International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jgee.htm
2014 Vol. 4 (3) September-December, pp. 38-50/Szekielda et al.
Research Article

EUTROPHICATION OF MANILA REGION, PHILIPPINES

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ABSTRACT
In the Philippines about 37% of the total water pollution originates from agricultural practices, which include use of animal waste, fertilizer and pesticide runoff. As a consequence, eutrophication is observed in the Manila coastal region in connection with the major drainage region around Manila. The Pasig-Marikina-Laguna de Bay Basin as a water drain to Manila Bay is unique because it represents an interconnection between several water bodies and is partly controlled by the Manggahan Floodway and the Napindan Hydraulic Control Structure. The high nutrient emission from Manila and the catchment area around the Manila Bay results in eutrophication of the bay and its adjacent coastal waters. Chlorophyll estimates with satellite measurements show elevated levels and it seems that eutrophication of Manila Bay is present throughout the year but is decoupled from the monsoon seasons.

Key words: *Eutrophication, Algal Blooms, Chlorophyll, Coastal Zone*

INTRODUCTION
Coastal regimes present the most valuable resource areas providing access to fish and shellfish production, maritime transportation as well as recreational and infrastructure development. Population growth in coastal areas and the emission of anthropogenic products however have been an increasing threat to the ecological functioning of the coast.

This is apparent especially with the impact from nutrient release and its consequences on water quality, biological structures and increase in biomass resulting from the dynamic process of eutrophication. Eutrophication takes place under natural conditions and without human interferences over geological times; however, eutrophication caused by nitrogen and phosphorus discharge as a consequence of human impact is on a different time-scale and is an accelerated process (Rast and Thornton, 1996).

In response to excessive nutrient loading into coastal waters, the presence of harmful algal blooms (HABs) can have far reaching consequences that may lead to paralytic shellfish poisoning (PSP) as a recurring problem to coastal areas. The occurrence of HABs is frequently observed in highly populated areas where there is nutrient discharge especially from agricultural fields, release of untreated sewage and discharges of nutrient loaded ground water into the coastal ecosystem and is the major cause for plankton bloom development.

Oxygen deficiency is a consequence in many regions where eutrophication appears. As an outcome of severe toxicity of several phytoplankton species, blooming in response to eutrophication can result in hazardous conditions when blooms are digested by filtering organisms, such as shellfish which may also be rapidly terminated by sudden physical perturbations (http://www.redtide.whoi.edu/hab).

Data of temporal and spatial distribution of HABs are limited due to short spans of hydrographic conditions that are not easily recognized with conventional methods. Under bloom conditions, plankton, in general, occurs in high concentrations and is present close to the surface where sufficient irradiance is available for the photosynthesis.

Aside from sufficient irradiance at the surface layer, the major controlling factors in plankton bloom development include vertical mixing rates, stratification of the euphotic zone, nutrient supply and high irradiance at the sea surface.

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Modifications of these forcing factors result from changes in surface circulation that defines the location and boundaries of provinces with varying primary productivity.

Eutrophication is to a high degree the result of the increasing need to enlarge the carrying capacity for a growing population. The increasing use of fertilizers however does not yield proportionally needed crops, rather the opposite occurs namely agrochemicals build up to relative declining crop yields with serious environmental impacts. The application of fertilizers in farming in the Philippines increased by 1000%, while the major staples like rice and maize increased only by 200 and 280%, respectively, and others remained approximately about the same. This indicates that an inappropriate use of fertilizers resulted in a loss of about 50% of synthetic fertilizer to the aqueous phase, leading to water pollution with detrimental effects on human health. According to the Philippine National Economic and Development Authority (NEDA), it is estimated that about 37% of the total water pollution originates from agricultural practices, which include use of animal waste and fertilizer and pesticide runoff (Food and Agriculture Organization of the United Nations, FAO 2004). Figure 1 shows an augment in emission of phosphates and nitrates through the environment without actually contributing to the equivalent in food production.

Aside from normal source of nutrients that causes eutrophication, the level of atmospheric pollution in Metro Manila is one of the highest in Southeast Asia (Oanh *et al.*, 2006; Zhu *et al.*, 2012). These atmospheric pollutants are washed out during rainy season from May to November, and they are drained to a major water catch basin in the area of major rivers. In Metro Manila, the major sources of the particulate pollution during wet season are from traffic and industry. Related to the high discharge of nutrients from the agricultural sector (Reyes and Bedoya, 2008) are outbreaks of red tide and other harmful toxic algal blooms in coastal waters with an increasing frequency in Manila and Masinloc Bays. In particular human activities are related to the development of harmful algal blooms that occur frequently in the Manila Bay (Wang *et al.*, 2008).

