Monitoring of Algal Blooms and Massive Fish Kill in the Jakarta Bay, Indonesia using Satellite Imageries

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ABSTRACT

The water environment in the Jakarta Bay gets more and more stress due to heavy eutrophication and pollution. In this study, we monitored the concentration of chlorophyll-a as an indicator of eutrophication using Terra and Aqua MODIS (Moderate-resolution Imaging Spectro-radiometer) satellites data from 2004 to 2007. During those periods, there were seven occurrences of massive fish kill, 2 cases in 2004, 3 in 2005, and 2 in 2007, respectively. This was correlated to the algal blooms, which were indicated by high chlorophyll-a concentration exceed than 10 mg/m^3 and covered more than a quarter of the bay. However, there were no fish kill occurred in 2006 at all, although stronger and more intense algal blooms were detected several times in that year. Weak water mass circulation and the forming of oxygen depletion after algal blooms ware suspected as the key factors that caused massive fish kills. Therefore, monitoring water mass circulation pattern and oxygen depletion is needed for developing the early warning system of the algal blooms in the Jakarta Bay.

Key words : *Algal blooms, MODIS, Fish kill, Jakarta Bay, Early warning system.*

INTRODUCTION

The Jakarta Bay is situated in the north of Jakarta, the capital of Indonesia. This bay covered an area approximately 514 km^2, with 72 km coast lines, and an average depth of 15 m. High population (> 20 millions) and very fast-unfriendly land used development around Jakarta and its big hinterland cities, and many small and big rivers (13 rivers) discharged their loads into the bay are become the main threads to the water quality of the bay. Any material discharged into the sea causes some changes. Such changes may be great or small, long-lasting or transient, wide spread or extremely localized. If the change can be detected and is regarded as damaging, it is constitutes pollution (Perez, at al., 2003). Literature review on water quality of the Jakarta Bay from 1970's to present indicated that the Jakarta Bay get continuous pressures due to eutrophication and heavy pollutions (Arifin et al., 2003). On the other hand, the Jakarta Bay is economically vital for various stake-holders who used this bay for many purposes (fisheries, tourism and recreation, industry, transportation, research, education and training and many others).

Regarding to the importance values of the Jakarta Bay, effort such as long-term commitment to monitoring the water quality with effectively and efficiently for managing this bay is inevitable. In this study we observed the algal blooms and the massive fish kills in The Jakarta Bay Utilizing Terra and Aqua satellites images, and discusses the possibility to use these satellites and other data for developing early warning system of algal blooms.

MATERIALS AND METHODS

This study was apart of Indonesian Institutes of Sciences (LIPI)'s competitive projects entitled "Integrated Watershed Management of Jabopunjur Areas" (Jakarta and its hinterland areas) We selected Jakarta Bay (Figure 1) as study sites with the assumption that > 20 millions peoples live in these areas will influence the water quality in the bay.

To monitor the algal blooms, we used chlorophyll-a concentration maps derived from empirical model developed using the Terra and Aqua satellites MODIS (Figure 2). This model was developed using 48 data

Figure 1. Map of study site

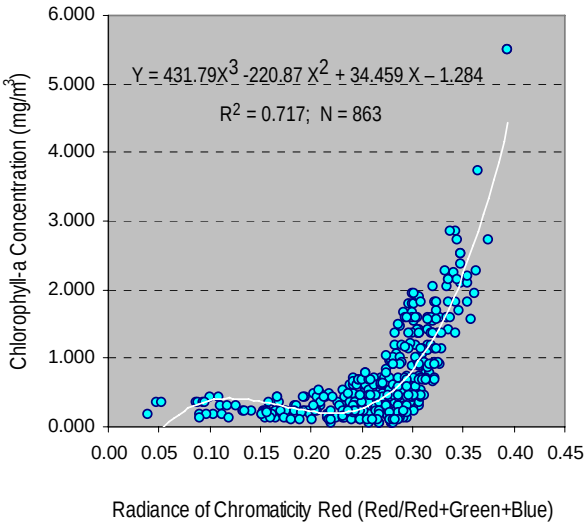


Figure 2. Chlorophyll-a estimation model derived from Terra ans Aqua MODIS satellites

sets of sea-truth chlorophyll-a concentration and relatively free cloud of Terra- and Aqua- MODIS satellites images that acquired near simultaneously with sampling times. Those data consisted of 18 data sets collected in 2004, 15 in 2005, and 15 in 2006 with total of 863 *in situ* or sea-truth chlorophyll-a measurements.

