REMOTE SENSING INVESTIGATION ON CHARACTERISTICS OF RIVER DISCHARGES INTO JAKARTA BAY

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ABSTRACT: Fresh water discharges from Citarum, Ciliwung and Cisadane Rivers are shown in different pattern over Jakarta Bay. Their characteristic and its seasonal variation are investigated based on historical remote sensing of ocean color of the last 10 years. In addition, this used climate and pattern of hydrology data from watershed which is passing the Jakarta area. We observed that freshwater discharge contains organic and inorganic materials, that influenced large coastal areas during the rainy season (December to March), and to a lesser extent during the dry season. We recognized from in situ measurement that Citarum and Cisadane Rivers are the major source of sediment discharges with concentration higher than 8 mg/l. Besides, phytoplankton abundance that existed in both river plumes which is dominated by diatom genus of Skeletonema sp. and Nitzia Sp. with 86% and 69% composition. However, in the middle Bay, Ciliwung discharge showed a different pattern which has a significant correlation between the occurrences of fresh water discharges that may bring nutrient with development of phytoplankton as well as algal bloom. During the period of algal blooming, the chlorophyll concentration from satellite is recognized higher than 10 mg/m^3. Further analysis, we investigated the potential blooming period during the transition phase from the rainy to the dry season or the spring tide (April and May) and during the dry season or summer (September and October). In application, we can apply this benefit for alert system of algal blooming to reduce the negative impact on marine aquaculture activities.

1. Introduction

Indonesian archipelago covers a wide area with around 81.000 km of coastline, which comprise one of the world's largest shelf areas, i.e., the Sunda Shelf, have also an impact on the global climate system. High discharge rates into the Java Sea which is located in Sunda Shelf area contain terrigeneous material (e.g. nutrients and organic matter) from the numerous rivers in Java, Sumatra and Kalimantan islands (Tomascik et al., 1997) as well as discharged material from diffuse sources and coastal erosion. Jakarta Bay is an important place to study in more detailed on the freshwater discharges since it is regarded as being heavily eutrificated which may cause the bloom of the dinoflagellate, *Noctiluca scintillans,* after a *Skeletonema* bloom, instead of the usual diatom species (D. P. Praseno et al., 1998).

Due to depending on the monsoon phases, remote sensing can contribute to investigate spatial distribution and temporal development of coastal discharges. These phenomena were investigated in relation to meteorological forcing dominated by the monsoon phases using a multi sensor approach by combining satellite data of ocean colour and sea surface temperature, including high resolution images.

This paper will give an overview on the utilization of remote sensing investigation from regional interpretation to the local analysis of river discharges over Jakarta Bay. We focused the discussion on characteristics of discharge substances in a particular condition.

2. Datasets and methods

Investigations were performed on the basis of Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS) data. Data were received from Goddard Space Flight Center of the National Aeronautics and Space Administration (NASA). We investigated seasonal variation of sea surface temperature, chlorophyll-a, and suspended matter as well as discharged water distribution near river mouths in Jakarta Bay. We also used long-term data of water discharge and precipitation from Ciliwung river basin area. Figure 1 illustrates a general approach for investigation of various phenomena of coastal processes, showing the different spatial and temporal scales. These range from coastal upwelling on a regional scale to moderate and local phenomena such as algal bloom and coastal discharge. Within this approach, investigations of individual processes can obviously be confined spatially as well as temporally.