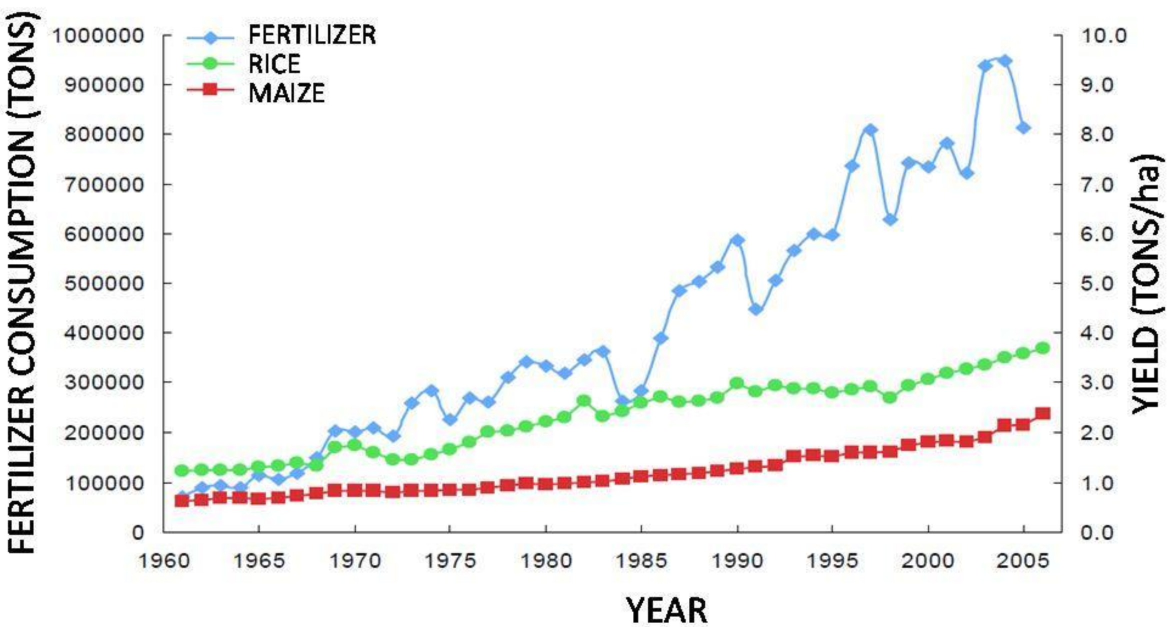

Figure 1: Fertilizer use in the Philippines increased by a factor of ten, while rice and maize yield increased only by a factor of two to three, respectively. Modified from Food and Agriculture Organization (2004)

Rainfall Pattern

The major transport of nutrients goes through the dissolved phase and precipitation and runoff are responsible for their transport to the coastal areas. In the Philippines amount of rainfall is typically

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determined by the monsoon seasons and for Metro Manila the seasons can be divided into the dry season that starts in November and ends in May of the following year while the wet season occurs from May to November. Vertical convection, summer monsoon and the regularly occurring typhoons from the Pacific Ocean are the main causes of rainfall in Manila. Figure 2 below shows the cumulative rainfall rate pattern over the Philippines from 1998 to 2010 obtained from the satellite Tropical Rainfall Measuring Mission (TRMM).It demonstrates that the lower portion of Luzon Island, including Metro Manila, experiences higher rainfall rate over these years compared to other areas in the Philippines. For instance, during the wet season, the TRMM 3-hour average precipitation rate in the Manila Bay and surrounding areas can reach 1.9 mm/hr. The onset of the wet season in Metro Manila is also the start of, at times, flooding and the excess water flows to the rivers and to the bay.

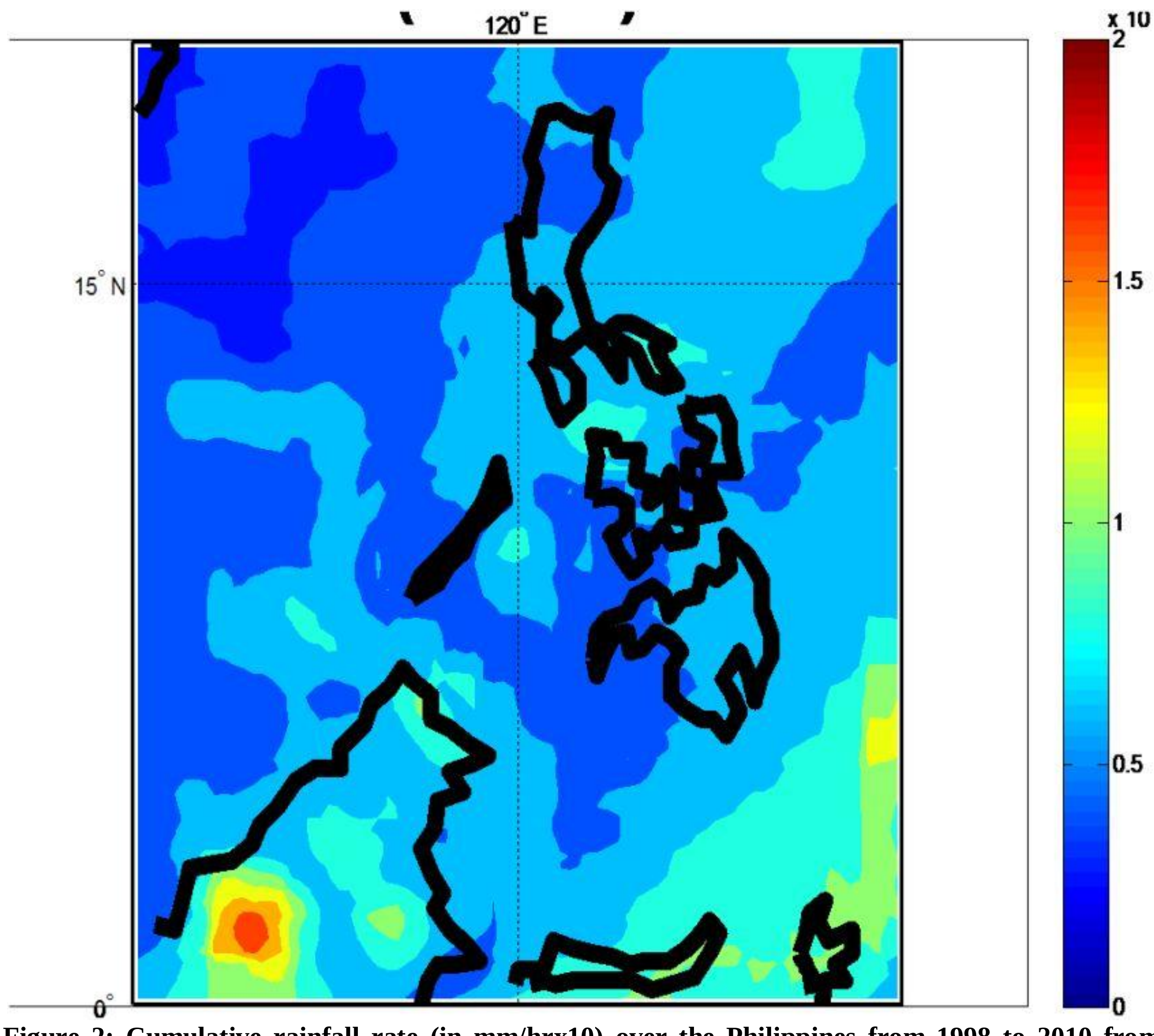

Figure 2: Cumulative rainfall rate (in mm/hrx10) over the Philippines from 1998 to 2010 from Tropical Rainfall Measuring Mission (TRMM)

The Pasig-Marikina-Laguna De Bay and Manila Bay System

The Pasig-Marikina-Laguna De Bay Basin- System

Eutrophication in the Manila coastal region needs an understanding of the major transport system in the drainage region around Manila. The Pasig-Marikina-Laguna de Bay Basin is unique because it represents an interconnection between several water bodies where flows are partly controlled by the Manggahan Floodway and the Napindan Hydraulic Control Structure as shown in Figure 3.