In this study, only three visible bands of MODIS in land/terrestrial application were use, namely band 1 in Red region of light spectrum (0.620-0.670 µm), band 4 in Green region (0.545-0.600 µm), and band 3 in Blue region (0.459-0.479 µm). The considerations not to use special bands for ocean color (bands 8-16) are firstly, due to the spatial resolution of these bands coarser (1000 m) than the bands in the land application (500 m), thus the Jakarta Bay looks too small. Secondly, is that those ocean color bands and their algorithms are valid only for study the oceanic waters, which is categorized as "case-1 waters" or oceanic waters, while the Jakarta Bay is categorized as "case-2 waters" or complex turbid coastal (IOCCG, 2000; Gao et al., 2007).

Based on the chlorophyll-a maps, we defined the algal blooms that if chlorophyll-a concentration exceed than 10 mg/m^3 and covered more than a quarter of the bay.

RESULTS AND DISCUSSUONS

From 4 years monitoring campaign, a total of 372 chlorophyll-a maps were produced using the empirical model in Fig. 2. We then used the maps for monitoring the algal blooms in the Jakarta Bay. Based on the algal blooms definition, the high occurrences of algal blooms were found from April to May (the transitional season from rainy to dry seasons) and from September to October (the transitional season from dry to rainy seasons) (Table 1).

High chlorophyll-a concentrations in April to May were due to high input of nutrients from the human activities (household/urban, agricultural, industries) in the land around Jakarta and its hinterland cities which discharged to the bay through 13 rivers as a runoff during the rainy season. Between September and October there was less nutrient input coming from the rivers discharge due to low precipitation in dry season (June to August), but strong and consistent easterly winds that started blow from June to August generated turbulences or local upwelling in which enriched the bay with higher nutrients coming from the deeper layer.

Table 1. Algal Blooms occurrences in the Jakarta Bay

Month	2004	2005	2006	2007	Occurrences (%)
Januari	-	-	-	-	0
Februari	-	-	-	-	0
Maret	✓	-	-	-	25
April	✓	✓	-	✓	75
Mei	✓	✓	✓	✓	100
Juni	✓	-	✓	-	50
Juli	✓	-	-	✓	50
Agustus	✓	-	-	✓	50
September	✓	✓	✓	✓	100
Oktober	✓	✓	✓	✓	100
November	-	-	✓	✓	50
December	-	-	-	-	0

The Regional Environment Management Board of Jakarta (BPLHD-DKI), that responsible to conduct monitoring the environment of Jakarta and its surrounding areas, included the water quality in the Jakarta Bay reported that there were 7 cases of algal bloom and water discoloration (red tide phenomenon) during the study periods that causes massive fish kills. Two cases were in 2004 (May and December) and 3

