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RESEARCH ON A WATER POLLUTION MECHANISM IN SAGULING RESERVOIR AND ITS MODELING

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Abstract
We have studied about a structure of pollutant load and a mechanism of water pollution in Saguling Reservoir and its catchment area which is located in the western part of Java island, Indonesia. Moreover, a numerical simulation model was constructed in order to suggest some improvement measures for water bodies based on the research. We have obtained the following results:
1) The inflow load was estimated by using a ratio method, and it became clear that the main inflow load was occupied by the industrial load. The estimation indicated it was from 66% to 81% of all inflow loads.
2) We obtain annual water quality data and certain parameters needed for the construction of modeling.
3) The pollution mechanism and estimated the inflow load in Saguling Reservoir become evident according to the result of the field survey.
4) A two-dimensional multi-layer model was constructed. Then, the vertical distribution of DO concentration was calculated. Moreover, the amounts of pollutant load that should be decreased for the improvement of water body was examined by the simulation model.

Keywords: water pollution mechanism, inflow load, numerical simulation model, improvement of water quality

1. Introduction

Saguling Reservoir is located in the western part of Java Island (Fig.1). The reservoir is used for the generation of electricity and for agriculture water resources. In recent years, water pollution has caused serious environmental problems in this water bodies such as corrosion of turbine at power plants and fishery damage[1),2)]. In the basin of this reservoir, several textile factories have been operating near the suburbs of Bandung City. The discharged wastewater flows into the Citarum River, therefore, the water quality of the river is always under an anaerobic condition and the color is black. The river has already been devastated. This situation is not only an environmental problem but also there is a concern about damage to the health of humans. The water is still used for agricultural irrigation[3)], and many people continue to use it for various purposes. This environmental disruption must be improved without delay.

Concerning this, it is regretful that, in spite of a large number of studies related to the investigation of the Saguling Reservoir, so far only a few studies have argued for a numerical simulation model for improvement of this water body. In addition to this, the analysis of the pollutant load is insufficient, as well. Accordingly, we have examined the structure of the pollutant load and constructed a numerical simulation model. Therefore, we have suggested various improvement measures for the Saguling catchment area.

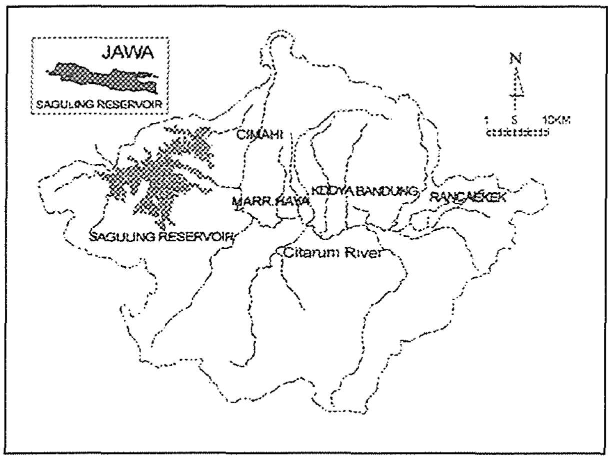


Fig. 1 Location of the Saguling Reservoir

2. Outline of the Saguling Catchment Area

1) Precipitation

The climate of the Saguling catchment area consists of a typical tropical type that is divided into two seasons, rainy and dry. Annual mean precipitation shows a range from 1,800 mm to 2,800 mm. The rainy season from November to April shows 70% annual precipitation. On the contrary, precipitation is less than 100 mm in the dry season. The seasonal change of inflow rate of Citarum River is shown in Fig. 2.