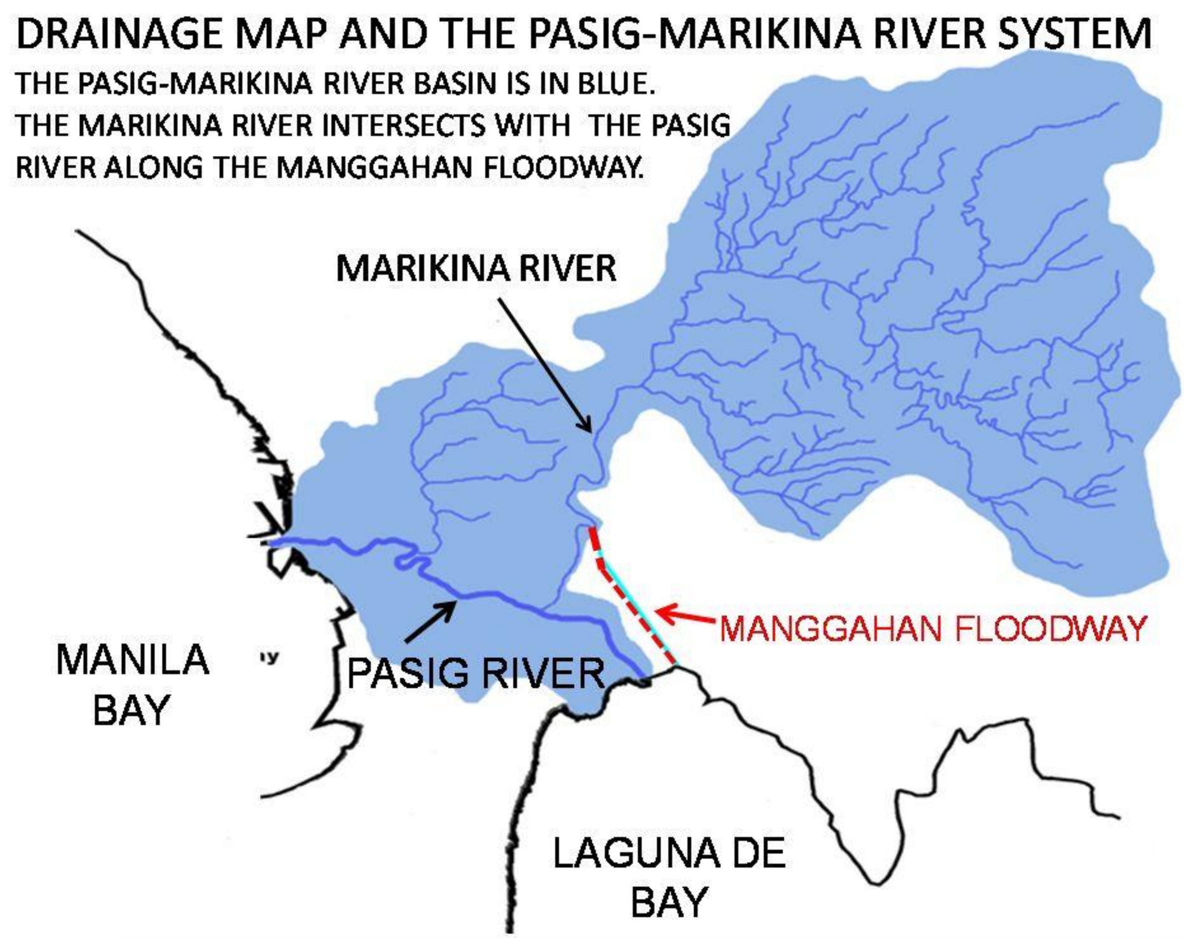

Figure 3: Drainage map of the Pasig-Marikina River Basin with the Manggahan Floodway shown in red. The Marikina River intersects with the Pasig River along the Manggahan Floodway.

The flow control includes the water flow to the Laguna Lake (Laguna de Bay) which is centrally located inside the drainage basin and has an average depth of 2.8 m. The lake is a habitat for fisheries, duck-raising and a waterway for minor passenger and cargo traffic, source of irrigation water in Laguna province, effluent sink by industries and municipalities, flood-control detention storage, and serves as the lower pool of discharge water through the Napindan Hydraulic Control Structure (NHCS) into the Manggahan Floodway. The Napindan Hydraulic Control Structure also regulates the flow between Manila Bay and Laguna Lake by blocking the high-tide inflow of saline and polluted water of Manila Bay-Pasig River and sometimes allowing reverse seaward flow to bring in saline water for fisheries. The Pagsanjan River also drains to the Laguna Lake and its flow is partially regulated by the Caliraya Reservoir.

To reduce the intrusion of saltwater from Manila Bay into the Laguna de Bay and the transport of pollutants from the Pasig River into entering the Laguna de Bay during the times of low precipitation, the Napindan Hydraulic Control Structure (NHCS)was constructed in 1983 at the confluence of the Marikina and Pateros-Taguig Rivers with the Pasig River (Figure 4). This confluence is also the downstream endpoint of the Napindan Channel, which is the upper part of the Pasig River that connects to Laguna de Bay.

