ANALYSIS OF WATER QUALITY TRENDS IN OSAKA BAY WITH A WEIGHTED REGRESSION APPROACH

Manisha MAHARJAN[1], Minoru YONEDA[2] and Yoko SHIMADA[3]

[1]Department of Environmental Engineering, Kyoto University
(Kyoto Daigaku-Katsura, Nishikyo-ku, Kyoto 615-8540, Japan)
E-mail: manisha@risk.env.kyoto-u.ac.jp
[2]Member of JSCE, Professor, Department of Environmental Engineering, Kyoto University
(Kyoto Daigaku-Katsura, Nishikyo-ku, Kyoto 615-8540, Japan)
E-mail: yoneda@risk.env.kyoto-u.ac.jp
[3]Member of JSCE, Associate Professor, Department of Environmental Engineering, Kyoto University
(Kyoto Daigaku-Katsura, Nishikyo-ku, Kyoto 615-8540, Japan)
E-mail:shimada@risk.env.kyoto-u.ac.jp

Understanding of physical, chemical and biological characteristies of the coastal areas is essential for the quantative analysis of driving factors for the change in the ecosystem as a whole. Trends of historical water quality parameters and their relationship help in better understanding of how the parameters are changing with climate and terrestrial forcings. In this study, the trends of dissolved inorganic nitrogen (ammonium, nitrate/nitrite, sum of former two) in the Osaka bay is modelled with a weighted regression approach. The Weighted Regressions on Time, Discharge, and Season (WRTDS) is adapted for the bay area to improve the long term changes in dissolved inorganic nitrogen. Modelled trends showed that the nutrient concentration is declining except in the 90th percentile. The predicted trends of the dissolved inorganic nitrogen is higher in the current years than the observed values. The trend of all forms of nitrogen in three groups of the Osaka bay, near to the coastline, in mid and the seaward side is analysed.

Key Words : *Coastal Areas, Nitrogen, Osaka Bay, trend, weighted regression*

1. INTRODUCTION

Increasing population and rapid urbanization have a serious impact on the water availability and water quality in coastal areas. Terrestrial loadings due to anthropogenic activities have increased the pollutant loads affecting the sustainability of ecosystem. Many estuaries and bay areas have been greatly influenced by the adjacent urban developments and waste water treatment factities. Undestanding the drivers of water quality change is very important to minimize the negative impact from various sources of pollution.

In Osaka Bay, land reclamation for factories, harbor facitlities and waste disposal sites have been increasing[1)]. As a result, the sand beaches are reduced and a number of small enclosed coastal areas with narrow channels increased. The waste disposal sites also resulted in the appearance of “red tides” (algal blooms)[1)].

The relationship between nutrient enrinchment and change in water quality is difficult to derive, however, the rates of primary production is often governed by nutrient concentrations[2)]. The variation of nutrient concentratrion in Osaka Bay is largely dependent on the environmental conditions. The high concentration of nutrients originates from various waste treatment plants upstream of the bay[3)].

The Weighted Regressions on Time, Discharge, and Season (WRTDS) approach have been used to illustrate decadal trends in river systems[4,5,6,7)]. This method was adapted for the trend analysis in tidal water[8)]. Although the use of the WRTDS method has been effectively carried out in the river systems, its application in the tidal water is less. This method has been applied to analyze the long term change of chlrophyll-a (chl-a) in the Tampa Bay and Patuxent River Estuary[8,9)] and the decadal change in different forms of nitrogen such as ammonia nitrogen NH_4^+, nitrite (NO_2^-) / nitrate nitrogen NO_3^{2-} and dissolved organic nitrogen (DIN) which is the sum of the former two[10].

The aim of this study is to analyze the trends of NH_4^+, nitrite (NO_2^-) / NO_3^{2-} and DIN in the Osaka Bay using the weighted regression approach.

2. STUDY AREA

Osaka Bay is a semi-enclosed coastal area located at the eastern end of the Seto Inland Sea. Awaji Island partially closes the bay entrance (**Fig. 1**). The bay is elliptical with a long axis of ~60 km and a short axis of ~30 km. It has a surface area of 1500 km^2 and an average depth of 20 m[11].

