Modelling of Eutrophication Process in Masan Bay, Korea

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1. Introduction

During recent two decades, red tide and oxygen deficiency, which are major undesirable phenomena related to the eutrophication, have been continuously observed in Masan Bay and the quantity is growing more and more as it goes. Masan Bay is a large bottleneck-shaped bay with a narrow opening to the sea through the Modo and Gadeogdo channels and generally polluted by untreated municipal sewage and discharges from a heavy-industry complex. Therefore, it has brought out a lot of environmental problems as one of the most polluted water bodies in Korea.

The basin boundary of bay system is shown in Figure 1 and the system is divided into a inner bay part north of Somodo and a outer bay part south of Somodo. The bay has been known to have the maximum tidal range of about 2.5m. Because the bay bends extremely and is semi-enclosed, any significant intrusion of waves and oceanic currents has not been observed. The average depth of Masan Bay basin is about 15m. The inner bay is shallower than the outer. The bay can be considered as a large enough estuary with a constantly changing environmental situation where rapid biological processes take place. The bay catchment covers an area of approximately 232km^2, most of which has been impacted by human activities in some form. 12 small streams (Nam, Changwon, Naedong, Palyong, Yangdug, Sanho, Samho, Hoiwon, Goobang, Chugsan, Jangun, and Changwon) flow into the bay with nutrients and one place of Waste Water Treatment Plant (WWTP) in Dugdong disposes of its waste in the middle of bay.

The watershed is divided into three administrative districts constructed by the cities of Masan, Changwon, and Jinhae. Population of Masan City shows a tendency to decrease gradually and in contrast population of Changwon and Jinhae to increase gradually. Therefore, population of the watershed remains nearly constant in total.

Climate is sub-tropical with a mean annual rainfall of 1150mm, most of which occurs in the summer months (March to September). Air temperatures range from -7.9 to 34.9℃ over the season. Wind records show the mean wind speed of 2.1-2.3m/s and a strong seasonal pattern in direction. Over the summer months April to August winds are mostly from SW and NE, the pattern then changing to NW during winter, and the daily average of sunshine is 6.9 hours.

For the effective management of Masan Bay, the following studies were carried out:

1. Analysis of monitored water quality data;

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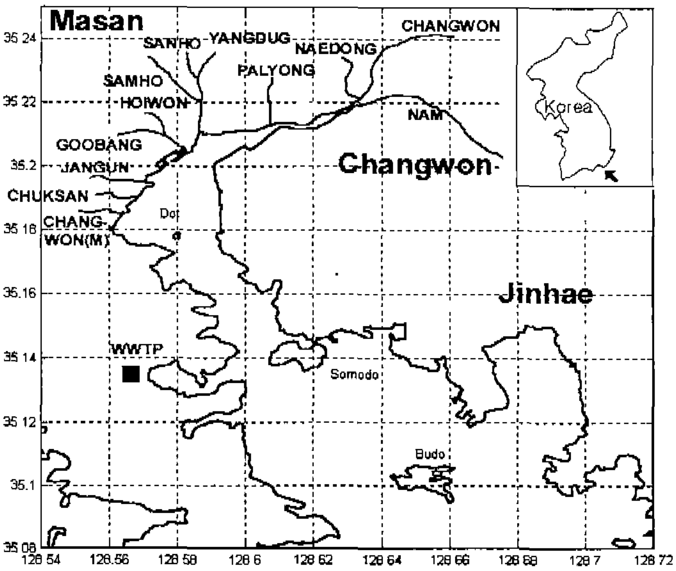

Figure 1: Location of Masan Bay and basin boundary of bay system.

2. Mathematical eutrophication modeling;
3. Application of WASP5 model;
4. Development and calibration of FDM model.

2. Mathematical modelling

The mathematical modeling through zero-dimensional analysis was carried out to understand the eutrophication status in Masan Bay. Although there have been many developments that make it possible to simulate the fate and transport of pollutants in great detail and with more realistic processes, mathematical models are necessary to determine allowable loadings for each plant as a part of their permit or to analyze the primary pollutant effluents causing the environmental problem.

The simple eutrophication kinetics simulates the growth and death of phytoplankton, with its effects on the nutrient cycles and DO balance. Growth can be limited by the availability of inorganic nitrogen, inorganic phosphorus, and light. Light limitation is described by the Di Toro formulation and complete mixing is assumed in the assigned control volume.