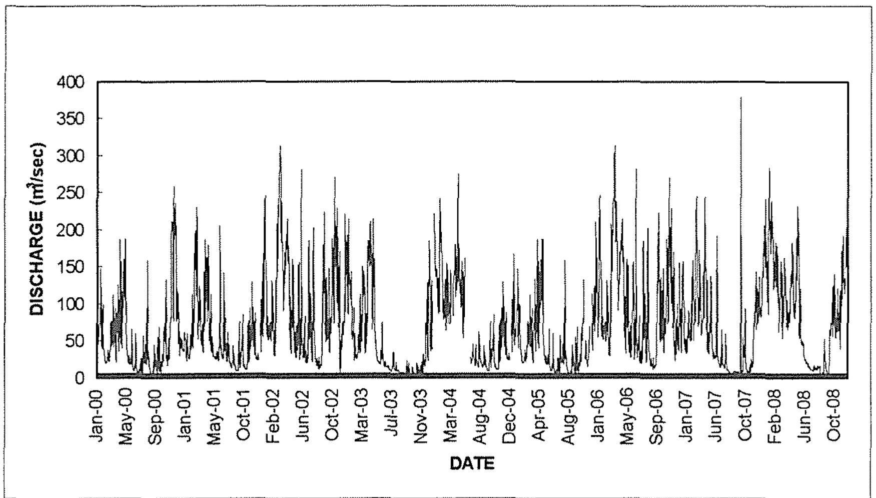


Fig.2 Seasonal change of inflow rate of the Citarum River

2) Population

The catchment area has been divided into eight sub-catchment areas in order to analyze the pollutant load, as shown in Fig. 5. The population of this catchment area was approximately 4.7 million in 1995 (Table 1). As for the population density, the sub-catchment area of R4 where Bandung City is located is the highest in this catchment area. The upper stream of Bandung City also shows a high density of population because there are many factories in the R2 sub-catchment area.

Table 1 Population and land use in the Saguling Catchment Area

Sub-Catchment Area	Area (ha)	Population	LAND USE AREA (ha)				
			Water	Forest	Paddy	Dry	City
R0	9,980	62,100	0	5,530	1,090	3,340	20
R1	4,850	56,700	20	1,670	1,900	1,115	145
R2	13,170	362,000	25	2,680	6,160	3,805	495
R3	56,940	50,400	80	7,940	27,830	19,020	2,070
R4	53,080	2,372,500	530	13,675	15,040	16,125	7,710
R5	8,930	385,300	40	190	5,730	1,930	1,040
R6	5,400	723,200	30	1,680	2,090	1,420	180
SGL	45,850	719,100	-	45,850	-	-	-
Total	198,200	4,731,300	725	79,215	59,840	46,755	11,660

3) Land Use
In this research, land use is classified into five categories, water, paddies and dry fields, forest and developed area. This catchment area mainly consists of forest area (Table 1), especially throughout the SGL sub-catchment. The center of Saguling catchment area is occupied by paddy fields and dry fields. Also, an urban area is located here.

4) Industry
The factories which operate in the Saguling catchment area is shown in Fig. 3. This Figure indicates that most industries here are textile factories, which consist of more than 90% of all the factories. Other industries are few compared to the textile industry, and their influence can be neglected. These textile industries are located in sub-catchment area R2, R3 and R4. Factories are especially intensively located in the sub-catchment area R4.

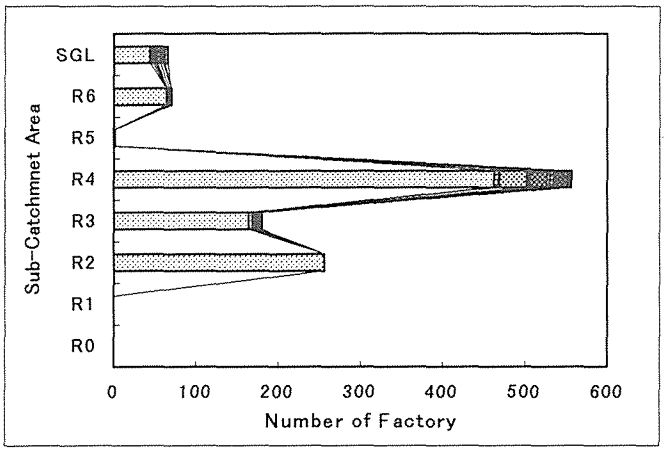


Fig. 3 Comparison of factory in sub-catchment area

5) Water Supply
In this area, most of the water supply is obtained from personal wells. A drinking water company, PDAM, only distributes water around the capital of sub-district of the Bandung regency. According to a field survey, the water supply for the people in the border villages of Citarum River is obtained from personal wells.