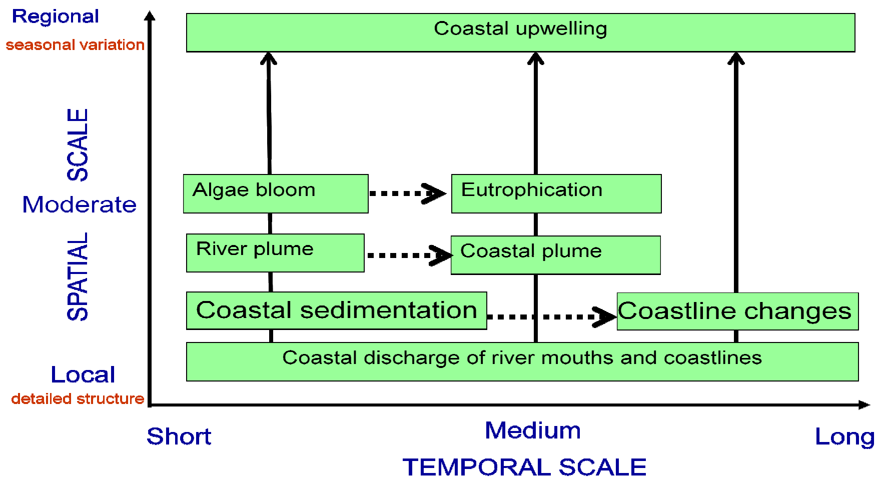

Figure 1: Diagram of general approach for remote sensing investigation

We produce chlorophyll images using Ocean Chlorophyll 4-band (OC4) algorithms (O'Reilly et al [7]). The OC4 is an improved chlorophyll algorithm using empirical maximum reflectance band ratios of 443, 490 and 510 nm with 555 nm. This OC4 algorithm has been validated for Indonesian waters, which obtained a correlation coefficient of 0.866 using this algorithm (Hendiarti, et. al., 2004). Concentrations of suspended sediment as an important parameter for this assessment were obtained using a single band algorithm based on reflectance distribution in the green channel. The spectral reflectance in this channel is mainly caused by backscattering of particulate matter. The TSM algorithm was developed by the Institute for Environmental Studies at the Vrije Universiteit, Amsterdam (Dekker and Hoogenboom, 1997) for for the North Sea with a limited accuracy, certainly not greater than 15-20% (Hesselmans et al , 2001). The formula is given as follows:

$$\text{TSM} = \frac{-0.5296 * R_{555}^{-} + 0.001004}{0.03040 * R_{555}^{-} - 0.005860}$$

where, R_{555}^{-} is the surface reflectance in the 555nm.

Using SeaDAS computer software, all provided by the Goddard Space Flight Center of NASA, we processed monthly images of global area coverage data with 4-km spatial resolution as well as selected local area coverage data with 1-km. Landsat TM, ETM and Formosat-2 images, where Landsat images were received from Landsat.org and Formosat-2 images were provided by NSPO Taiwan under the APEC SAKE (Satellite Application on Knowledge-based Economy) project were used for a qualitative assessment of Jakarta Bay water.

Data on precipitation were collected from the meteorological station in the river basin of Ciliwung for a period between 1997 and 2004. The amount of liquid precipitation is measured at the station every morning at 7 o'clock by meteorologist using the rain gauge which is known also as a udometer or a pluviometer. There are 14 stations for Ciliwung. These stations are operated by the National Meteorological, Climatological and Geophysical Agency (BMKG). The stations are distributed in the upstream and downstream regions in each river basin. In data analysis section, we discussed rain fall distribution pattern for both regions of stream.

Data on water discharge were collected from the hydrological station in the river basin of Ciliwung from 1990 to 2003. The stations are distributed in the upstream and midstream regions in each river basin. Unfortunately, there is no representative station from the downstream region. The hydrological data managed by the Hydrological Bureau under the Ministry of Public Works. Water flow intensity or called as water discharge is measured using AWLR (Automatic Water Level Recorder) to estimate the water level and if that number is multiplied by the appearance unit then we get water discharge in debit.

3. Results and Discussion

3.1. Regional view of coastal discharges

Coastal regions are strongly influenced by eutrophication because of increasing loads of nutrients. High concentrations of organic and inorganic material from river-discharge and diffuse-impacts increase the turbidity of coastal water. During wet season (February and December) higher amount of suspended material discharges, showed in Fig. 2 with a red color, into larger areas in Karimata and Malaka Straits compared to the condition during transition phase (May) and dry season (July). In addition, higher concentration of discharged organic material, showed with a light green color in Fig. 2, occurred in a larger area of Sunda Shelf during dry season (in July) than the condition in other seasons. Remote sensing can support coastal zone planning and management by observation of spreading direction of these discharges. Surface features in the form of river plumes can be distinguished easily by ocean color images.

The algal blooming occurred sometimes in Jakarta Bay such as a disaster in May 14 – 22, 2004. During that period, we observed high concentration of suspended sediment with higher than 10 mg/l as well as chlorophyll higher than 10 mg/m^3. They gave a negative impact to the natural resources, where thousand fish were killed in and near Jakarta Bay.