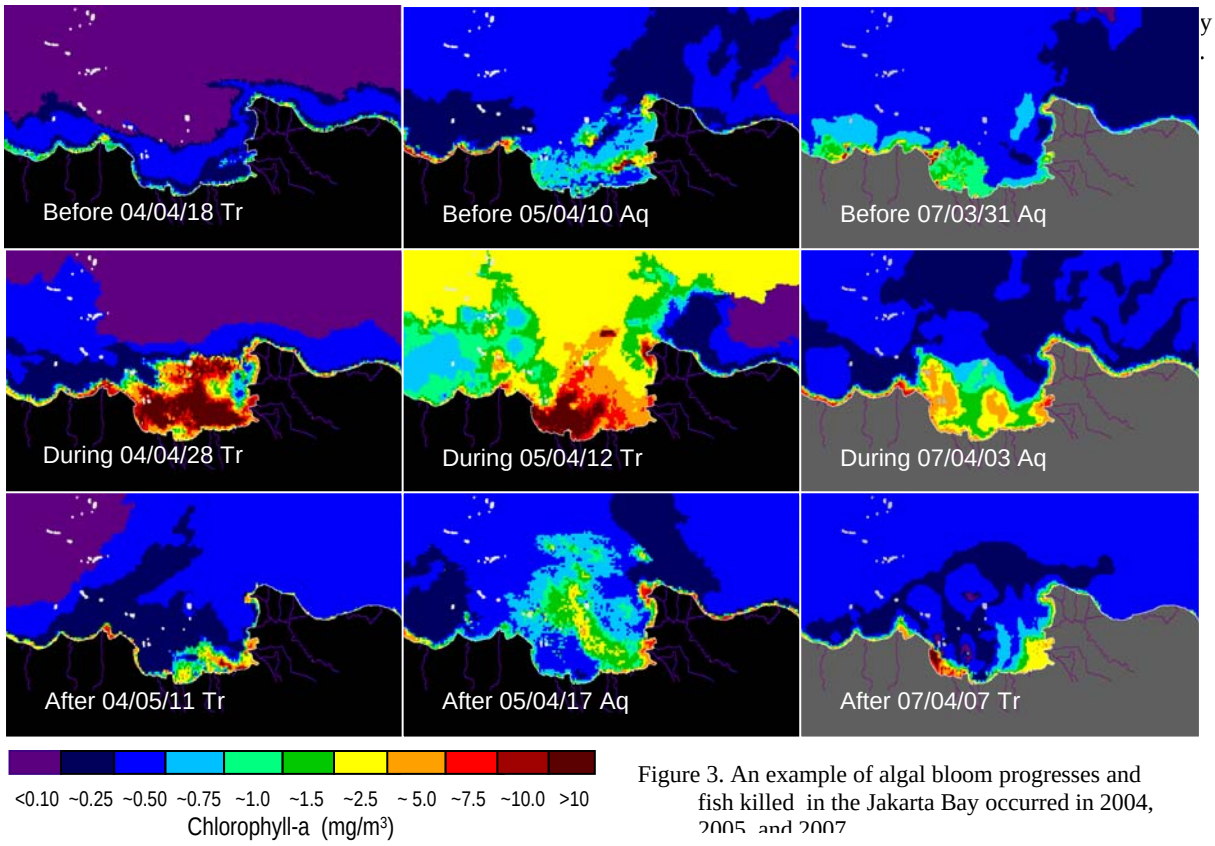


Figure 3. An example of algal bloom progresses and fish killed in the Jakarta Bay occurred in 2004, 2005, and 2007

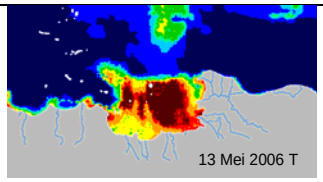
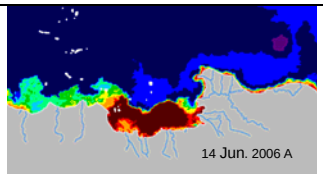
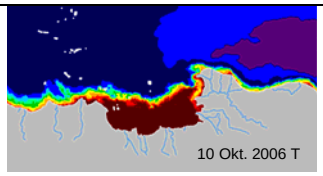
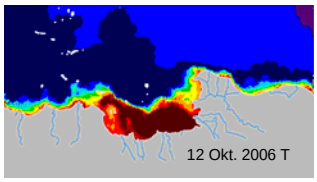
cases in 2005 (April, June 15, and October 15), no cases in 2006, and 2 cases in 2007 (April and November). By plotting the date of algal blooms to the the chlorophyll-a maps before and after the bloom events, the pattern of massive fish kill were seen. In the most of the cases, massive fish kills happened several days after the evidence of algal blooms (Fig. 3).

Among algal bloom events, the fish kills occurred on May 7, 2004 was the biggest one. Based on limited available *in situ* data, during the bloom, *Skletonema costatum* dominated the phytoplankton composition (76 %) with the density of $188x10^6$ cell/liter. After the bloom event *S. costatum*, *Prorocentrum* sp. and *Thalassiosira* still dominated the phytoplankton composition with lower density ($<10^5$ cell/liter). *Prorocentrum* and *Thalassiosira* are well known as fish kill type species in algal blooms. On April 13, 2005, *stephanopysis* sp occupied 86.5% of the phytoplankton composition, but with low density of $12x10^3$ cell/liter. On August 5, 2005 algal bloom that occurred out side of Jakarta Bay was dominated by blue-green alge of *Trichodesnium* sp. On November 16, 2007, again *S. costatum* dominated the phytoplankton composition with the density of 10^6 cell/liter. On the other bloom events, there were no phytoplankton composition data available. Other conditions that also recorded 1-2 days before algal bloom and massive fish kill events were unusual (heavy) rain, and followed by unusual calm condition of the sea state in the next day. Wong et al. (2007) reported this same condition.

