J. of the Environmental Sciences
Vol. 13, No. 11, 1001~1007, 2004

The Change of Water Quality in Osaka Bay during Recent 70 Years

Dong-Jin Han* and Jong-Sung Yoon

*Hydro-soft Technology Institute Co., Ltd., Osaka 550-0015, Japan
Department of Civil Engineering, Inje University, Kimhae 621-749, Korea

(Manuscript received 25 October, 2004 ; accepted 23 November, 2004)

The rapid industrialization and urbanization in Osaka Bay have produced many serious water pollution problems since the 1960s. A symbolic phenomenon is algae bloom (red tide), which occurred 53 times in 1976. The special law was enacted in 1973 and a number of administrative steps were taken, such as cutting COD loading, reductions in phosphorus (P) and restriction of land reclamation. As a result, the pollution of Osaka Bay has gradually been reduced, and the environment has been improved to some extent. In this study, to analyze the relations between water qualities as well as a social, economic activity by the coastal zone, the water quality data in Osaka Bay of 70 years past since 1921 were collected. Data such as population, livestock, fertilizer, industrial product etc. were also collected for estimating nutrients flowing into bay from land. It was found that the water quality was changed of a similar trend of estimated nutrients load, with delay of about four or five years.

Key Words : Water quality, Nutrients load, Field data analysis

1. Intoduction

During the period of industrial reconstruction after World War II, the coastal zone of the Seto Inland Sea had experienced explosive increases of population, and construction of many heavy industries. As a result, a large amount of untreated wastewater caused great damages to ecosystem and fisheries. The problem had also affected human being: the local residents, with disasters such as Minamata disease due to mercury contaminant. During the rapid economic growth started from around 1960, the problem of water pollution became more widespread and severe year by year. Red tide, namely algae bloom, has occurred with high frequency as a result of the eutrophication of seawater, and some kinds of red tide result in destruction of marine creatures including cultured young yellowtail.

Corresponding Author : Jong-Sung Yoon, Department of Civil Engineering, Inje University, Kimhae 621-749, Korea
Phone : 055-320-3434
E-mail : civyunjs@inje.ac.kr

The Japanese Government established the Environmental Agency in 1971 on the basis of public concern. In 1973, to prevent the more and more serious water pollution, the Environmental Agency enacted the Law Concerning Special Measures for Conservation of the Environment of Seto Inland Sea (called Seto Inland Law for short). Comprehensive measures have been taken under the law; for example, the decrease of the COD loading from the coast of the Seto Inland Sea to the half of the loading in 1973 before 1978, the reduction of phosphorus load, and the law prohibition of land reclamation larger than 0.5 ㎢ along the Seto Inland Sea[1]. Furthermore, legislation has been introduced to limit an area-wide total pollutant load control of flow rate and nutrient fluxes discharged into Osaka Bay since 1978. There were 44 sampling stations to measure the ambient water quality every month. In particular nutrients were analyzed 4 times per year. Such data sampling and averaging is essential to make the marine environment in Osaka Bay under control. The coastal and sea area were classified and the environmental quality standard value was established to the each waters according to utilization in Japan.

The purpose of this study is to estimate the change of the water quality of Osaka Bay according to the change of the amount of the nutrient loading that flows in from the land to the sea during the period from 1921 to 1995, and to evaluate the impact by the change of the water quality of Osaka Bay quantitatively.

2. Research Area

2.1. Characteristics of Topography of Osaka Bay

The Seto Inland Sea is the largest enclosed coastal sea in Japan. As shown in Fig. 1, it is enclosed by the three main islands of Japan; namely Honshu, Kyushu and Shikoku. It covers an area of 23,000 km^2, a total length of coastline of 6,900 km and average depth is 38 meters. In addition, it is a shallow, long and narrow sea, and there are one thousand small islands. The Seto Inland Sea is connected with the Pacific Ocean through the Kii Channel in the eastern end and through the Bungo Channel in the western end. The average temperature is 15 degrees; and the average rainfall is 1,300 mm per year. The population around the coastal zone is 30 million, contributing 24% of the entire population of Japan.