The nutrient loads of Masan Bay are divided into one wastewater treatment plant and twelve streams. The wastewater treatment plant (WWTP) discharging into the Masan Bay catchment is administered and licensed by Masan City. Because the WWTP situated in Dugdong is primary level in wastewater treatment, most of nutrients are been discharging into the bay. Particularly, a nitrogen flows to the bay always in large quantities. The nutrients from twelve streams are influent with various distributions in the bay because inflow from streams is in proportion to rainfall. The total loading rate of each nutrient discharging from streams and WWTP is shown in Table 1. The data were reffered by Masan City [2]. Total volume, mean depth, cross-section area, and mixing length of Masan Bay used to zero dimensional analysis are 936,580,000m^3, 13.5m, 88,860m^2, 8000m, respectively. Table 2 presents kinetic coefficients determined through mathematical model study. Temporal variation of phytoplankton is compared in Figure 2, showing the peak in late summer.

Table 1. The loading value of nutrients (unit: kg/day).

	Mar.	Jun.	Jul.	Aug.	Sep.	Oct.
NH	10972.71	14545.58	12250.69	11286.99	15701.11	12370.03
NO	3472.75	4044.72	4540.27	102.30	2885.66	5687.81
OPO	445.86	619.99	751.86	375.33	721.66	680.72
CBOD	24571.05	44034.84	45953.45	89359.97	50745.86	56116.70
DO	2055.51	2401.40	3560.28	4774.99	3096.72	3002.26
ON	9918.08	14447.82	13000.	12289.84	6227.58	5611.29
OP	225.80	1107.03	1108.54	1168.21	567.44	699.16
Q	528462	687350	1136448	1088000	731668	641361

Table 2. Kinetic coefficients used in simple eutrophication(day^{-1} at 20°C).

Constant	Code	Value
Nonpredatory phytoplankton death rare	XK1D	0.02
Deoxygenation rate constant	XKD	0.01
Reaeration rate constant	THD	1.01
Mineralization rate constant	XK71	0.01
Nitrification rate constant	XK12	0.04
Average phytoplankton growth rate constant	XK1C	2.00
Average phytoplankton respiration rate constant	XK1R	0.125
Denitrification rate	XK20	0.05
temperature coefficient	TH20	1.08
Mineralization rate of dissolved org. N	XK71	0.01
temperature coefficient	TH71	1.045
Mineralization rate of dissolved org. P	XK83	0.03
temperature coefficient	TH83	1.08

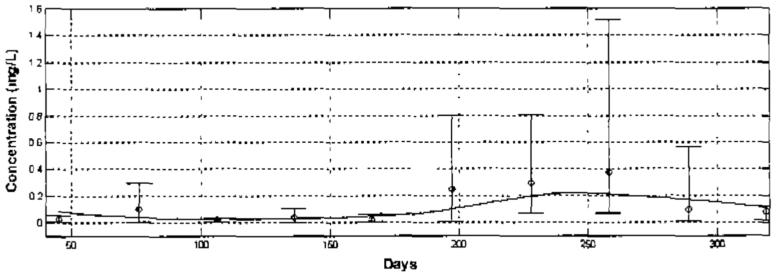

Figure 2: Temporal variation of phytoplankton by zero-dimensional analysis.

3. Application to WASP5 model

WASP5 model was run on the segment system dividing the Bay into nine segments. Three segments of them cover over Dot island, three segments between Dot island and Somodo, and the rest between Somodo and Budo. Segment No. 10 is taken account into the total bottom layer for deposit materials. Figure 3 shows the 9-segment configuration for the study area from Nam, Changwon, and Naedong streams to Budo. Loading by streams and WWTP discharge in segment 1, 2, and 8.

In segment 1, inflows are Nam, Changwon, Naedong, Palyong, Yangdug, Samho, and Sanho stream and Hoiwon, Goobang, and Jangun stream flow in segment 2. Discharge by WWTP flow in segment 8. As shown in Figure 4, the WASP5 model predictions are in general agreement with phytoplankton field data. The model was also used to investigate phytoplankton-nutrient dynamics. The calculated influence of load reduction on the phytoplankton concentration is presented in Figure 5. The tendency is toward a reduction of biomass with reduction in the nutrient loading. In the inner bay, the 10% reduction shows about a half reduction of phytoplankton.

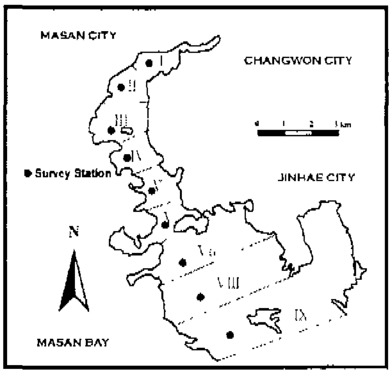

Figure 3: Segment system of Masan Bay.