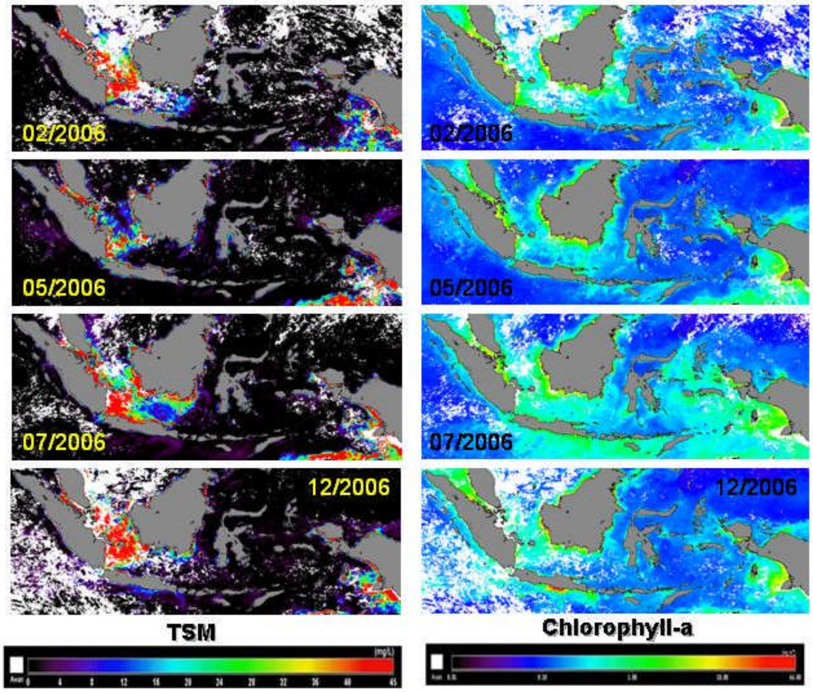

Figure 2. Monthly images of chlorophyll *a* and suspended matter observed in February, May, July and December 2006, showing distribution pattern of both environment conditions from different monsoonal forcing.

3.2. Qualitative assessment of Jakarta Bay using high resolution images

Significant modifying influence of mainland Java on water quality of Jakarta Bay and Kepulauan Seribu is reflected as a strong inverse relationship between water transparency and the distance from mainland Java (Tomascik et al., 1997). The Bay of Jakarta is one of the most polluted water in Indonesia. During rainy season, the majority of water discharged into the bay is from rivers such as Ciliwung, Citarum and Cisadane. For qualitative assessment of Jakarta Bay, we used Landsat TM, ETM and Formosat-2 images. The channels blue, green, red, and NIR are on the same wave bands for both satellites. The coverage of Landsat images is represented by black rectangle and the coverages of Formosat are in green, blue and red rectangles (Fig. 3). The following images are displayed using an RGB combination of channels NIR, Green, and Red, respectively. Moore, 1980 presented a method to estimate relative turbidity of water using this RGB combination. For relative turbidity in the heavy category, the color displayed is light blue, which is noticeable along the coast in the Landsat TM and ETM images. With higher spatial resolution of the Formosat-2 images, the extent of turbid water is more easily seen. From these images, one can conclude that Citarum and Cikarang Rivers are the major source of pollutants, while Cisadane River's discharge is highly visible in the Landsat TM' 1989 image. It expected algae blooming occurrence near the river mouth of Ciliwung from an image in 1989, as shown the specific structures like red threads (Fig. 3, upper). Mass mortality of demersal fish was first reported in Jakarta Bay and was suspected to be related to red tides of *Noctiluca sclntillans* (Adnan, 1989 and Hendiarti et al., 2007).

