Nutrients, Algal Blooms and Red Tides in Hong Kong Waters

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1. Introduction

The Pearl River is China's second largest river in terms of the volume of water discharged, after the Changjiang (Yangtze) River and it is located on the northwest corner of the South China Sea on the western side of Hong Kong. The oceanography of Hong Kong waters is complex due to large spatial gradients from the estuary to the oceanic waters in the eastern areas. There are large seasonal gradients with the summer wet season being the critical period. High river discharge occurs for at least three months in the summer and this discharge has a marked influence on the water quality of Hong Kong waters.

Rapid urbanization and industrialization has taken place during the past half century in the lower part of the Pearl River, called the Pearl River Delta, and in Hong Kong, with a particularly high intensity during the past 15 years. The total population in the Delta, Hong Kong and Macau is now about 35 million people, and growing. Over 100 million people live in the entire watershed of the Pearl River. As the Delta becomes more crowded, further development will move to upstream areas.

Hong Kong is concerned about its water quality and therefore it has developed an excellent monitoring program that has been operating for more than 20 years. This program has provided a very valuable data set for documenting the changes in water quality in Hong Kong waters. The Environmental Protection Department (EPD) has divided Hong Kong waters into 10 water quality zones (WQZ) with each zone having its own set of water quality standards. The EPD monitoring program has excellent spatial coverage with 76 water monitoring stations that they sample for a wide range of water quality parameters on a monthly basis. In addition, bottom sediments are monitored twice a year at 60 stations. Their annual reports and monitoring data are available on EPD's website (www.epd.gov.hk).

The Agriculture, Fisheries and Conservation Department (AFCD) monitors fish and shellfish culture zones and marine conservation sites. They have several fish culture zones, offshore stations and some seasonal stations that they monitor monthly for algal species. Their reports are available on their website (www.afcd.gov.hk).

This article will illustrate how various factors interact to make the Hong Kong waters less susceptible to nutrient pollution impacts than one would expect, based on the high nutrient loads that these waters receive.

Processes Influencing Environmental Impacts

Like land plants, algae require nitrogen (N), phosphorus (P) and other nutrients to grow. However, if there are too many nutrients, then too much algal biomass is produced and it sinks to the bottom and oxygen is used up during their decomposition by bacteria. Hence, the main environmental impacts associated with too many nutrients are excessive algal blooms (red tides) and subsequent low oxygen in the bottom water, also referred to as 'dead zones'. These dead zones have a large economical impact on coastal fisheries since marine animals cannot live in these areas because the oxygen concentration is too low. The oxygen concentration in air is very high and winds and tides help to mix the oxygen from the air into the surface waters. However, river water and rain are lighter than seawater and form a layer on top of the seawater and this process of the formation of a layer of water with different densities is called stratification. When light fresh water lies on top of heavier seawater, this stratification reduces the transfer of atmospheric oxygen into the seawater and greatly increases the tendency for the occurrence of low oxygen in the bottom water (also referred to a hypoxia).

Nutrient pollution (excessive nutrients; also termed eutrophication) was first observed in lakes in the 1960s and 1970s. In the last two decades, many marine coastal areas also exhibit nutrient pollution symptoms of an increase in N and P, excessive algal blooms and low oxygen in bottom waters. Therefore, nutrient pollution has become a major world wide problem for many coastal areas, especially those coastal areas with a high human population. The increase in the excessive nutrients correlates closely with the increased use of fertilizer since the 1950s. The nutrients that are not taken up by the agricultural crops, enter the ground water which drains into rivers. Nutrients from rainfall, sewage and animal manure also contribute to the excessive nutrient loads in rivers.

Influence of Physical Factors on Environmental Impacts

Hong Kong has well defined wet (summer) and dry (winter) monsoon seasons. During winter, there is little or no contribution of the Pearl River water to Hong Kong waters because northeast monsoon winds push the river water to the Macao side of the estuary. Therefore, nutrients are low in winter and therefore there are no large algal blooms in winter. Physical mixing controls algal growth along with low temperatures and low light. In addition, these winds transport relatively clean (low nutrient) surface waters onshore and this helps to reduce the nutrient polluted water that has accumulated during the previous summer.

During the summer, the winds reverse direction and the SW monsoon winds push the river water into the Hong Kong area. The area covered by the estuarine waters (a mixture of river water and seawater) is very large because of the high rainfall and river discharge during the summer. The western Hong Kong waters receive large amounts of river water in the summer and this causes a large increase in nutrients. However, for the eastern Mirs Bay area, there is almost no influence of the river water because it does not reach this far. The river water flows out of the estuary at the surface since it is lighter (lower salinity) and mixes with deeper relatively nutrient-poor water that dilutes the nutrient-rich river water and this decreases the surface nutrient concentration and reduces potential environmental impacts by reducing the amount of algal biomass produced.

Influence of Chemical Factors on Environmental Impacts

Nutrient sources include sewage, river discharge and rainfall. Algae require nitrogen (N) and phosphorus (P) in a ratio of about 16 units of N to 1 unit of P for their growth. The water from the Pearl River and rainfall has very high N relative to P. Therefore when algae grow, they run out of P before N (i.e. algal growth is limited by P) and in summer the amount of algae that is produced is controlled by the concentration of P, especially in the western and southern waters that receive large amounts of N from the Pearl River.

Since anthropogenic nutrient sources generally have very nitrogen, reducing the concentrations of P during the sewage treatment process should reduce the amount of algal biomass produced and decrease the potential occurrence of low bottom oxygen.