Limited data showed that depletion oxygen after algal bloom is the main factor caused the fish kill on November 16, 2007. Low dissolved oxygen content < 2mg/l) still found in the subsurface layer a few days after fish kill. Based on this fact, it is suspected that the main factor caused the massive fish kills in the Jakarta Bay was due to oxygen depletion in the bottom after bloom events. This also confirmed by the most dominant of dead fish were the bottom fishes, as well as invertebrate such as blue swimming crabs (*Portunus pelagicus*), shrimp (*Peneus* spp) and green mussels.

Although the pattern of fish killed that occurred after algal blooms was recognized, but many of strong and intense algal bloom events, such as always observed in October, especially on October 2006 did not caused fish kill at all. Examine on the tidal pattern several days after bloom events showed that if the differences of the highest and the lowest tide > 0.5, which is relatively indicate strong water mass movement, then the possibility of fish kill would be low, or vise versa (Tabel 2). This probably explained why the big algal blooms events were not occurred in 2006. Thus, in the near future, monitoring dissolved oxygen and water mass movement is the important for establishing the early warning systems of algal blooms in this bay.

Tabel 2. The high differences values between high and low tide that could be use as an indicator of the possibility negative fish kill events in the Jakarta Bay..

Date	Diffrences High-low Tide (m)	Images of high algal blooms.
2006/05/13	0.9	
2006/05/14	0.9	
2006/05/15	1.0	
2006/05/16	1.0	
2006/05/17	1.0	
2006/05/18	0.9	No fish kill occurred
2006/06/14	1.0	
2006/06/15	1.0	
2006/06/16	0.9	
2006/06/17	0.7	
2006/06/18	0.6	
2006/06/19	0.6	No fish kill occurred
2006/10/10	0.7	
2006/10/11	0.8	
2006/10/12	0.8	
2006/10/13	0.8	
2006/10/14	0.8	
2006/10/15	0.7	
2006/10/17	06	
1006/10/16	0.6	No fish kill occurred

Regarding to ALOS data, it is rather difficult to use this image for monitoring purposes, such as algal bloom phenomenon in the Jakarta Bay compared to MODIS data. However, ALOS has its own advantages of high resolution (10 m), that possible to detect in more details the coastal areas features, where many activities conducted here by many stakeholders. Besides that, ALOS spectral bands are almost the same with the spectral bands of MODIS for land application. Thus, it is also possible to develop model using these images for mapping the chlorophyll-a concentration. In Figure 4, we mapped chlorophyll-a concentration by regressing the red chromaticity of the same day images both MODIS and ALOS and use the empirical model in Fig 2 to derived chlorophyll-a concentration. ALOS image shows the ocean features, such as the direction of water movements and small eddies in details.

CONCLUSION

Monitoring Algal blooms in the Jakarta Bay using Terra and Aqua satellites MODIS shows that the high

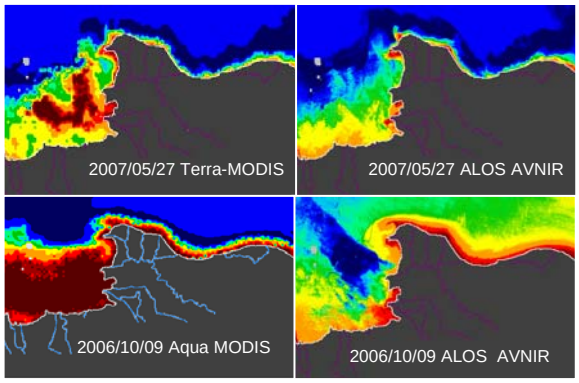


Figure 4. Chlorophyll-a maps of derived from ALOS and MODIS satellites images of May 2007 and October 2006

occurrences of algal blooms are in April to May and September to October. Massive fish kill follows Algal-blooms events if the oxygen depletion formed and the water circulations are weak. Therefore, to develop early warning system these two parameters are needed to be monitored. Combination between high resolution of ALOS images and high repetitiveness of MODIS images will make the algal blooms phenomenon clearer.

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