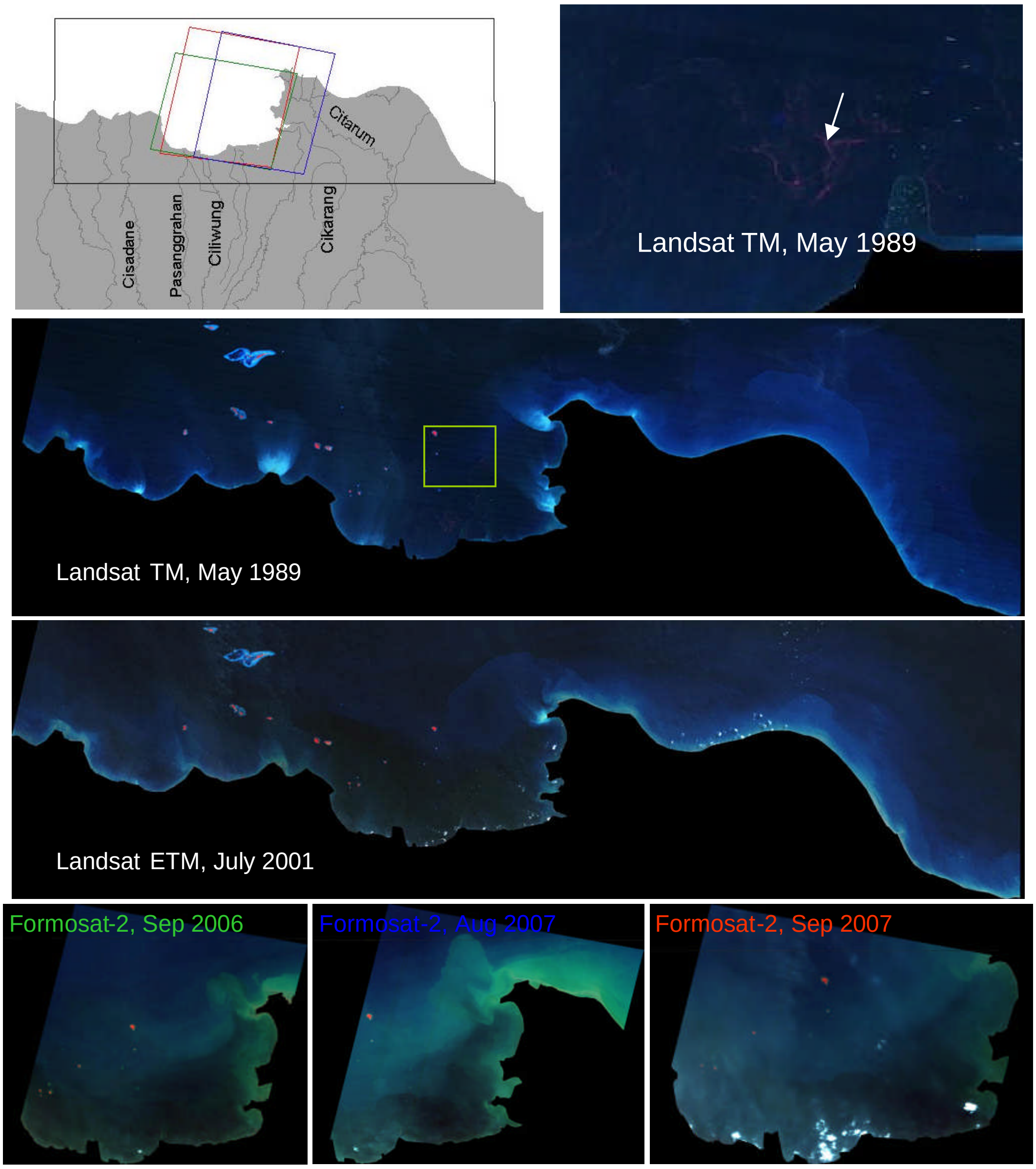

Figure 3. Relative turbidity of water of Jakarta Bay using RGB combination from Landsat ETM and Formosat-2 imageries, showing that Citarum and Cikarang Rivers are the major source of pollutants, while Cisadane River's discharge is highly visible in the Landsat TM' 1989 image.

We investigated the seasonal variation of chlorophyll-a and suspended matter concentrations for discharged water distribution near the river mouths over Jakarta Bay. The location and coverage of each river mouth is presented in Fig. 4 and Table 1. The distribution patterns were analyzed using MODIS data for the period between 1997 and 2007 which are taken from the *Aqua* satellite with 4 km spatial resolution.

The annual chlorophyll and suspended sediment concentrations between Ciliwung, Cisadane and Citarum Rivers are shown in Fig. 5. The discharged waters from Citarum and Cisadane Rivers were investigated with similar environment characteristics. River discharge of Ciliwung has a different pattern which is potential for further development of algal blooming.