The Osaka bay is adjacent to the most populated cities in Japan; Osaka, Kobe and Sakai with population of 2,670,000, 1,540,000 and 840,000 respectively[12]. Increasing population, urbanization and industrialization has affected the environment and water quality of the bay area. As per the report from Ministry of Environment, the anthropogenic loadings from the land to the sea was observed resulting in the higher level of nutrients in the surface of the inner bay. On the other hand, in the offshore area, the nutrient level showed the vertical trend with peak in the mid, and low level in the surface[13]. Total Nitrogen and Phophorus are the main factors for the eutrophication in the bay.

3. METHODS

(1) Data

Nutrient and salinity time series of monthly observation from year 1994-2015 were obtained for twelve stations in the Osaka Bay, producing 264 observations per stations from the Osaka Prefectural Government (Fig. 1). Stations were categorised in three different groups II, III, IV based on the Total Nitrogen and Total Phosphorus reference. Therefore, Group IV includes stations C2, C3, C4(near to the coastline); Group III includes B2, B3, B4, A2 (in mid) and Group II includes A3, A6, A7, A10, A11 (to seaward). The three nitrogen forms that were evaluated were ammonium (NH_4^+), nitrite/nitrate (NO_2^- / NO_3^{2-}), and DIN (as the sum of the former two).

(2) Weighted Regression Analysis

A regression equation[4] is used to express the relationship of the log transformed response variable as the function of time, flow, and season given by the equation 1:

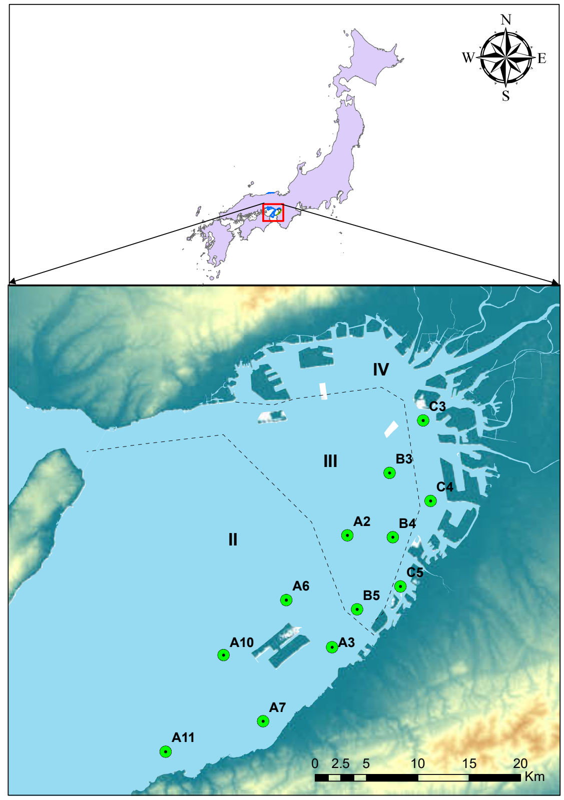

Fig 1. The Osaka Bay with monitoring stations categorized in three groups IV, III, II

$$ln(N) = \beta_0 + \beta_1 t + \beta_2 Sal + \beta_3 \sin(2\pi t) + \beta_4 \cos(2\pi t) + \in \quad (1)$$

where N is one of three nitrogen forms, time t is a continuous variable as decimal time to capture the annual (β1) or seasonal (β3, β4) trend, and Sal is the salinity variable (either flow or salinity depending on station).

The WRTDS model is a moving window regression that fits unique parameters (i.e., β0, …, β4) at each observation point in the time. Hence, one regression is fit to every observation. Observations within a window for each regression are weighted relative to annual, seasonal, and flow distances from the observation at the center of the window.

Predicted values are based on the interpolation matrix from the unique regressions at each time step. A sequence of salinity/flow depending on minimum or maximum values for the data is used to predict the nitrogen form using observed month and year based on the parameter fits to the observation. Salinity/flow normalized values are also estimated from the prediction grid that interprets nitrogen form trends that is independent of the variation related to fresh water inputs.

The WRTDS models require flow/salinity data paired with the nutrient data. Salinity is considered as a tracer of freshwater influence to apply WRTDS models in tidal waters[8]. The nutrient data should match the time of salinity data for the analysis. The analysis for this study was done using the WRTDStidal package for the R statistical programming language[14, 15].