Figure 4: The Mangahan Floodway and the Napindan Hydraulic Control Structure (NHCS)

The Pasig River

The Pasig River system runs through five cities and four municipalities and, as pointed out before, connects the Manila Bay in the west and Laguna de Bay in the east. The Pasig River's main watershed is concentrated in the plains between Manila Bay and Laguna de Bay. The watershed of the Marikina River tributary mostly occupies the Marikina Valley, which was formed by the Marikina Fault Line. The Pasig River connects Laguna de Bay to Manila Bay and it is lined by Metro Manila on each side. Its major tributaries are the Marikina River and San Juan River. The river is basically at idal estuary and the flow direction depends upon the water-level difference between Manila Bay and Laguna de Bay. During the dry season, the water level in Laguna de Bay is low and the flow direction of the Pasig River is determined by the tides. Contrary, during the wet season, when the water level of the Laguna de Bay is elevated, flow is normally from Laguna de Bay towards Manila Bay. The banks of the Pasig River are lined by squatter colonies consisting of approximately 12,000 households. The settlements along the river banks discharge their liquid and solid waste straight into the river contributing to the degradation of river water quality and the environment, and the continuous dumping of untreated organic matter and non-bio degradable wastes contributes to occasional flooding.

Tidal backflow of the Pasig River and salt intrusion can be observed during the dry season when high tide has a level of about 1.5 m and depends on the wind conditions. Heavy rainfall leads to an elevation of the level in Laguna de Bay surface that results in draining the lake again through the Pasig River. This flushing out of the salt content in the lake was estimated to take approximately 2-3 months (Gonzal *et al.*, 2001).

Degradation of water quality was recognized as early as the 1930s when fish migration from Laguna de Bay diminished and the water quality of the Pasig River no longer permitted bathing or washing of clothes in the 1950s, and in the early 1990s, the Pasig River was considered biologically inactive but with extraordinarily high coli form content. In response to this detrimental development, the Pasig River Rehabilitation Commission (PRRC) was established to oversee rehabilitation efforts for the river. Supporting the PRRC are private sector organizations, e.g., Clean and Green Foundation, Inc. that implemented the *Pisoparasa Pasig* (*A peso for the Pasig*) campaign (http://en.wikipedia.org/wiki/Pasig_River).

Manggahan Floodway

The Pasig River is vulnerable to flooding in times of very heavy rainfall, with the Marikina River tributary as the main source of the floodwater. To overcome serious flooding, the Manggahan Flood way was constructed to divert excess floodwater from the Marikina River into the Laguna de Bay, which serves as a temporary reservoir. The Manggahan Floodway is an artificially constructed waterway that aims to reduce the flooding in the Marikina Valley during the rainy season, by bringing excess water to the Laguna de Bay. Although the capacity is laid out by design to handle 2,000 to 2,400 $m^3 sec^{-1}$, extreme high water flow, as during tropical storms, and large-scale flooding occurs. Pollution and high sediment carried by the floodway have the potential to jeopardize the existing and potential uses of the Laguna de Bay. The sedimentation rate of the lake is estimated at 1.5 million m³/year with the Marikina River as a major contributor of silt to the lake through the Manggahan Floodway. Additional pollution comes from the shoreline settlers and waste that goes directly into the floodway.

Laguna De Bay

The Laguna de Bay is the largest lake in the Philippines and serves multiple purposes with the dominant use for aquaculture in the form of fish pen technology. The lake has an average depth of only about 2.8 m and an elevation of about 1 m above sea level which determines the water flow between the lake and Manila Bay via the Pasig River. Bathymetric data based on hydrographic surveys during 1997 to 1998 showed an average water depth of 2.24 m and demonstrated that the total lake surface area was reduced from an area of 922 km^2 in a previous survey to the more recent one, to an area of 869 km^2. The causes for surface area changes are partly due to eutrophication but the main contributor to the sediment deposits is through the high transport rate of sediments through the Manggahan Floodway (http://en.wikipedia.org/wiki/Laguna_de_Bay).

The Laguna de Bay represents approximately 40% of the fish production through aquaculture in the Philippines and annual fish yields in the lake are estimated at approximately 450 kg ha^{-1} and are sustained entirely by the natural biota of the Laguna de Bay. Chlorophyll concentrations in the Laguna de Bay range from 3.2 to 47.4 µg $^{-1}$ showing the highly eutrophic level of the lake (Martinez-Goss, 1999). Results of modeling suggest that steady backflow of saltwater from Pasig River reaches deep inside the bottom layer of the lake although the lake water flows out through the Pasig River. Thus, the water quality model for Laguna de Bay focused on the unique role of the salt water intrusion in limiting phytoplankton productivity (Mitsumoto and Santiago, 2001).

A rough estimate of the dimension of nutrient loading (pollution) in the Laguna de Bay was estimated by Reyes (2012) (see Table 1), and it was reported that for the year 2008, domestic, industrial, agricultural and forest sources were contributing 39,622 MT of nitrogen and 9506 MT of phosphorus. The negative impact of eutrophication is that high primary productivity, in response to the ample nutrient supply, leads occasionally to massive fish mortality. This can be triggered by certain meteorological changes or the senescence of *Microcystis* blooms. The sudden breakdown of a bloom and its bacterial decay in the water column may create aerobic or even anaerobic conditions due to the actual collapse of bloom conditions. This is considered to be an outcome from possible viral or bacterial attack, depleted nutrients, excretion of toxic substances, and exposure to anoxic and toxic water.

Table1: Nitrogen emission into Laguna de Bay. Data were extracted from Reyes (2012).