There is a marked temporal variation to the nutrient enrichment coming from the Pearl River, which is in contrast to the relatively constant input from sewage discharge. In the dry season, monsoon winds bring nutrient-poor surface waters from offshore and hence a large portion of Hong Kong surface waters is potentially nitrogen limited for algal growth. In contrast, during the summer wet season, the high Pearl River discharge plus runoff from rain produce surplus N and therefore the size of algal blooms is limited by phosphorus. Hence, there is a shift from P limitation in the southern waters to N limitation in the eastern Mirs Bay area over a relatively short distance of 40 km during summer.

Why Is Hong Kong Waters Less Susceptible to Eutrophication Than Expected?

Physical factors play a major role is diluting the nutrients and dispersing algal blooms. The NE and SW monsoon winds vertically mix the water column, except during the summer months on the west side, where there is strong stratification due to the river discharge. Tidal currents are strong through Ma Wan Channel and Victoria Harbor and there is significant vertical mixing that helps to reduce the occurrence of algal blooms and low bottom oxygen.

In 2001, Hong Kong implemented chemically enhanced primary sewage treatment (removal of particles and phosphate) at Stonecutters Island through the Harbour Area Treatment Scheme (HATS). The result has been a reduction in some nutrients, an increase in bottom oxygen, but not significant decrease in algal biomass because algal blooms in Victoria Harbour are controlled by physical factors such as mixing and not by nutrient concentrations since nutrients do not limit algal growth.

The summer is the critical period because nutrient loads from the river are the highest and additional nutrient loading comes from rainfall and runoff. High water temperatures, strong sunlight, and stratification promote algal growth and bloom formation. In addition, hypoxia may occur in the bottom water due to the sinking and decomposition of the algal biomass and strong stratification which impedes the mixing of O_2 into the bottom waters

In addition to the physical factors which help to reduce eutrophication impacts by diluting nutrients and dispersing algal blooms, there is also an addition chemical factor controlling the amount of algal biomass formed. During the critical summer period, the low P concentration relative to N in the western and southern waters, reduces the amount of algal biomass formed since all of the excessive N can not be taken up and converted into algal biomass. The Pearl River has a lower P concentration compared to the other large rivers such as the Mississippi River and hence the chl concentration is lower. The size of the ‘dead zone’ is strongly correlated with the freshwater discharge volume from the Mississippi River. For example, when the Mississippi River discharge is high (high rainfall), stratification is strong and vertical mixing is reduced and the area of low oxygen bottom water increases.

The potential eutrophication impacts of concern in Hong Kong are excessive algal blooms leading to low dissolved oxygen in the bottom waters which could kill fish and other animals that live in these bottom waters. The term red tide refers to surface algal blooms that are highly visible. These red tide events tend to be over emphasized in newspaper reports because the public think that all red tides are harmful. The concern over red tides is mainly associated with fish kills near fish culture zones that are likely due to low oxygen stress, but there have been no significant fish kills due to low oxygen for the last 10 years. In addition, the earlier fish kills were not due to red tides that produce a toxin that kills organisms. So far, no toxins have been detected in any tested shellfish in response to reports of toxic algal species from AFCD's monitoring program. Generally, the maximum number of red tides occurs in spring and these are mostly occur in eastern waters such as Mirs Bay. The lowest number of red tides occurred in the western waters, near the estuary. Therefore, most red tides occur in spring when the Pearl River discharge is low and in the eastern waters far from the estuary. Therefore the Pearl River is not associated with the occurrence of these highly visible surface blooms, but the river discharge is associated with the formation of large algal blooms that occur throughout the water column and these blooms can contribute to the short-lived low bottom water oxygen events that occur in southern waters.

Summary

The waters in Port Shelter have the best water quality (low nutrients and low algal blooms), while waters in Tolo Harbour, Deep Bay and southern waters are areas of concern. Hong Kong waters exhibit less impacts from excessive nutrients than one would expect, because of:

a) Physical factors

- winds and tides cause vertical mixing that dilutes the high surface nutrients from the river and vertically mixes algal blooms, which slows their growth due to possible light limitation.
- wind and tidal vertical mixing transports oxygen to the bottom waters which helps to reduce hypoxia.

- summer water circulation brings relatively nutrient poor deep water to the surface and this dilutes the nutrient-rich river water. However, this circulation also brings in relatively low oxygen deep water and this may increase the potential for hypoxia when algae sink into this relatively low oxygen bottom water and are decomposed by bacteria.

b) Chemical factors

- low P concentrations in the western and southern waters controls the amount of algal biomass produced and the potential occurrence of hypoxia. Hence, the shortage of P relative to N means that not all of the large amount of N coming from the river can be converted to algal biomass. Consequently, this surplus N is transported offshore, but we do not know if there are any further potential impacts offshore.

c) Biological factors

- The main eutrophication-related impacts of concern are excessive algal blooms which could increase hypoxia in the bottom waters when the bloom sinks and decomposes.
- Red tides have not caused any significant fish kills due to low oxygen in the last 10 years, and few produce toxins that contaminate shellfish. Most red tides occur in spring when the river discharge is low and in the eastern waters, far away from the Pearl River estuary.
- the main environmental impact of concern is the occurrence of hypoxia (low oxygen in the bottom water). Presently, episodic occurrences of hypoxia have

been reported in western and southern waters, but no long term problems have occurred yet.

Future Directions

We must maintain the very valuable monitoring programs of EPD and AFCD in Hong Kong waters. There is a need for the exchange of data arising from the mainland's monitoring program in the Pearl River estuary. The development of a physical-biological coupled ecosystem model would assist in the management of Hong Kong's waters.