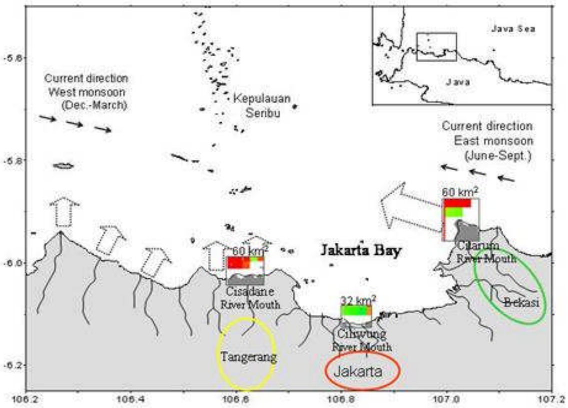

Fig. 4. Map of the Jakarta Bay, the Citarum River and Kepulauan Seribu. Shaded arrows indicate river runoff (Modified from Tomascik et al, 1997). The coverage of three main river mouth illustrated in box.

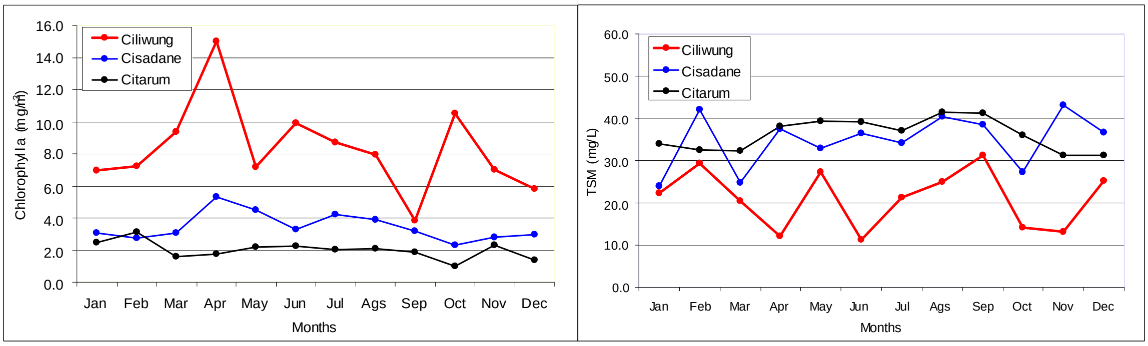

Figure 5. Comparison of annual chlorophyll and suspended material concentrations between Ciliwung, Cisadane and Citarum Rivers. These concentrations were calculated from monthly average in each subset areas between period of 2002 and 2007.

The following conditions are general characteristics among the three rivers analyzed from the series images of chlorophyll and suspended material, as shown in Table 1:

- Discharged water from Citarum River has relatively high concentration of suspended particulate matter (30 – 40 mg/l) and lower concentration of chlorophyll-a (1 - 3 mg/m^3). Distribution of both materials is not closely related to the seasonal monsoon pattern.
- Discharge from Ciliwung River contained low concentration of suspended material (10 – 15 mg/L) and high concentrations of chlorophyll-a (10 – 15 mg/m^3), which were observed in April, June and October. The distribution pattern of both materials is influenced by seasonal monsoon.
- Discharged water from Cisadane River contained high concentration of suspended material (about 35 – 45 mg/L), which were observed in February, April-September and November. A higher concentration of chlorophyll *a* (about 5 mg/m^3) in April and other months during the dry seasonal (west monsoon). Those distribution patterns are slightly influenced by the seasonal monsoon.

Table 1: Characteristics of discharged waters near the river mouths

River Name	Suspended Material		Chlorophyll-a		Distribution Pattern	Water turbidity level	Potential Algal blooming
	Conc. (mg/L)	Peak months	Conc. (mg/m^3)	Peak months			
Citarum (Eastern)	30 – 40	a little in Apr- Sept	1 – 3	a little in Feb.	No seasonal influence	Very turbid	less
Ciliwung (Middle)	10 - 30	Feb,May, Sept	4 - 15	Apr,Jun, Oct.	Seasonal influence	turbid	more
Cisadane (Western)	25 - 45	Feb, Apr-Sept., Nov	2 – 5,5	Apr., Jul.	Lesser amount of seasonal influence	Very turbid	less

Citarum and Cisadane Rivers showed more potential of land accretion than algal blooming development mainly because of high concentrations of sediment particulate matters (very turbid water) observed at the river mouths.