Osaka Bay is located at the east end of the Seto Inland Sea and it is an oval-shaped bay with a 60 km major axis northeastward and a 30 km minor axis southwestward. The bay bottom is made from soft clay and gravel sedimentation which have been transported and laid down by the Yodo River and the Yamato River, which have been reducing the water depth to less than 20 m in the eastern section of bay over the past years. The basin slopes down toward the west side of the bay. There is 40~70 meters deep valley to the north of Awaji Island. In the eastern section, there is the Okino-se sandbank, which has a minimum depth of 23 meters. At the north-west end of the bay the Akashi Strait connects Osaka Bay to the Sea of Harima, while at the south end the Kitan Strait connects the bay to the Kii Channel. The Sea of Harima leads to the Seto Inland Sea 、 and the Kii Channel leads to the Pacific Ocean. The length of coastline is about 550 km, while natural coastline is only 30 km, only about 5.5% of the total length.

2.2. Social and Economic activities in Osaka Bay

This area is called as 'Kansai District', with population up to about 16 million and a production amount of industry of about 40,000,000 million yen. Because of the advantage and convenience of labor force, transportation, climate and topography of the Seto Inland Sea and Osaka Bay area, a large number of heavy chemical industries and petrochemical complexes had been constructed along the coast, in almost all cities around Osaka Bay. Fig. 2 and 3 show the change in population and production amount of industry in Osaka city and Osaka Prefecture, respectively. The production amount is represented as an index normalized by the amount in 1970, which is 785,900 million yen. It accounts for almost 60% of the total population and more than

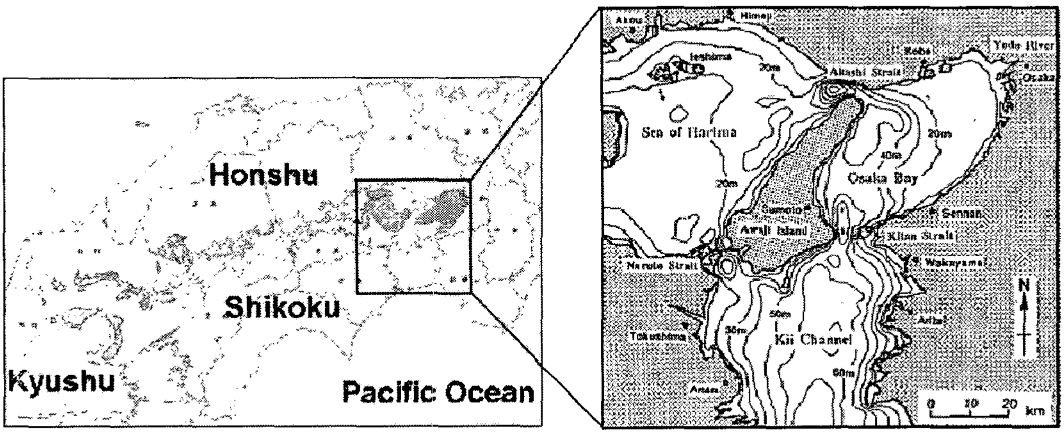

Fig. 1. Location of Seto Inland Sea and topography of Osaka Bay.

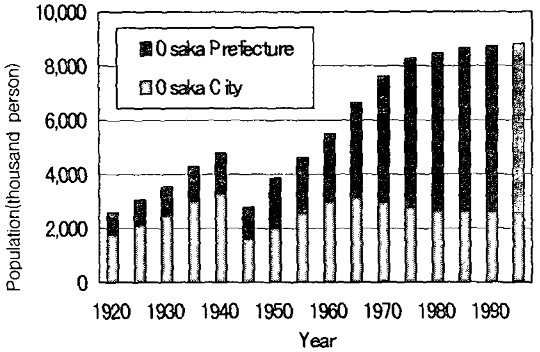

Fig. 2. The change of population in Osaka City and Osaka Prefecture.