Source ofn-Emission	1973: 13,800 TONS N y^{-1}	2000: 13,800 TONS N y^{-1}
Domestic	26%	79%
Livestock and poultry	36%	16.5% (Agricultural)
Fertilizer	11%	-
Pasic river	22%	-
Industrial	5%	4.5%
Total	100%	100%

The impact of bloom conditions can be demonstrated with a fish kill in May 2012 near the municipalities of Pakil, Pangil, and the city of Calamba in Laguna and in Jalajala, Rizal. Species affected included tilapia, big head carp, knife fish and kanduli with an estimated damage of about Php 1,382,500, affecting 1,500 fish cages and 20 fish pens. It is suspected that the fish kill was triggered by the change in weather during the transition from elevated temperatures to the somewhat cooler rainy season that might have been responsible for a decrease in temperature and turnover of the lake water causing the uplift of the anoxic or anaerobic bottom water. The inflow of nutrient-rich seawater from Manila Bay and sewage discharge from metropolitan Manila can lead to concentrations of oxygen to almost anoxic conditions 2-4 mg/lcon current with the non-occurrence of thermal overturn. Estimates of nitrogen emission into Laguna de Bay is summarized in Table 1 (Reyes, 2012).

Manila Bay

Manila Bay is a semi-closed bay system with a high population density of about 10,000,000 residing mainly in the catchment area of the bay. The bay is exposed to several stress factors that include not only the fast population increase but also the rapid industrial development. The primary economies in catchment areas around the perimeter of the bay area agriculture, forestry and fishery with a variety of industrial manufacturing, to mining and quarrying. These activities are responsible for rising emission of nutrients and heavy metal concentrations that raise the frequency of hypoxia and anoxia events and also frequent appearance of harmful algal blooms (Chang *et al.*, 2009).

The Pasig River Basin (9,000 km^2) and the Pampanga River Basin (3,900 km^2) make up more than 75% of the watershed of Manila Bay. The Pampanga River contributes approximately 49% of the net freshwater influx into the bay, while the Pasig River contributes about 21%. The other river systems make up 26% of the freshwater source and the remaining 4% come from precipitation onto the bay.

The tide in Manila Bay is predominantly diurnal with an average of 1.2 m during spring tide and 0.4 m during neap tides. Changes in the monsoons and short fluctuations in wind direction and speed determine the current pattern especially in regions with low bathymetry. Variations in temperature undergo only slightly around 30^{o}C. The salinity is normally vertically homogeneously distributed especially during the dry season but shows stratification during the raining season which is a result from dilution by the discharging rivers. Salinity however shows only small fluctuations between 30-35 psu with reduced values at the surface during the raining season. Seasonal and temporal variations in water temperature are slight and vary around 30^{o}C (Pasig River Rehabilitation Program, 1999). The estimated residence time of the bay water is about one month.

Suspended sediments enter the bay at a high rate and at high concentrations and as a consequence, the bathymetry of the bay underwent changes that were estimated by ^{137}Cs measurements on sediment cores and established rates in the range of 3.2 to 5.5 cm y^{-1} (Santos and Villamater, 1986). The Pasig River discharges its suspended sediments into the bayin a NE direction and along the shoreline, the major sediment transport occurs during the time of high precipitation from July to December. Additionally, the tide-driven onshore-offshore sediment transport and the geomorphology with the predominant long shore current determine the rate and location of deposition (Sirigan and Ringor, 1997).

About 5,000 to 6,000 tons of solid waste is generated daily in Metro Manila alone of which only a minor fraction is handled at transfer stations or solid waste management facilities. As a result, a large amount of waste and sewage enters the bay directly from the catchment area and coastal communities that comprises a population of about eight million people. Waste and sewage enter the bay from the river catchments and the existing sewage collection system is at present inadequate and discharges without treatment into the bay (Pasig River Rehabilitation Program, 1999).

As an outcome from discharge of waste and sewage, dissolved oxygen concentrations near the bottom can be lower than 3 mg l^{-1} inside the bay. Average concentrations and standard deviations of dissolved inorganic nitrogen; nitrate, nitrite and ammonium in near surface were 0.90 ± 0.53, 0.10 ± 0.16 and 8.00 ± 1.35 µM, respectively. Phosphate and silica showed higher concentrations near the northern shore with average concentrations of 0.92 ± 0.34 and 28.87 ± 9.53 µM, respectively. These high concentrations document that Manila Bay is highly eutrophicated, in particular, through the high nitrogen concentration especially in the form of ammonium (Chang *et al.,* 2009). The response of the ecosystem to anthropogenic emission in the form of elevated nutrient levels is transferred to the higher trophic level, like fishery and aquaculture, and can be regarded as a sink or transit phase for the discharge of domestic and industrial wastes from Metro Manila and the surrounding provinces (Velasquez and Jacinto, 1995) and occasionally leads to hypoxia in the bay (Jacinto *et al.,* 2011).

Eutrophication of Manila Bay and its Offshore Region

High nutrient transport, weather conditions and surface currents are the major factors to developing algal bloom conditions at the end of summer and are usually terminated towards the end of the SW monsoon

(Villanoy and Martin, 1997). It is therefore anticipated that during the NE monsoon, high turbulence causes strong vertical mixing resulting in strong re-suspension of sediment and cysts. In addition, the use of coastal waters for shellfish farming may actually enrich the water from the food and excretion of the cultured species, supplying the nutrients to sustain the bloom.

The high nutrient emission from Manila and the discharge from the catchment area around the Manila Bay result in eutrophication of the bay and the adjacent coastal waters (Szekielda, 2013). With respect to the circulation and hydrographic fluctuations in response to the monsoonal changes, the question arises whether the reversal of the monsoon season has an impact on the distribution of biomass in the coastal region adjacent to Manila Bay. In particular, the relation between nutrient discharge from Manila Bay and the offshore circulation has to be understood. Unfortunately, not much information of the near-coastal circulation is available although an extensive review on the currents in the South China Sea (SCS) has been published (Hu *et al.*, 2000). This review is based on a regional analysis and concludes that the seasonal SCS circulation is mostly driven by the monsoon winds such that the upper layer, between 0 m and 200 m, has a mean circulation that is cyclonic in winter but changes to anticyclonic in summer.

The change in current system, in response to the monsoonal changes, lasts from November to February with prevailing winds from the NE, and from June to August, the circulation is dominated by prevailing SE and SW winds. Fang *et al.*, (1998) surveyed the upper ocean circulation in the SCS and indicated that the Luzon coastal current changes its direction during the winter from December to January from south-SW to a northerly current during summer.