Algal blooms in Masan Bay are caused by the considerable external load of nutrients. Therefore, the only way to decrease eutrophication is to reduce the nutrient load. Because the removal of nutrients is expensive, it is important to know where, when and by how much we have to put in efforts to get satisfactory results.

4. Water quality prediction by FDM

Although current and wave stresses are the major physical factors in water quality studies, their effects have been given little consideration. Furthermore, most of previous models were restricted to long term predictions with time steps of a day or longer. In the present study because the temporal and spatial plankton distribution inside so big an area is very variable, a depth-integrated two-dimensional FDM model is developed to simulate short-term and fine-resolved spatial variations of eutrophication process and follows three phases; hydrodynamics, transport and algal dynamics. All submodels operate on the same grid.

The hydrodynamic component simulated the main tidally-driven advective flows throughout the bay. The shallow water equation was solved by a fractional step method in conjunction with the characteristic method for an advection step and the approximate factorization technique for diffusion and propagation steps leading to the stable and fast computation. The transport component of the model uses a subset of the hydrodynamic model configuration. It simulates the movement of dissoved materials in response to the tidally-driven advective and dispersive processes coupled with freshwater from 12 streams flowing into Masan Bay. The pollutant transport was determined by a new hybrid method [1] which is superior in both result accuracy and time-saving ability.

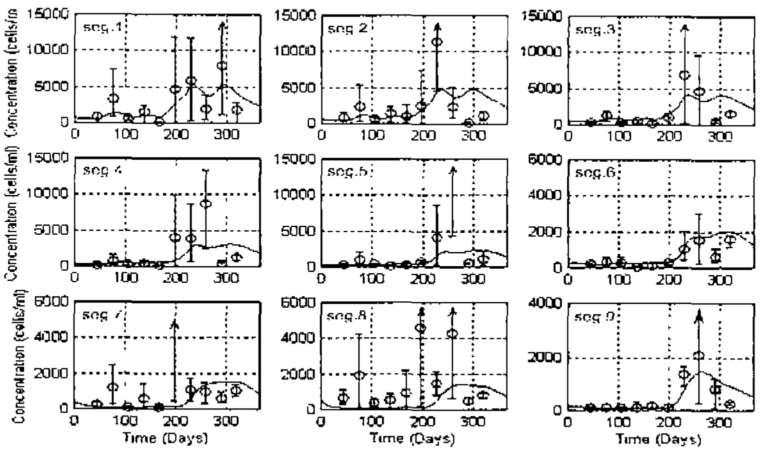

Figure 4: Comparison between model results and field data for phytoplankton.

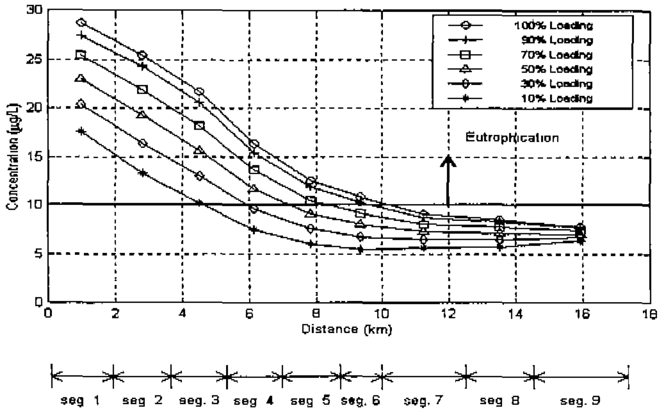

Figure 5: Influence of load reduction on chlorophyll-a.

It is based on the forward-tracking particle method for advection. However, unlike the random-walk Lagrangian approach, it solves the diffusion process on the fixed Eulerian grids, which requires neither an interpolating algorithm nor large number of particles.

In eutrophication model, two forms of phosphorus (inorganic and organic), three forms of nitrogen (oxides of nitrogen, ammonium nitrogen and organic nitrogen), dissolved oxygen kinetics and CBOD as well as phytoplankton were simulated. The same kinetic coefficients as determined by zero-dimensional analysis (Table 2) were used. Dynamic transfer of dissolved and particulate material between water column and benthic compartments was incorporated in a semi-empirical manner.