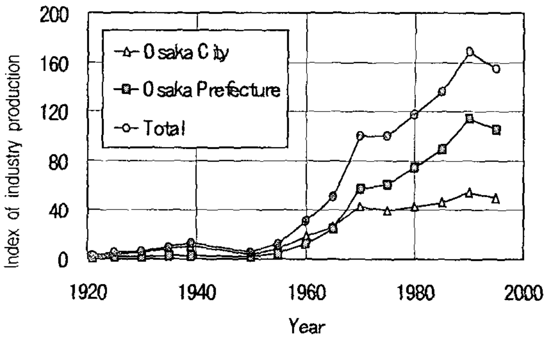

Fig. 3. The change of production amount of industry in Osaka City and Osaka Prefecture ; Index means normalized amount by 785,900 million yen in 1970.

50% of the total industrial products of the 'Kansai District'. The population of Osaka Prefecture was 4.3 million in 1935, and it decreased for World War II in 1945. And then it increased dramatically, reaching 7.6 million in 1970 during the period of rapid economic growth and then 8.8 million in 1995, almost doubled the prewar level. The amount of industrial products was 1,400,000 million yen in 1935 and then started to increase sharply after 1960, reaching 13,500,000 million yen in 1970 and 20,900,000 million yen in 1995.

Therefore, the acquisition of land as the base for the economic activity depended on the reclamation of the coastal waters in Kansai where the demand of the land, especially the ground, was high. The area reclaimed after 1945 is as large as 6,300ha, and huge steel and petrochemical complexes as well as a number of container terminals were built in the waterfront. The history of the landfill project is shown in Fig. 4[2]. To cope with the intensified water

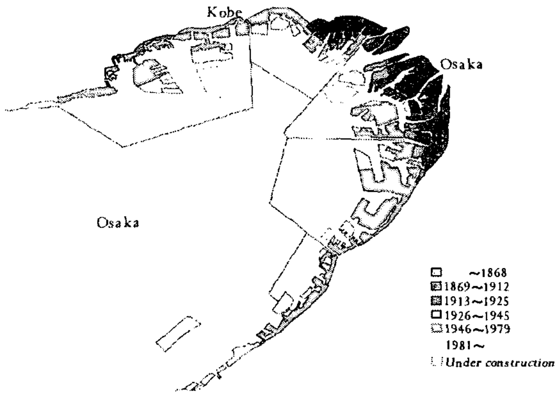

Fig. 4. The history of reclamation projects and the change of coastline in Osaka Bay.

pollution in the Seto Inland Sea, the Law Concerning Special Measures for Conservation of the Environment of the Seto Inland Sea (generally speaking, Seto Inland Sea Law) was established in 1973. The number of reclamation projects has decreased rapidly since then. However, there have been still large reclamation works. At the present, the following reclamation projects are now under construction; the second stage of Kansai International Airport (514 ha), the Kobe Airport (300 ha) and two Phoenix for the treatment of industrial and domestic waste (203 ha and 112 ha). With the progress in the reformation of the industrial structure in recent years, the Law Concerning Development and Restructuring of the Osaka Bay Area was established in 1992, aiming at promoting the utilization of existing reclaimed land which have been less used or totally unused, in parallel with redevelopment of the coastal zone. Many projects have been planned based on this law and are being promoted actively.

3. Analysis of Observation Data

3.1. Field Data Observed in Recent 70 Years

The list of collected data for analysis is shown in Table 1. Osaka Prefecture Fisheries Experimental Station has carried out a regular observation by the locations of 20 in the Osaka Bay every month since 1972. The similar monitoring system set up at 27stations by the Environmental Agencies of Osaka and Hyogo Prefectures. Irregular field surveys were conducted in 1928, 1935, and 1950~1953. In addition,

Table 1. List of field observation data used for analysis in Osaka Bay

Organization	Observation year	Month	No. station
Kobe Marine Observatory 2nd Survey	1928	June	16
Kobe Marine Observatory 3rd Survey	1935	May	57
Kobe Marine Observatory Regular Survey	1950 - 1953	Jan. - Dec.	8
Osaka Pref. Fisheries Experimental Station	1972 - 1992	Jan. - Dec.	20

large scale observation often has been conducted, since marine developers have obligation to carry out field survey as one of environmental impact assessment, which is close to the public as usual.