Aside the high nutrient levels from Manila Bay, upwelling in the offshore region could be considered as a process that adds to the nutrient pool. However, upwelling has been observed only further north of Manila Bay at around 12^{o} to 21^{o}N (Shaw *et al.*, 1996), and it is therefore speculated that nutrient flow from Manila Bay might be the dominating factor to initiate high concentrations of chlorophyll in the offshore vicinity of Manila Bay. This assumption is supported by chlorophyll measurements shown in Figure 5 representing averages for six selected months based on satellite observations.

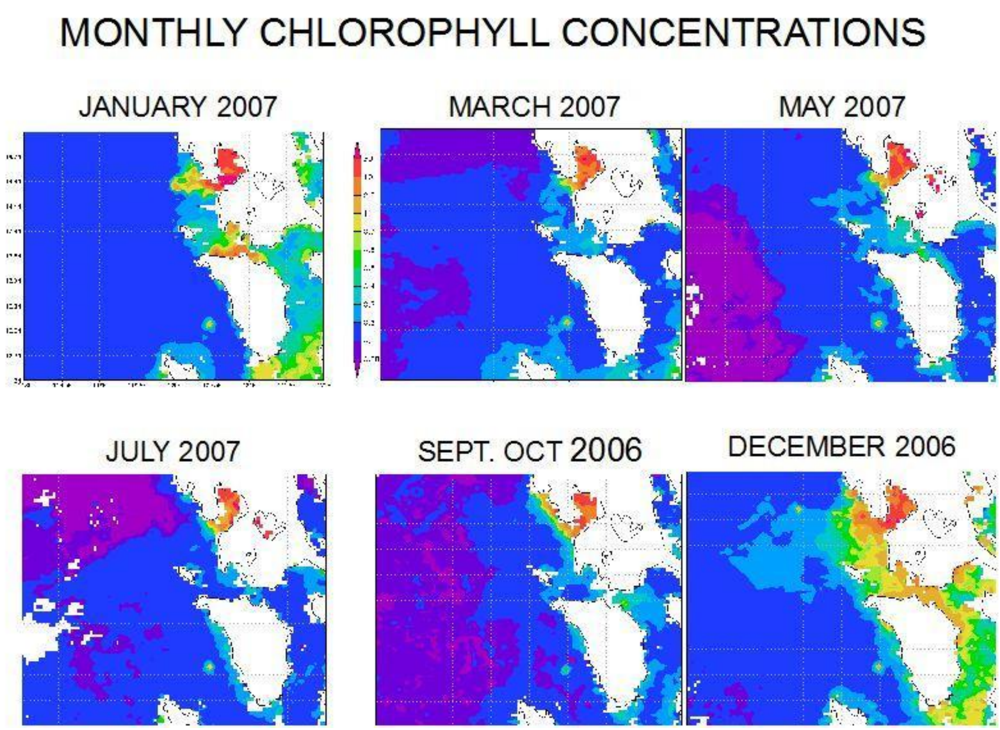

Figure 5: Average of chlorophyll concentrations at 4km resolution obtained with MODIS for monthly data for one year analyzed with Giovanni. Due to cloud coverage, not all months were fully covered and consequently, the best coverage was selected from data obtained in the years 2006 and 2007. Concentrations are in mg m^{-3} and are visualized with the color bar

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In addition to the seasonal variations of chlorophyll, an assessment was done to evaluate possible yearly fluctuations of chlorophyll concentrations with regard to the monsoon seasonal changes over a timeframe of six years. For each NE and SW monsoon season, chlorophyll concentrations were averaged for the specific monsoon season for the years 2003 to 2009, whereby the NE monsoon was defined from November to February and the corresponding chlorophyll values for the SW monsoon were averaged for the period July to September.
Chlorophyll data for the NE monsoon in the near shore region off Manila Bay, shown in Figure 6, reached concentrations around 1 mg m^{-3} with an indication of NE transport along the coast whereas the open ocean had concentrations between 0.2 to 0.3 mg m^{-3}.