4. RESULTS AND DISCUSSION

(1) Observed trends of nutrients

The boxplot of observed three nitrogen forms NH_4^+, NO_3^{2-} and DIN averaged from different stations for each type category of bay is shown in **Fig. 2**. The variations in nutrients were analysed to assess the degree of eutrophication. The concentration of nutrients is higher near to the shoreline i.e. Group IV whereas lower in II. Range of variation of nitrate nitrogen is higher in all three categories compared to ammonium nitrogen. The ammonium nitrogen concentration suddenly increase in the year 2008. From 1994-2015, the mean value of DIN is fluctuating along the period with highest value being in the year 2008 which can be attributed to increase in ammonium nitrogen in that year. The contribution of NO_3^{2-} concentration is seen more prominent in the values of DIN concentration than the NH_4^+contentration. Since the concentration of NO_2^- was not much significant than other forms, its variation is not shown here.

(2) Modeled trends of nutrients

The predicted trends of the dissolved inorganic nitrogen is higher in the current years than the observed values for Group IV i.e. near the coastline (**Fig. 3**). The predcited trends of DIN showed the drastic decline of DIN (mg/l) after the year 2010. It may be attributed to the efficiency of the waste treatment palnts in the upstream.

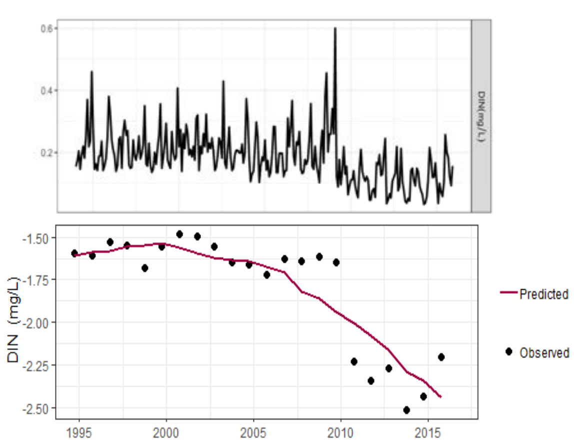

Fig 3. Observed, predicted and normalized trends of DIN (mg/l) at Group IV

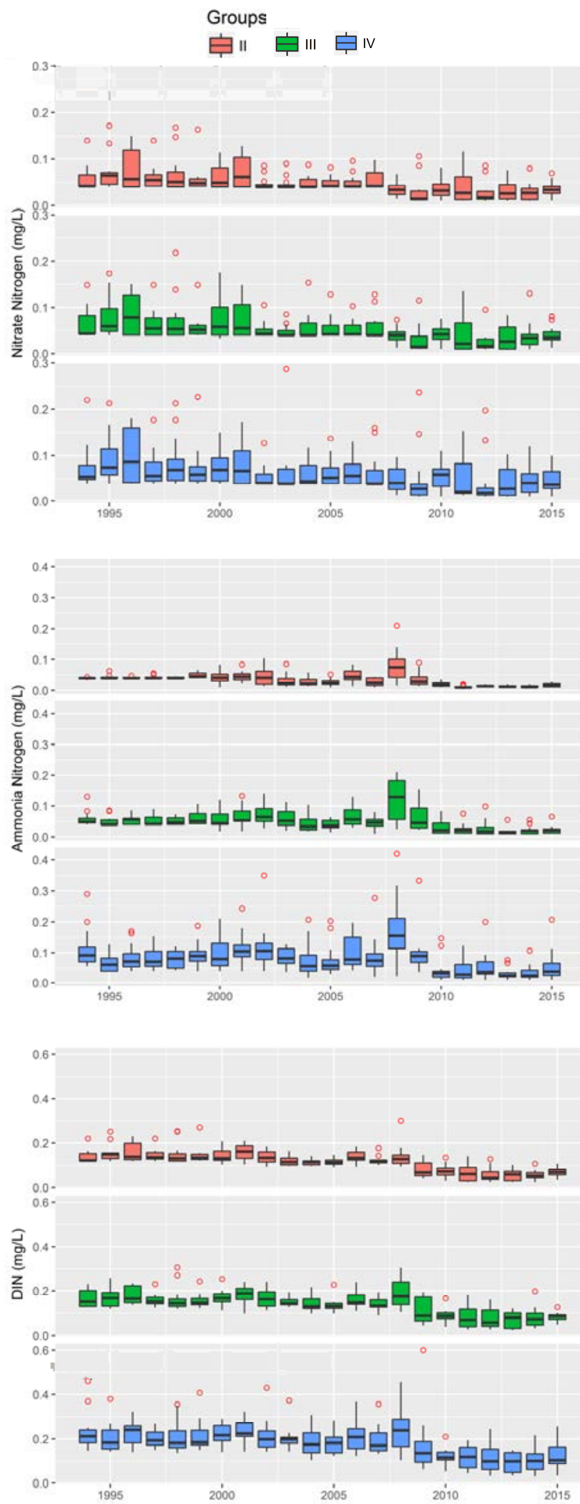

Fig 2. Boxplot of observed NH_4^+, NO_3^{2-} and DIN for Osaka Bay at Group IV