6) Present situation of pollution
The main pollutant source is derived from industrial wastewater according to the estimation

of the inflow load as shown in the following chapter. Moreover, most of all the factories have not treated the wastewater. Therefore, Citarum River and Saguling Reservoir have already become devastated. These days, the water quality in Citarum River and Saguling Reservoir is under an aerobic condition. Moreover, a substantial amount of garbage has accumulated along the river and the inlet area. In the dry season especially, water quality is remarkably deteriorated, and therefore, methane fermentation occurs. Because of this, the amenity condition is inferior; and there is considerable worry about health damage because of this disruption of the environment.

7) Fish culture

The Saguling Reservoir consists of a vast development of floating net fish culture. There were 4,425 units of floating nets owned by 1,236 fishery households, and these produced 454,000 kg of fish[4]. However, recently, tons of fish have died every year during rainy season. The latest report describes that 110 ton of fish died on October 1994[5]. This economic loss has become enormous.

3. Pollutant Inflow Load

1) Outline of Estimation

It is very important to grasp the inflow load that is based on an analysis of pollutant mechanism and construction of a numerical simulation model. Then, in order to make a strategy for improvement of this water body, to estimate the carrying capacity is indispensable, as well.

Generally, industrial wastewater and miscellaneous water have not been treated entirely in the Saguling catchment area. Therefore, attenuation of this inflow load was not calculated because purification in the process of the reduction was not expected. Moreover, the load from the night soil was not estimated because it usually has been used for a septic tank in this district. Accordingly, we have estimated the inflow load of COD, total nitrogen and total phosphorus from industrial wastewater, miscellaneous water, forested area, paddy fields, dry fields and a city area by using a ratio method.

2) Results

The total amount of inflow load of COD, TN and TP is estimated to be 240.7 t/day, 58.0 t/day, 11.8 t/day, respectively. In this case, the pollutant ratio of COD, TN, TP is shown below.

COD: TN: TP = 20: 5: 1

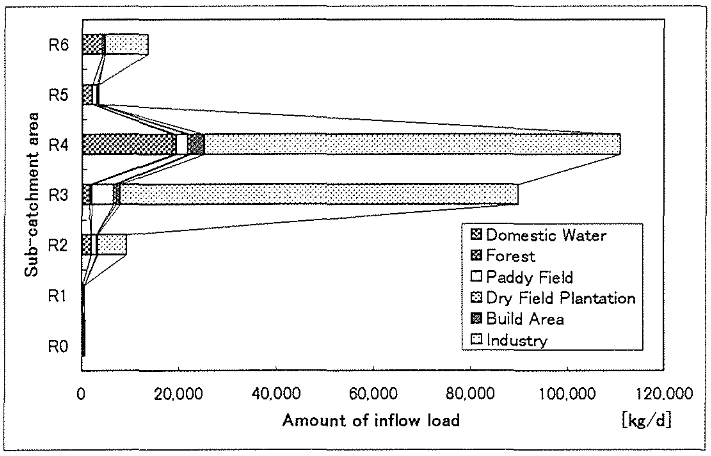


Fig.4 Inflow load of COD in the Saguling catchment area

The details of the COD inflow load are shown in Fig. 4. They shows that the inflow load is occupied by the industrial load which indicates that it is from 66% to 81 % of all inflow loads. Then, there are few environmental effects related to the rate of domestic wastewater that is from 11% to 16 % of the total inflow load. Moreover, our results show that most of all the inflow loads are derived from R3 and R4 sub-catchment areas where many factories exist in Bandung city. The total amount of the inflow load from R3 and R4 reaches 83% of the Saguling catchment area.

4. Present Situation of Water Quality

1) Methods of field survey

The field survey that is related to the water quality and the parameters for numerical simulation model was carried out four times at Saguling Reservoir and Citarum River during fiscal 1996, in July, September, November and January. In this survey, ORP, pH, DO, conductivity and turbidity were observed at the site by using a water quality checker. The sampling of river water was from the surface and, in Saguling Reservoir, the water sample was taken from 0, 20%, 40%, 60% and 80% of the water layers, respectively, at each station (Fig. 5).