3.2. Data Analysis

Fig. 5 shows the variation of transparency observed at the bay head and at the western area of the bay in May. Two representative observation stations are shown in Fig. 1 by solid circles. The transparency is an index of the turbidity of the suspended solids and chlorophyll-a. In the west area, the transparency was beyond 8 m in 1923 and 1935, while it varies from 3 m to 9 m with average 6 m in recent years. In the bay head, its value was only 3 m even in 70 years ago and less than 2 m now. It means the water pollution in the bay head began to deteriorate in 1930's. The same tendency was able to be observed to the change of surface COD almost as shown in Fig. 6. Their values in the western area were less than 2 mg/L in 1975 and it is the same in recent years. In the bay head, COD was about 3 mg/L in 1983, and has changed widely from 3 to 6 mg/L. These values were observed in May. Environmental quality standard regarding the preservation value COD in this area are less than 2mg/L, and, the change COD concentration such shows that the bay head area has been polluted since 1935.

Fig. 7 shows the annual change of the saturation ratio of dissolved oxygen near bottom of the sea; DO concentration in the bay head and the west area is an annual average of the value, the value indicated by the closed triangle is data observed by the bay head in August. The annual average value of DO reached 90% in 1950's. In the recent 40 years, the pollution has been deteriorating rapidly; Saturation ratio of DO decreased to about 60% in the bay head and about 80% in the west area. The concentration has been lower than 20% in not only recent years but also 1950 in summer. The DO saturation over 100% means that there are abundant phytoplanktons, which

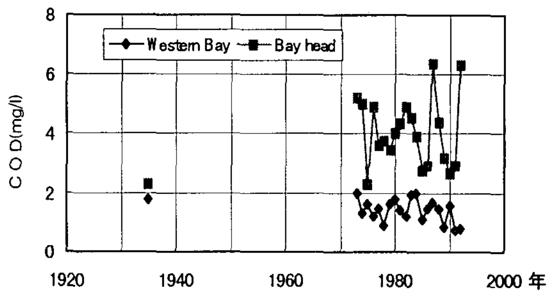

Fig. 6. Variations of COD at bottom water in bay head and in western area.

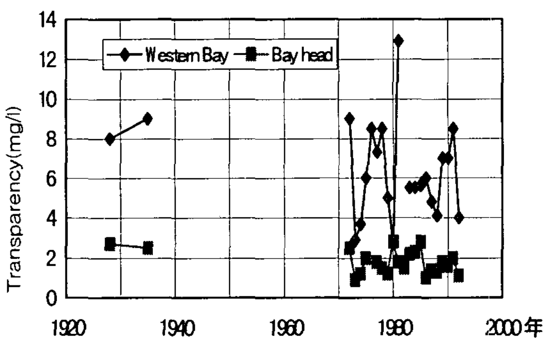

Fig. 5. Variations of transparency in the bay head and in western area.

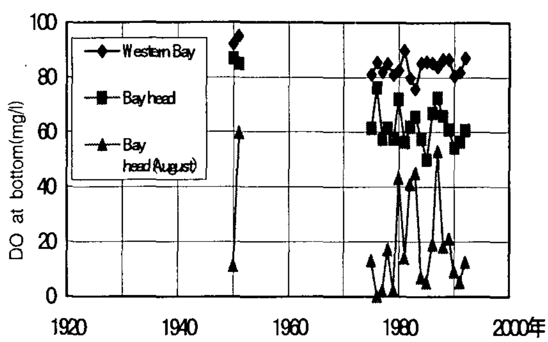

Fig. 7. Variations of DO at bottom water in bay head and in western area.

generate oxygen through photosynthesis. The abnormal multiplication of phytoplankton brings out the occurrence of red tide near the water surface, which results in heavy damage to the marine products[3]. On the other hand, excess organic substances and phytoplankton, which are born in the water using as a nutrient source of nitrogen and phosphorus, deposits on the bottom of the sea. They are resolved by microorganisms, and consumption of a lot of oxygen results in a remarkable decrease of DO near the bottom of the sea at this time.

4. Estimation of Disposal of Liquid Wastes and Effects of Total Pollutant Load Control

A basic unit method[4] was applied to estimate the nutrient loads discharged from Osaka Prefecture area into Osaka Bay during 76 years from 1920 to 1995. The estimated nutrients were chemical oxygen demand (COD), phosphorus (P) and nitrogen (N). Sources of liquid waste discharges include: (1) domestic, e.g., households, offices, public institution; (2) industrial activities; (3) agriculture activities; (4) livestock activities; (5) precipitation in terms of urban storm runoff from areas of reclaimed land and from the remaining land areas of the watershed. The last source (5) is usually treated as non-point source; hence it was excluded from the estimation.

