of the previous land cover classification (Saville et al 2019) was confirmed, edited and updated through the extensive ground truth survey via supervised land cover classification. In addition, the analysis of hydrologic characteristics was conducted to determine the characteristics of waterways flowing to Lampung Bay through DEM data with the potential for runoff from agricultural land, especially during the rainy season.

Water quality measurement. The in-situ water quality measurement was conducted at four sampling stations (two stations each in upstream and downstream near river mouths), as shown in Figure 1. The sampling stations were selected based on the combination of the previous study (Saville et al 2019) and spatial analysis results conducted in this study. The measured water quality parameters consisted of water acidity (pH), electrical conductivity (EC), nitrite (NO_2) and ammonia (NH_3). This study used 0.2 μm syringe filters for the removal of particulate impurities from water samples prior to water quality parameters measurement. EC was measured by HORIBA LAQUA twin-EC-33B, while pH, NO_2 and NH_3 were measured by using MERCK RQflex plus 10 while referring to the measurement guideline from MERCK. The water quality measurement was repeated 25 times from February 2020 to March 2021. Those water samplings were conducted in the morning (at 8 to 10 AM) after rainy days. A t-test statistical analysis was then performed using R statistical computing language on the water quality data to examine fertilizer runoff possibility from upstream to downstream.

Results and Discussion

Spatial analysis. We went to 49 different spots during 5-day extensive ground truth survey as shown as yellow star and green flag icon in Figure 1 (left). The land cover classification is shown in Figure 1 (right). This study divided land cover area into six categories, namely, (1) sea, (2) area covered by cloud, (3) area covered by cloud shadow, (4) agricultural land as the main target, (5) non-vegetation such as residential housings and roads or vacant areas that used to be a shrimp pond, and (6) forest. Based on the land cover classification result, the area of agricultural land in the target area is approximately 1,200 ha. After conducting extensive ground truth survey this study confirmed that a large portion of agricultural lands were classified as forest in the previous classification result. Those areas look like a forest on hills from the satellite image, yet during the ground truth survey, we found those areas are actually agricultural land. At the center of the issue is the notion that numerous agricultural lands are located on steep hills. With this in mind, fertilizer runoff would occur in the target area due to the agricultural land steepness. This study also confirmed that various waterways are available in the target area determined from DEM data as shown in Figure 1 (right). Waterways in the spatial analysis results are not always visible even during the ground truth survey. Yet, several of the waterways emerge only during rain. This condition was confirmed by in-depth interview with farmers as the farmers also stated the same thing about the appearance of waterways during a relatively heavy rain. This result is as expected because target area has numerous hills.