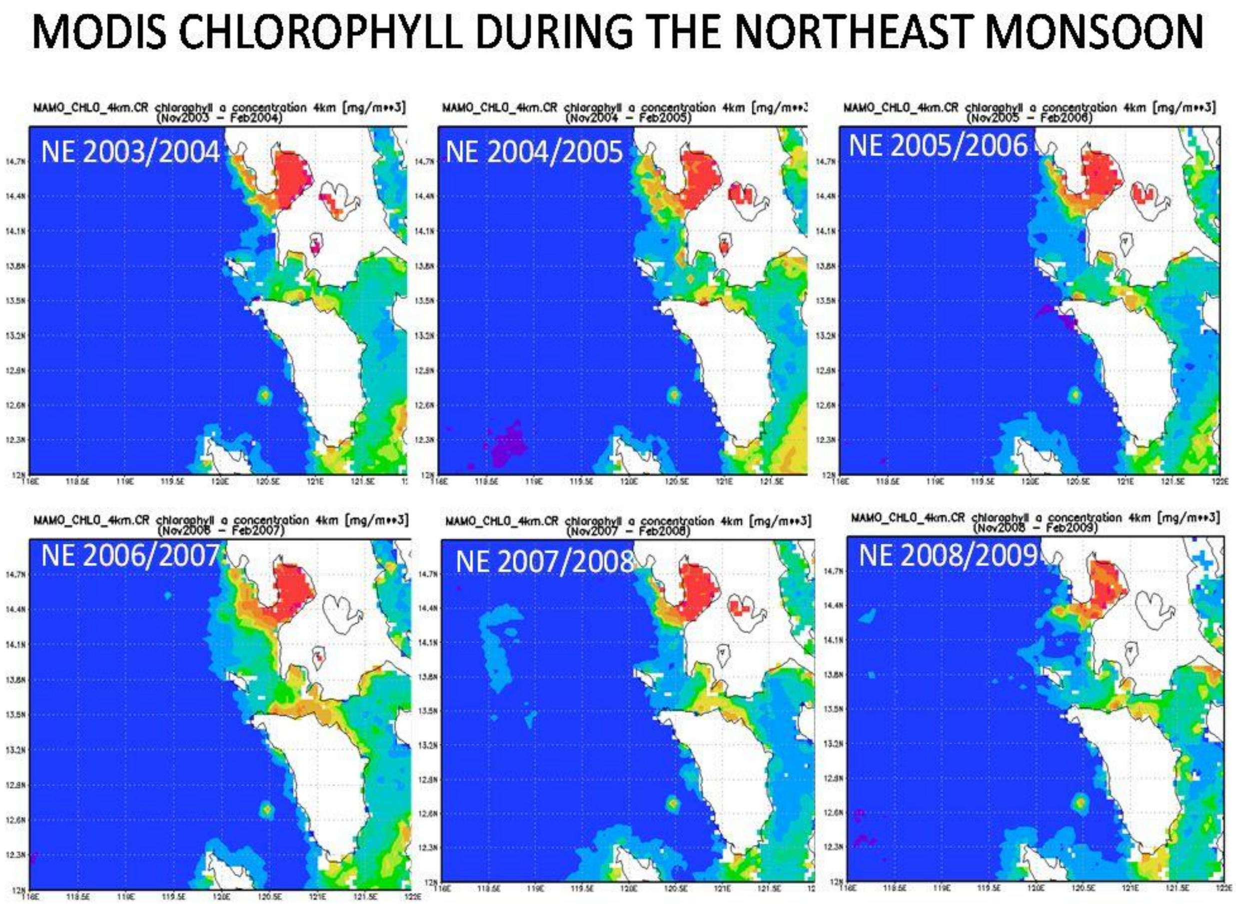

Figure 6: Chlorophyll distribution during the NE monsoon from November to February. The selected years are indicated in the figures. See Figure 5 for the corresponding color of chlorophyll concentrations

The strong blooming in Manila Bay and its progression to the coastal environs is evident but seems to be restricted in its distribution to the near-coastal regime. Wider areas are covered by high concentrations of chlorophyll but were observed only during December. However, elevated chlorophyll concentrations in the region outside of Manila Bay have been observed during the whole year and can be around 30 mg m^{-3}. During the period March to October, chlorophyll concentrations in the open ocean region are around 0.08 mg m^{-3} whereas Manila Bay shows concentrations around 30 mg m^{-3} throughout the year. Offshore augmentation of chlorophyll is evident for the period December to January where concentrations are around 1mg m^{-3} and the distribution pattern is an indication of nutrient discharge from Manila Bay to the near-shore region.

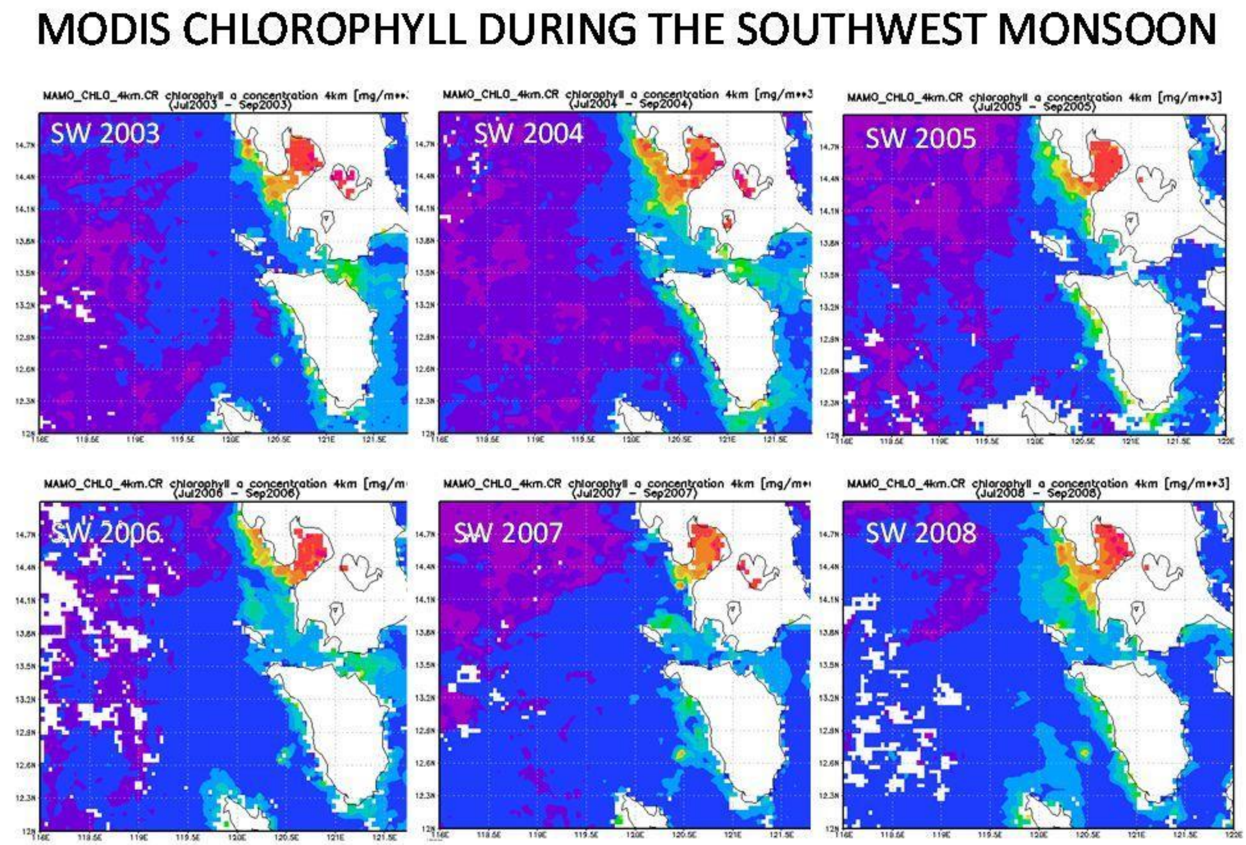

Figure 7: Chlorophyll distribution during the SW monsoon July to September for the years indicated in the figures. See Figure for the corresponding color of chlorophyll concentrations