In the basic unit method, generally speaking, the product amounts of COD, P and N were estimated beforehand per person for (1), per each a category of industry (kg/day) for (2), per each chemical fertilizer (kg/year) for (3), and per livestock for (4). Total loads were able to be estimated by multiplying such amount per unit by yearly amount of breakdowns for individual source, and by adding all amounts of breakdowns to four discharging sources. Increase in municipal and industrial sewage treatment system should be taken into account. It is because it directly affects removal and outflow rates. In order to estimate the inflow loads during the period from 1920 to 1995, the author, therefore, collected statistical data of population, the number of domestic animals, the amount of chemical fertilizers used, the production amount of 21 categories of industry obtained from the statistical year book of Osaka Prefecture, materials from the Environment Department of Osaka Prefecture as the framework. For example, the estimated values of COD, P and N were 306.2, 11.5 and 178.3 ton/day in 1990 respectively.

4.1. Estimated Inflow Loads in Recent 70 Years

Fig. 8 shows the yearly change of estimated inflow loads of COD, P and N with breakdowns for individual discharge sources. All estimated loads and their breakdowns show a rapid increase from 1950 after a temporary decrease during the period from 1935 to the end of the World War II. Total inflow COD has increased rapidly along with a large amount of industrial wastewater and reached its peak in 1970; since then, COD was decreased every year until 1995.

The decrease of COD was attributed to the decrease in the amount of industrial wastewater and

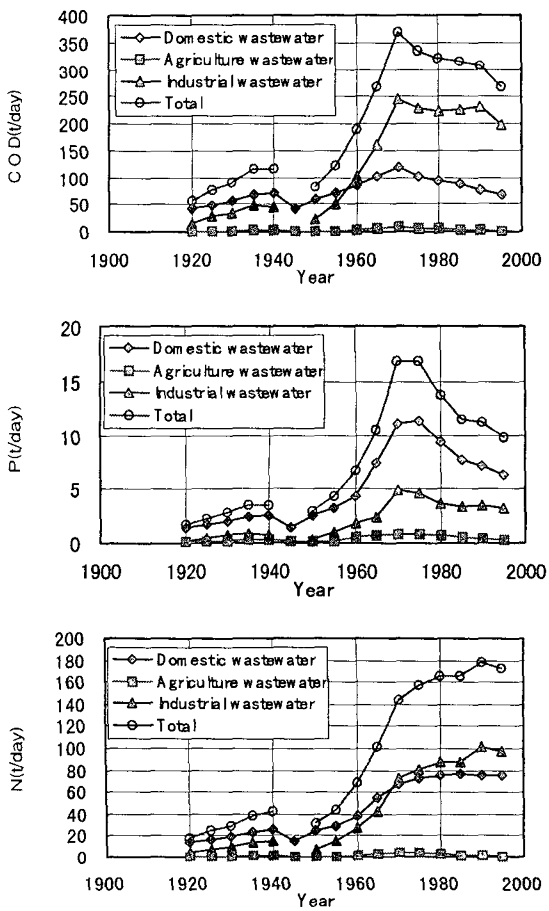

Fig. 8. Yearly change of inflow loads of COD, P and N.

domestic wastewater. Inflow P showed the similar tendency to inflow COD which increased quickly until 1975, and then decreased remarkably. As a result, the value of total P in 1995 became a level as the same as that in 1965. These changes were primarily due to the decrease of domestic wastewater.

The ratio of domestic wastewater to industrial wastewater is about 2.5 times in 1975 or 1980. A lower figure demonstrates the change of inflow N. The inflow N had a same tendency like COD and P before 1975. However, inflow N kept increasing though the growth rate was comparatively little. Another different characteristic was that the contributions of domestic and industrial wastewater of total N were almost the same.