Conversely, Ciliwung river discharge is a potential place for the algal blooming development due to less turbid water with chlorophyll concentrations of greater than 10 mg/m^3 that observed in April, June and October. More detailed information on substances composition of water discharges from Citarum and Cisadane Rivers was observed based on the *in situ* measured in September 2005 (Fig. 6). We found phytoplankton abundance in the coastal area near Cisadane River mouth that dominated by Skeletonema sp with 86%. Moreover, the waters near Citarum River mouth or Canal Bekasi Laut (CBL) are dominated by 89% of Nitzschia sp. (Hendiarti, et al., 2007). In general, Skeletonema is one of phytoplankton species which is always exist and dominate in Jakarta Bay waters. We analyzed that the occurrences of Skeletonema sp in Jakarta Bay waters was influenced by the supply of silicate concentrations (3.35 – 53 mg/L) from the mainland through the river flow.

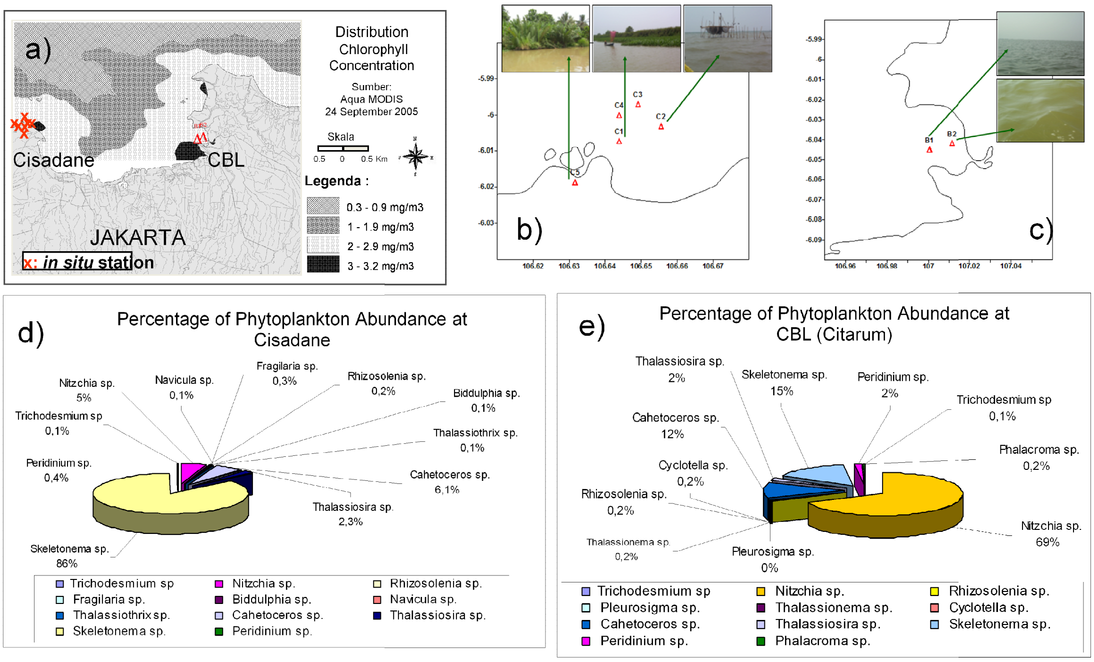

Figure 6. (a) Area of interest with position of in situ station; (c-d) Different water characteristics measured at observation stations; (e-f) Phytoplankton abundance from Citarum and Cisadane river discharge.

We assumed maximum river run-off from Ciliwung River occurred during a peak of suspended material concentration which was observed in February, May, September and December. The phytoplankton development needs nutrients that may come from river discharges and sun light. Phytoplankton development will also need time and calm water circulation. Furthermore, peak of chlorophyll concentration was observed in April, June and October. In the weather with enough sun light, phytoplankton needs about one month to develop after the peak of run-off like in May to June and September to October. Nevertheless, development of phytoplankton in February to April need about two months since there is not enough sun light during the rainy season. This development process may induce the algae blooming.