The FDM model covers the study area as shown in Figure 6. The study area is discretized by 149×125 rectangular grid mesh of 500×500m resolution and the time interval is given 30minutes. The simulations were carried out for 1995 where the monitored data are available. Results of phytoplankton by FDM model are shown in Figure 7. Because most of loadings are discharged into the inner bay and matters are transported to the outer bay, the regional distributions of concentration show a tendency that it is high at inner bay and low at outer bay. Comparison between observed data, WASP and FDM model results for the concentration of phytoplankton is shown in Figure 8. The FDM model provides somewhat higher values than those by WASP5 model.

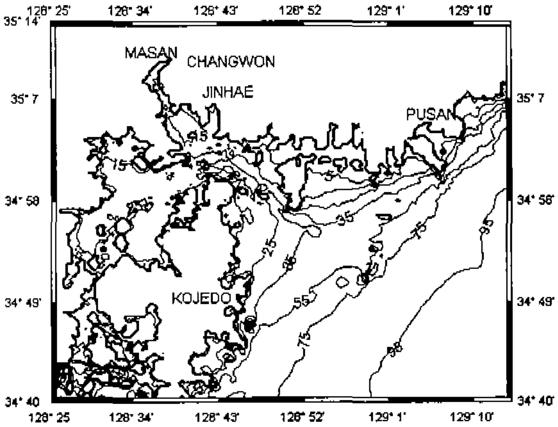

Figure 6: Bottom topography around Jinhae Bay.

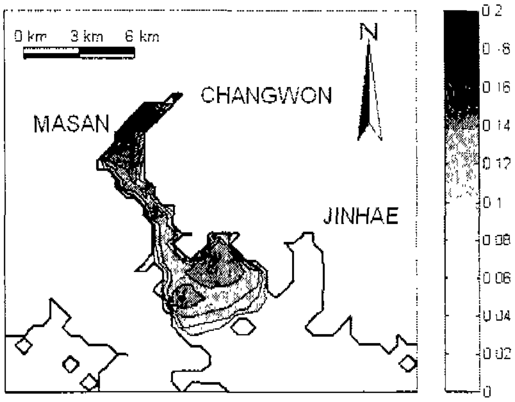

Figure 7: Spatial distribution of phytoplankton concentration by FDM model in July 1995 (unit in).

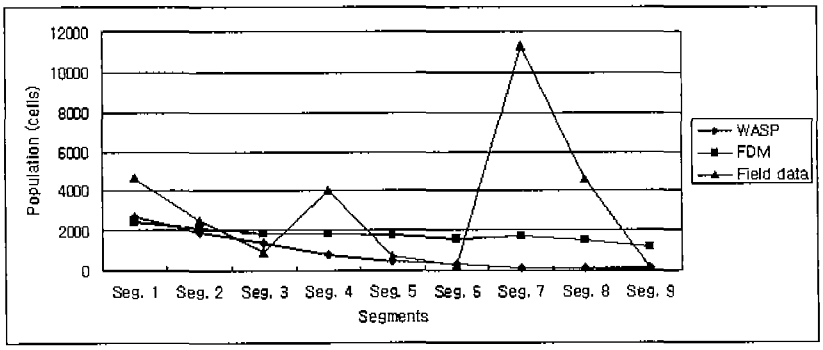

Figure 8: Comparison between observed values, WASP5 and FDM model results for concentration of phytoplankton.

5. Conclusions

The zero-dimensional analysis was carried out through a simple eutrophication process to understand the eutrophication status in Masan Bay. The model predictions were in general agreement with field data in simulating the long-term growth and decay of phytoplankton. The WASP5 model was also employed to ascertain the more detailed eutrophication status in space and to investigate phytoplankton-nutrient dynamics.

Because the temporal and spatial plankton distribution in estuary is very variable, a depth-integrated two-dimensional FDM model is developed to simulate short-term and fine-resolved spatial plankton distribution. The model follows three phases; hydrodynamics, transport and algal dynamics. All submodels operate on the same grid.

In water quality model, two forms of phosphorus (inorganic and organic), three forms of nitrogen (oxides of nitrogen, ammonium nitrogen and organic nitrogen), dissolved oxygen kinetics and CBOD as well as phytoplankton were simulated. Phytoplankton growth is subject to nutrients and light limitation. The pollution sources were given unsteady and their mass loadings were estimated based upon monitoring records. The same kinetic coefficients as determined by mathematical model were used in FDM model. The comparison of FDM results with monitoring data shows that the method could represent the algal growth dynamics and water quality processes reasonably.

In the future the model should be supported by higher resolution data to investigate the meso-scale prediction. In addition, coastal circulation of the bay under the combined action of wind and tide should also be investigated because the influence of wind is of great importance on the ecological model.

Acknowledgement

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References

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