4.2. Effects of Total Pollutant Load Control

Fig. 9 shows the annual changes of estimated inflow pollution loads of COD, P and N and observed water qualities in sea surface at the bay head. The dotted lines represent estimated loads as the same as total lines shown in Figure 10, while the thick solid lines do the practical loads discharged from Osaka Prefecture area from 1978. The difference between values means the quantity of reduced pollutant loads; namely, 146 ton per day for COD and 5.9 ton per day for phosphorus in 1995. The concentration of COD was observed in May, while those of phosphate-phosphorus and the nitrogen were yearly mean values. In order to have a clear grasp of tendency of the observation data, three-year moving averages were also plotted in the figures. It can be seen from these figures that the changes in the water quality concentrations are very close to the changes in the estimated inflow loads. The estimated COD loads decreased gradually after its peak in 1970.

At the same time, the observed COD concentrations showed a slow decline in general. Such a tendency is more obvious in the changes of phosphorus, where the estimated phosphors loads showed a quick increase from the 1950s and then surface water observed at the bay head also started to increase rapidly from around 1970 and then decreased quickly after the peak in a drastic decrease after reaching its peak in the early 1970s. The phosphorus concentrations in the surface water observed at the bay head also started to increase rapidly from around 1970 and then decreased quickly

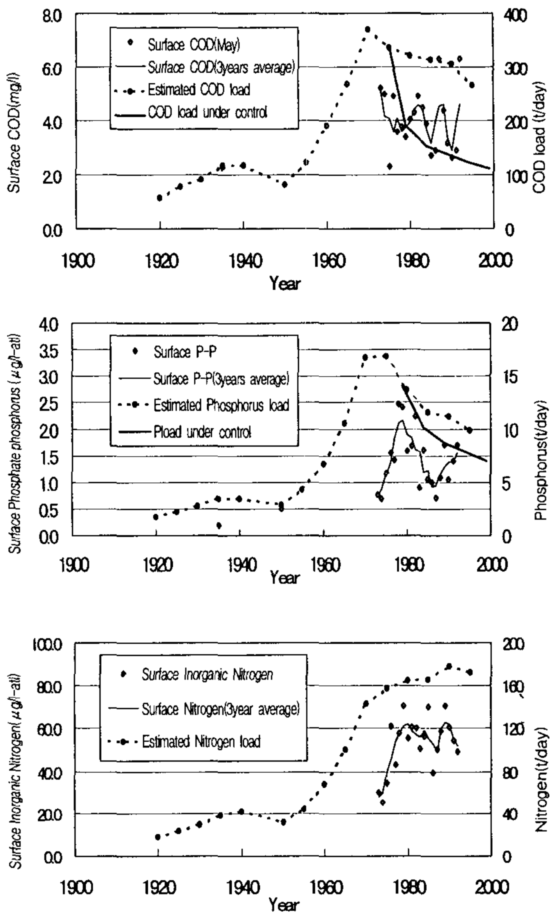

Fig. 9. Comparison between estimated inflow of COD, P and N, and their concentration values observed in bay head.

after the peak at 1979. In the case of nitrogen, the observed concentration increased from 1972 to 1980. Although the data showed to be scattered, three-year moving averages indicated the almost same tendency as the variation of phosphorus concentrations. Both concentrations of phosphorus and nitrogen dropped in 1987 and tended to increase again.

The latter two figures have something in common with each other. The change of observed phosphorus or nitrogen concentrations is almost identical with that of estimated phosphorus or nitrogen loads, although there is a delay time of four to five years. Such a delay occurs by various phenomena of not only physical system but also chemical and biological processes. It is largely conjectured that one of important reasons is the water-sediment interaction in terms of sedimentation of organic detritus from the pelagic zone into the benthic zone and release of nutrients in the reverse direction.

5. Conclusions

Field data observed in Osaka Bay and socio-economic data during the period from 1921 to 1995, were collected in order to clarify the processes of water pollution and restoration in Osaka Bay. The analyses of these collected data led us to the interesting results; (1) water quality in the bay head had been polluted before this survey, namely 1928, (2) the change of water quality had influenced by the socio-economical activities in the bay hinterland, (3) water quality changed following the similar trend of estimated nutrient loads with delay of about four or five years, and (4) an area-wide total pollutant control had good results in order to promote conservation for water quality in enclosed coastal waters.

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