The weighted regression and salinity normalized results are calculated for the annual trends for three different qualntile i.e. 10th, 50th and 90th quantile (τ) distributions. The aggregated of model results by the year of predicted concentrations of nitrogens and salinity normalized concentration of three model types for 10th, 50th and 90th percentile is shown in **Fig. 4**. The predicted concentration shows the response of nitrogen forms as per the model types, whereas the estimates of salinity-normalized illustrates the annual trends by the model segment. The salinity normalized values are independent of variation due to fresh water influence. Trends of predicted NH_4^+ for 90th percentile is increased till the year 2005 and then drastically decreased, whereas, the 10th and 50th percentile values showed similar trends. For DIN, the trends were similar for all the three percentile predictions. For NO_2^-/ NO_3^{2-}, the higher prediction values is observed in the early years in the 90th percentile and then followed the same trend as 10th and 50th percentile.

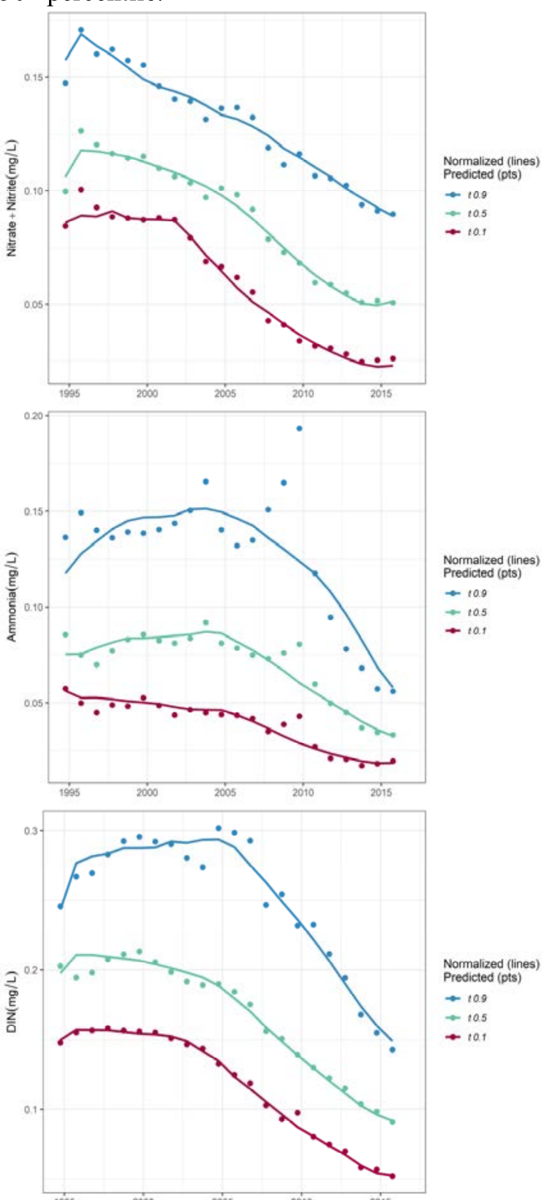

Fig 4. Weighted regression predictios and salinity normalized results for the 10th, 50th and 90th quantile distibutions

5. CONCLUSIONS

WRTDS model enables the analysis of change water quality parameters due to different external forcings such as terrestrial loadings due to waste treatment facilities, land use and reclamation and others. This method allows to evaluate variation in the nutrient concentration due to effect of time, flow/salinity, and season.