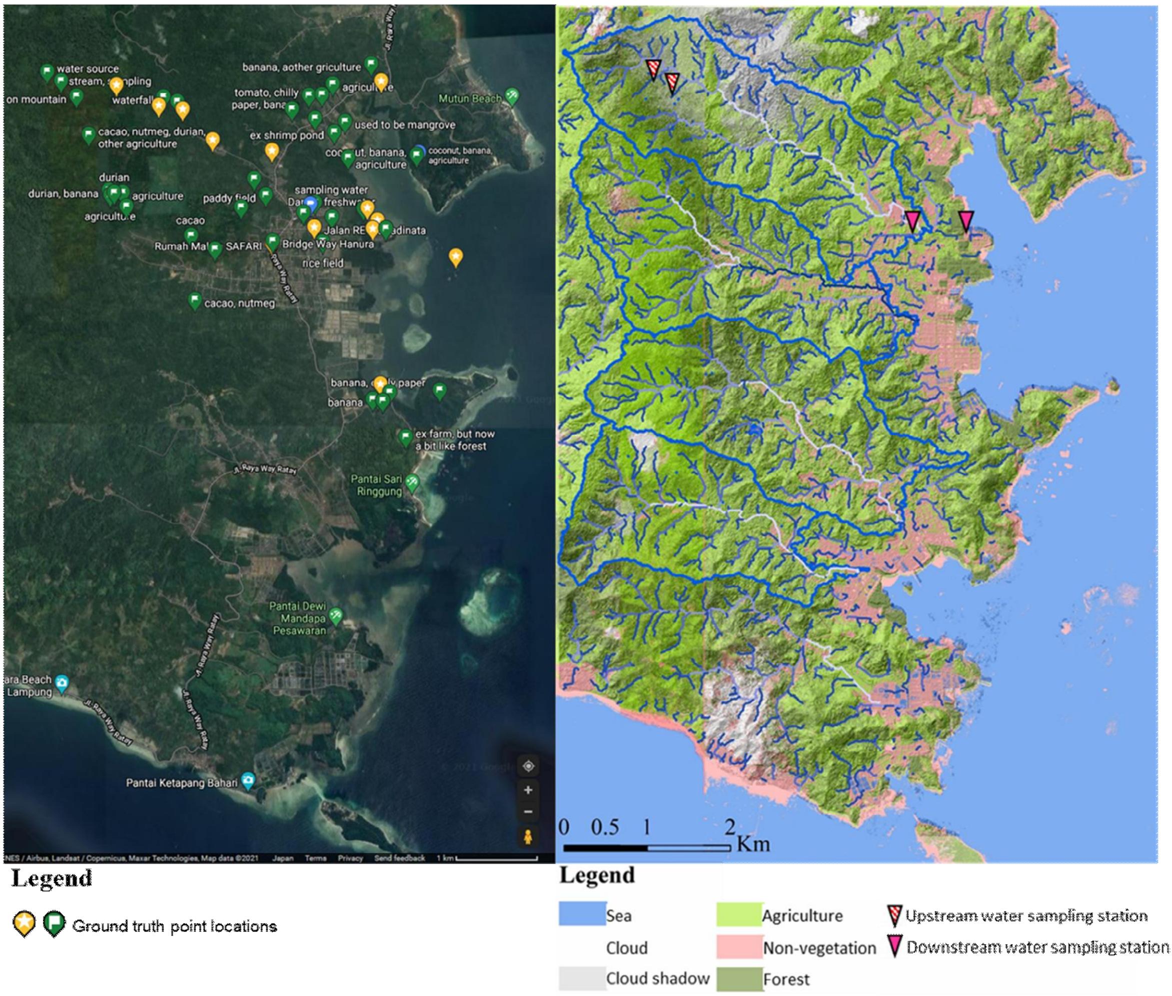

Figure 1. (Left) Plot of places visited on ground truth survey. (Right) Result of spatial analysis and sampling station location.

Based on the land cover classification, this study examined a potential runoff of fertilizer from agricultural land. Figure 2 shows cacao trees as a typical forest-like agricultural land on a steep hill. The forest-like agricultural lands are typically mixed of several orchards in one area, specifically a mix of cacao, durian, banana, nutmeg, rambutan, chilly paper, coffee, clove and teak. We also conducted a free flow in-depth interview with three different farmers on different days during ground truth survey. This study confirmed that all of the interviewees usually give 200 kg of fertilizer in 1 ha scale of agricultural land per year. According to the farmers, the forest-like agricultural land in the target area is identified as a community-based forest. In a community-based forest, farmers who live nearby work as a community and they agree with each other to manage the area as long as it does not disturb the forest. On the other hand, two sampling stations upstream were selected because those stations were less affected by fertilizers since the location are located on the hill (upstream area) and the water are even used directly as a water source for residents in the village nearby through pipeline. Furthermore, the other two water sampling stations downstream were selected because the river from upstream is divided into two and flows into two different river mouths. Water quality measurement is discussed in the next section in order to examine the fertilizer runoff.

Figure 2. Picture of typical forest-like agricultural land area in a steep hill along Lampung Bay coastline.

Water quality measurement. After conducting 25 times water quality sampling in four sampling stations, a t-test statistical analysis was performed on the water quality data in order to examine fertilizer runoff possibility from upstream to downstream. In particular, when nutrition difference is statistically significant between upstream and downstream, fertilizer runoff from upstream to downstream possibly occurred. Boxplot comparison of EC, NO_2 and NH_3 data record in upstream as well as downstream are shown in Figure 3. The measured values of EC, NO_2 and NH_3 downstream are significantly higher than that of upstream in 95% probability, with the p-value of EC, NO_2 and NH_3 are, 1.89×10^{-4}, 2.25×10^{-6} and 1.89×10^{-3}, respectively. Figure 3 also clearly shows that the values of EC, NO_2 and NH_3 downstream are higher than that of upstream. The results show that nutrients are flowing along the river, with fertilizer being one of them, indicated by high value of NO_2 and NH_3. Misra et al (2016) reported that 50% of the nutrients used as fertilizers are consumed by plants, and the remainder is left as residue in soil. In another study, Widowati et al (2011) stated that urea, widely used in fertilizers in Indonesia, contains 46% of N yet, 60% of the N is not absorbed by plant and remains as residue with potential runoff to the river.

EC shows the concentration of ions in the water which is related to the dissolved mineral, organic and inorganic matter (Gali et al 2012). This study also confirmed a negative relationship between pH and EC values (correlation coefficient of -0.67). As pH is measured by H^+ ion, pH is a part of the EC, when the pH in the water decreases EC value will most likely increase. This study showed low values of pH and high EC value which were observed in downstream sampling stations. Such situation indicated that ions from land flowed to the river. One of the possibilities that cause high EC value downstream is the runoff residues of fertilizer in the agricultural land to the river along with the rain.