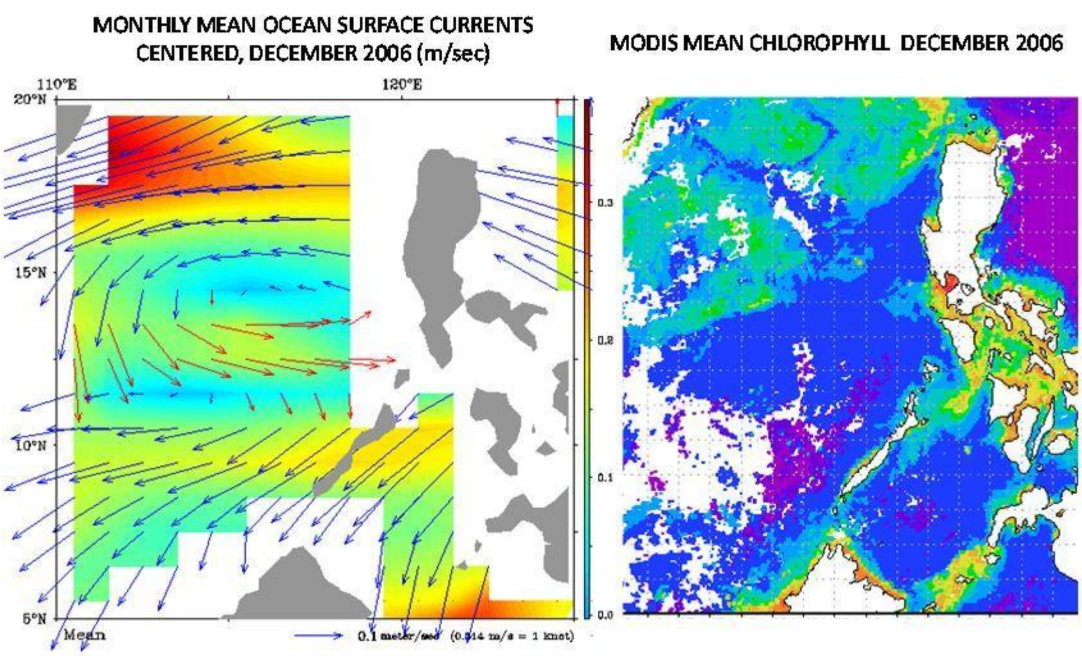

Figure 8: Current and chlorophyll distribution for December 2006.Current data were accessed through the NOAA site www.oscar.noaa.gov that provides currents on a one-degree global grid.

The SW monsoon season is characterized with averaged chlorophyll concentrations for the months July through September as shown for the years 2003 to 2008 in Figure 7. During the SW monsoon season, the open ocean undergoes a decrease in chlorophyll concentrations and minimum values are observed around 0.08 mg m^{-3} for all analyzed SW seasons. Considering the rather coarse resolution of 4 km of acquired data, the distribution of chlorophyll in the vicinity of Manila Bay during the SW monsoon resembles the distribution of chlorophyll during the NE monsoon which is an indication that the monsoonal changes have no major impact on the chlorophyll distribution for Manila Bay and its vicinity. However, data at higher resolution may reveal a more complicated but more detailed scenario for the near-coastal regime and the corresponding vectors of chlorophyll.

The distribution of chlorophyll in December 2006 (refer to Figure 5) represents a deviation from other years and can be considered as an anomalous situation because high chlorophyll concentrations extends farther west than observed during other years. Currents derived from OSCAR (see reference for Dohan *et al.*, 2012), shown in Figure 8, and the simultaneous derived chlorophyll concentrations for December 2006 make it apparent that a cyclonic motion is present with its center located at approximately 15^{o}N and 15^{o}E. This current seems to be responsible for the offshore drift of the chlorophyll plume whereas the eastward component of this gyre develops a boundary to the SW circulation that is responsible for the low chlorophyll concentrations in the south.

Conclusion

This study showed that high nutrient emission from the catchment area around Manila Bay is responsible for eutrophication of the bay and in the adjacent coastal waters.

The increasing use of fertilizers in the Philippines leads to an increasing discharge of nutrient levels but not proportionally to an increase in needed crops and in addition, the fraction not taken up by plant and washed off the soil is eventually transported to the coastal zone. Research on eutrophication in Manila's coastal regions therefore has to include an understanding of the major transport systems in the drainage region around Manila.

The consequences of nutrient flow through the Pasig-Marikina-Laguna de Bay Basin system are shown with chlorophyll concentrations in the Manila Bay to around 30 mg m^{-3} throughout the year.

For comparison, it is shown that offshore augmentation of chlorophyll is evident for the period December to January but concentrations were observed to be only around 1mg m^{-3}. The SW monsoon season is also characterized with low chlorophyll concentrations in the offshore region, compared to Manila Bay with a minimum of around 0.08 mg $m^{-3}$for the open ocean.

Similar conclusions could be drawn from observations during the NE monsoon when the near-shore region concentrations were about 1 mg m^{-3} with an indication of NE transport along the coast while the open ocean had concentrations only between 0.2 to 0.3 mg m^{-3}. This concludes that the high nutrient emission from Manila and its catchment area leads to eutrophication of the bay and the adjacent coastal waters. However, as the chlorophyll estimates showed elevated levels in Manila Bay, it seems that eutrophication of Manila Bay is present throughout the year and is decoupled from the monsoon seasons.

ACKNOWLEDGEMENT

Satellite data and their visualizations were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC. Part of the study in this manuscript were generated while K. H. Szekielda was supported under the US Fulbright Specialist Program and the very generous support of Ateneode Manila University during the stay as a Visiting Professor in 2012 teaching remote sensing of the environment in the Department of Environmental Science.

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