We also investigated a possible correlation between precipitation and water discharge measured in dams for upstream and downstream watershed areas. The precipitation in upstream area i.e. Bogor City with intensity of greater than 200 mm were observed in longer period than that condition in downstream areas i.e. Tanjung Priok, as shown in Fig. 7 (top). The pattern of water discharges in upstream and midstream are similar, which increases in January untill April and November to December. During the rainy season, fast-flowing water can bring and suspend more soil than calm water. Fig. 7 (bottom) shows that water discharges measured in the middle-stream were higher than the discharges in the upstream.

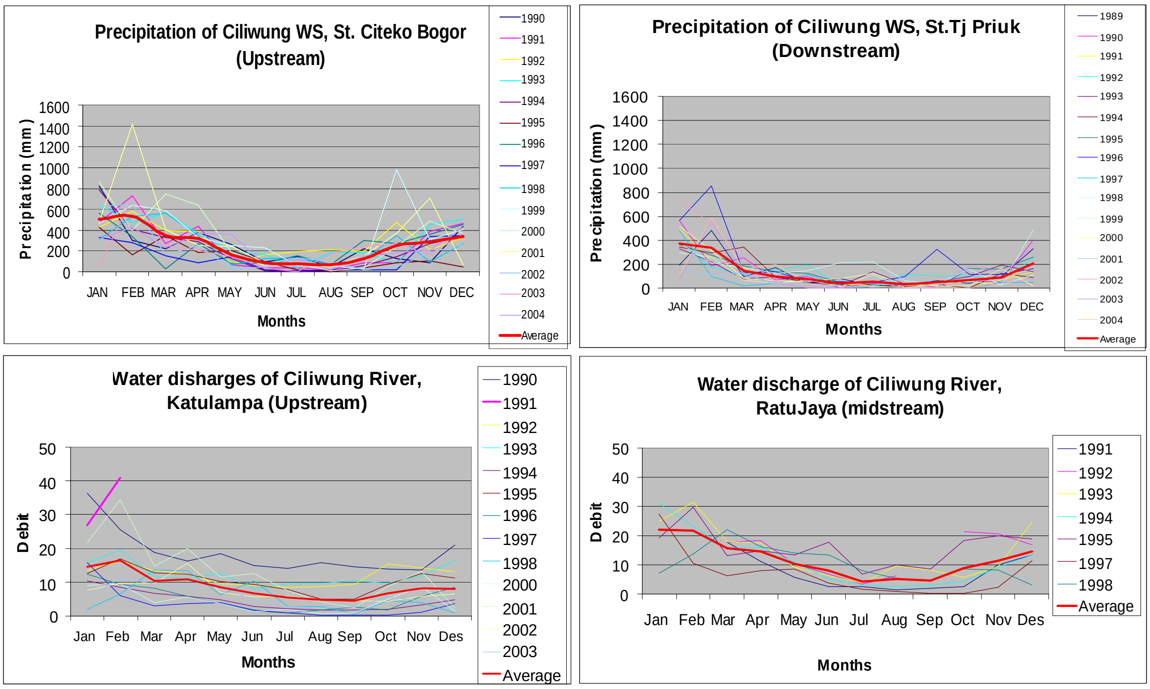

Figure 7. Comparison of annual precipitation in upstream and downstream for Ciliwung watershed (upper), and water discharge in upstream and midstream for Ciliwung (lower). The precipitation and water discharges were observed from the monthly data between period of 1990 and 2004. The average intensity for each parameter has shown in the red bold line.

The results for Ciliwung River showed that it is difficult to form a relationship between precipitation, water discharges (water flow), suspended matter and chlorophyll-a (Table 2). We found there is a correlation between the occurrences of suspended sediment from river discharges that may bring nutrient, with chlorophyll-a development. This correlation was observed during the transition phase from the rainy to the dry season or the spring tide (April and May) and during the dry season or summer (September and October). The lag time (approximately 1 – 2 months) between the maximum occurrences of suspended sediment and chlorophyll is assumed that it is used for phytoplankton development depend also on intensity of sun light. The potential algae blooming may occur in April, May, June, July, October and November. These results are similar to Sam et al., 2008.

The hypothesis is that satellite data may be useful for investigation and prediction of the occurrences of algae blooming (Hendiarti, et al., 2010). This remote sensing investigations need to be improved to include light intensity derived from satellite data that is received by water. However, these optic remote sensing data have a limitation in cloud cover as well as the spatial and spectral resolutions, in order to predict the occurrence of algae blooming in Jakarta Bay.