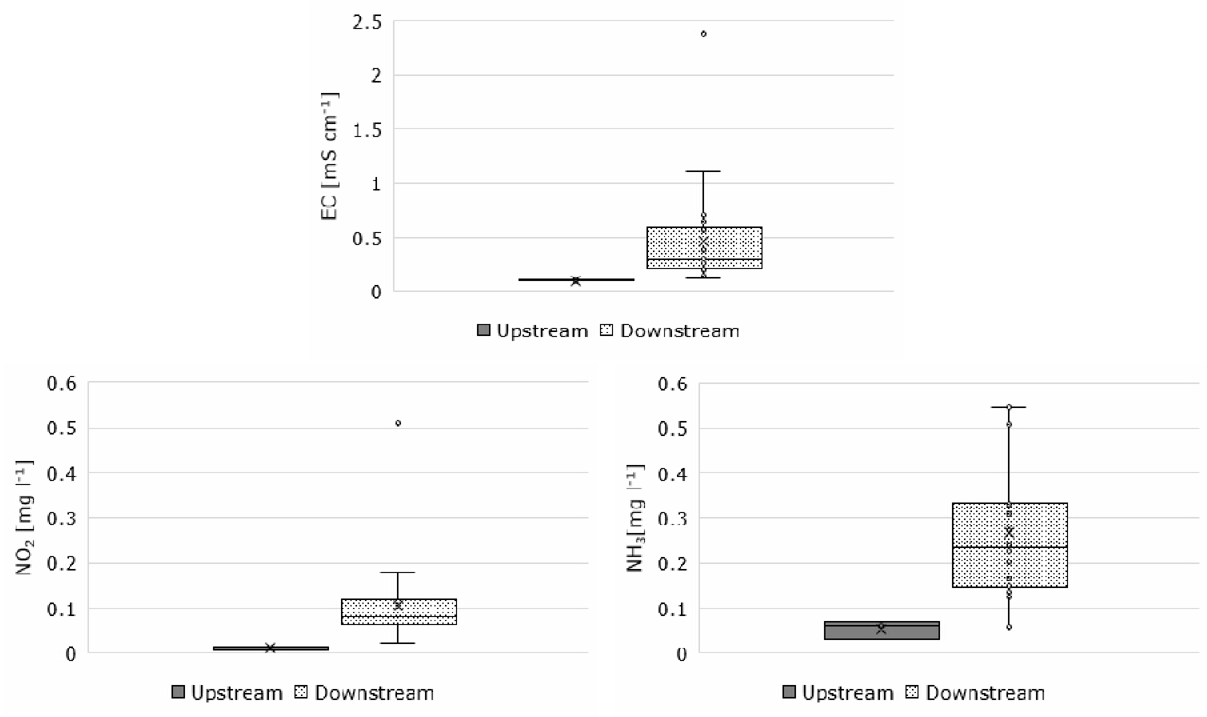

Figure 3. Boxplot of nutrients (EC, NO_2 and NH_3) in upstream as well as downstream sampling stations.

Future studies could fruitfully explore this issue further by sampling and analyzing P contents in the upstream as well as downstream of the waterways as one of the elements of fertilizer other than N. Besides, anthropogenic activities may cause P to flow to the sea as one of the other triggers of HABs in Lampung Bay as this study also found that waterways from upstream to downstream pass through residential and urban areas. It should also be evident that we need to conduct runoff simulation from fertilizer and anthropogenic activities along the waterways from upstream to the sea, especially during the rain.

Conclusions. In this paper, an investigation of fertilizer runoff as one of the triggers of HABs through spatial analysis and water quality measurement in Lampung Bay has been presented. The study showed that the area of agricultural land in the target area is approximately 1,200 ha with plenty of the agricultural lands are located in steep hills. With such condition the possibility of fertilizer runoff to occur is high. Water quality measurement in four sampling stations also showed that there is a significant difference of EC, NO_2 and NH_3 in upstream and downstream which confirm N as fertilizer element runoff. This study provides evidence that fertilizer runoff could be one of the triggers of HABs in the bay. Future research should consider the potential effects of fertilizer runoff more carefully, for example by measuring P contents and conducting simulation of fertilizer runoff during rainy days as well as constructing numerical model simulation of the fertilizer flow to the sea.

Acknowledgements. The work in this paper was conducted under the JST/JICA SATREPS project titled “Optimizing Mariculture based on Big Data with Decision Support System” (grant number: JPMJSA1610). We express our gratitude here. We also wish to thank Mr. Tri Haryono, Mr. Wahyu Widiatmoko and BBPBL team for their cooperation in this study.

Conflict of interest. The authors declare that there is no conflict of interest.

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Received: 16 May 2022. Accepted: 31 August 2022. Published online: 30 October 2022.
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How to cite this article:
Saville R., Shimojima H., Muawanah, Puspasari R., Hatanaka K., Albasri H., Nugroho D., 2022 A study on nutrients enrichment in waterways as a trigger factor of harmful algal blooms in Lampung Bay, Indonesia. AACL Bioflux 15(5):2701-2708.