ACKNOWLEDGMENT: The first author acknowledges Monbukagakusho scholarship for the financial support of the research. We would like to thank Ministry of Land, Infrastructure, Transport and Tourism, Japan Oceanographic Data Center (JODC) and local governments for providing the necessary data.

REFERENCES

1) Irie, M., Nakatsuji, K., Nishida, S., Yuasa, K. : Seasonal variations in temperature, salinity and dissolved oxygen in the enclosed area at the head of Osaka Bay, Japan, *Asian and Pacific Coast*, 2003.
2) Cloern, J.E. : Our evolving conceptual model of the coastal eutrophication problem, *Mar. Ecol. Prog. Ser*., Vol. 210, pp. 223–253, 2001.
3) Irie, M., Yamaguchi, T., Nishida, S., & Nakatani, Y. : Modeling of Water Quality in Tidal River Network in Osaka, Japan, *J. of Water and Env. Tech.*, Vol. 13, No. 2, 2015.
4) Hirsch, R. M., Moyer, D. L., and Archfield, S. A. : Weighted regressions on time, discharge, and season (WRTDS), with an application to chesapeake bay river inputs, *J. Am. Water Resour. Assoc.*, Vol. 46, No. 5, pp. 857–880, 2010.
5) Medalie, L., Hirsch, R.M., Archfield, S.A. : Use of flow-normalization to evaluate nutrient concentration and flux changes in Lake Champlain tributaries, 1990-2009, *J. Great Lake. Res*,. Vol. 38 (SI), pp. 58–67, 2012.
6) Hirsch, R.M., De Cicco, L. : User Guide to Exploration and Graphics for RivEr Trends (EGRET) and DataRetrieval: R Packages for Hydrologic Data. Technical Report Techniques and Methods book 4, ch. A10. US Geological Survey, Reston, Virginia, 2014.
7) Zhang, Q., Harman, C.J., Ball, W.P. : An improved method for interpretation of riverine concentration-discharge relationships indicates long-term shifts in reservoir sediment trapping, *Geophys, Res. Lett*., Vol. 43, No. 10, pp. 215–224, 2016.
8) Beck, M. W., and Hagy III, J. D. : Adaptation of a Weighted Regression Approach to Evaluate Water Quality Trends in an Estuary, *Environ. Model. Assess.*, Vol. 20, No. 6, pp. 637–655, 2015.
9) Beck, M. W. and Murphy, R. R. : Numerical and qualitative contrasts of two statistical models for water quality change in tidal waters, *J. Am. Water Resour. Assoc.*, Vol. 53, No. 1, 2017.
10) Beck, M. W., Jabusch, T. W., Trowbridge, P. R., and Senn, D. B. : Four decades of water quality change in the upper San Francisco Estuary, *Estuar. Coast. Shelf Sci.*, Vol. *212*, pp. 11-22, 2018.

11) Tsujimoto, A., Yasuhara, M., Nomura, R., Yamazaki, H., Sampei, Y., Hirose, K., andYoshikawa, S. : Development of modern benthic ecosystems in eutrophic coastal oceans: The foraminiferal record over the last 200 years, Osaka Bay, Japan, *Mar. Micropaleontol.*, Vol., 69, pp. 225–239, 2008.
12) Miki, S., Uno, S., Ito, K., Koyama, J., and Tanaka, H. : Distributions of polycyclic aromatic hydrocarbons and alkylated polycyclic aromatic hydrocarbons in Osaka Bay, Japan, *Mar. Pollut. Bull.,* Vol. 85, pp. 558–565, 2014.
13) Ministry of the Environment: Present Status of Marine Pollution in the Sea around Japan, (October), 2009.
14) Beck, M.W. : WRTDStidal: Weighted Regression for Water Quality Evaluation in Tidal Waters. R package version 1.1.0., 2017.
15) RDCT (R Development Core Team) : R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.Rproject.org, v3.3.2, 2017.