Table 2: The specific conditions of suspended matter, chlorophyll-a as well as the precipitation and water discharges for Ciliwung River.

Occurrences	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High precipitation: >200mm (BMKG)	√	√	√	√						√	√	√
High water dis-charge: >10(Hydro-logical Bureau)	√	√	√	√							√	√
High suspended sediment >20mg/L (MODIS data)		√			√				√			√
High chlorophyll >10mg/m^3 (MODIS data)				√		√				√		
Potential of algae blooming				√	√	√	√			√	√	
Algae blooming (Sam et al [8])	-	-	√	√	√	√	√	√	√	√	√	-

4. Conclusions

Remote sensing investigation may useful to observe general characteristics of coastal discharges as well as to investigate algae blooming in Jakarta Bay. River discharge of Ciliwung has shown a major correlation between the occurrences of suspended sediment that may bring nutrient with chlorophyll-a, which is potential for further development of algal bloom. This relationship was observed during the transition phase from the rainy to the dry season or the spring tide (April and May) and during the dry season or summer (September and October). Furthermore, a qualitative assessment of Jakarta Bay from Landsat and Formosat-2 images can conclude that Citarum and Cisadane Rivers are the major source of sediment pollutants. The high resolution image showed structures of algae bloom that occurs near the river mouth of Ciliwung in May.

References from Journals:

Hendiarti, N., H. Siegel, and T. Ohde. 2004. Investigation of different coastal processes in Indonesian waters using SeaWiFS data. *Deep Sea Research Part II* 51:85–97.

Hendiarti,,N., A. Ribotti, R. Sorgente. An operational approach to the ocean management in the Indonesian Archipelago, Journal of Operational Oceanography, Vol. 3 No. 1 February 2010, ISSN 1755-876X, page 27-35.

References from Books:

Adnan, Q. 1989. Red tides due to *Noctiluca scintillans* (MacCartney) Ehrenb. and mass mortality of fish in Jakarta Bay. pp. 53-55. In: Red Tides, Biology, Environmental Science and Toxicology, eds. T. Okaichi, D.M. Anderson and T. Nemoto, Elsevier Press, New York.

D. P. Praseno, Y. Fukuyo, R. Widiarti, And Sugestiningsih, 1998. Red Tide Occurrences in Indonesian Waters And The Need to Establish A Monitoring System.

Dekker, A.G. and Hoogenboom H.J., 1997: Operational tools for remote sensing of water quality: A prototype toolkit. BCSR report NRSP-2, 96-18.

Moore, GK, 1980, Satellite remote sensing of water turbidity, Hydrological Sciences Bulletin, 25, no. 4, 407-421.

O'Reilly, J.E., and 24 Coauthors, 2000: SeaWiFS Postlaunch Calibration and Validation Analysis, Part3. NASA Tech. Memo, 2000-206892, Vol. 11, S.B. Hooker and E.R. Finestone, Eds., NASA Goddard Space Flight Center, 49 pp.

Tomascik, T., Mah, A.J., Nontji, A., Moosa, M.K., 1997. The Ecology of the Indonesian Seas Part I. Periplus Editions (HK) Ltd., Singapore, pp. 94-100.

References from Other Literature:

Hendiarti, N., E. Aldrian, C-T Liu, M. Sadly, M.C.G. Frederik, 2007. Remote sensing investigation on seasonal variations of river discharges and their influences to marine environmental changes over Jakarta Bay. Extended abstract presented in the Second APEC SAKE Workshop on Satellite Application on Fishery and Coastal Ecosystem.

Hesselmans, G.H.F.M., 2001. Sediment Mapper, user manual for processing optical remote sensing data (draft report), ARGOSS, pp. 9-11.

Sam, W., C.K. Tan, J. Ishizaka, Tong Phuoe Hoang Son, and Varis Ransi, Salam Tarigan, and Agus Sediadi, 2008. Monitoring of Algal Blooms and Massive Fish Kill in the Jakarta Bay, Indonesia using Satellite Imageries. http://www.eorc.jaxa.jp/ALOS/conf/Proc_PIsymp2007/ contents/proceedings/ Oceanography_Opt/OCO05.pdf