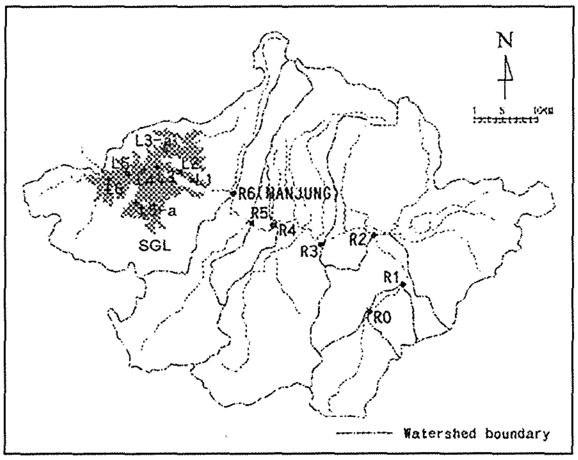
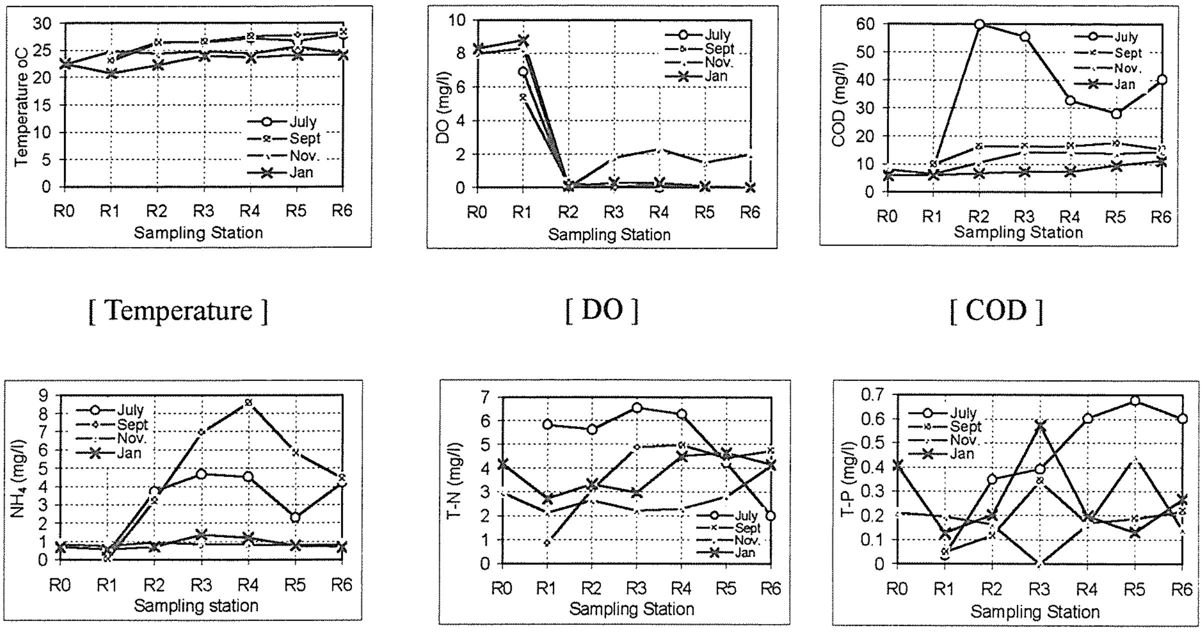


Fig.5 Sampling station of the field survey

2) Characteristics of Citarum River

Characteristics of water quality in the Citarum River are described as follows (Fig. 6):

- The water color was black in the dry season. On the contrary, it became dark brown in the rainy season because of an increased flow rate.
- It is clear that water temperature increases from upstream to down stream throughout the year. Therefore, the temperature showed that the water temperature in the dry season (23.1°C - 18.3°C) was higher by 3 degrees than in the rainy season (22.4°C - 25.7°C).
- One of the characteristics of Citarum River is that it has very low level concentration of DO. It declined more rapidly down stream from station R2. According to the observation, DO shows 0 mg/l in the dry season and 0 - 2 mg/l in the rainy season.
- COD showed equal to or more than 10 mg/l in the dry season and less than 10 mg/l in the rainy season, moreover, it increases from upstream to the down stream.
- As for the concentration of TN and TP, it is shown that the dry season was higher than the rainy season. NH_4 showed a very high concentration level especially in the dry season.



[Temperature] [DO] [COD]

[NH_4OH] [TN] [TP]

Fig. 6 The result of water quality in the Citarum River

3) Characteristics of Saguling Reservoir

The characteristics of the water quality in the Saguling Reservoir are described as follows (Table 2):

- Oxygen exists with photosynthesis at the euphotic zone, however, the aphotic zone is always in the oxygen less condition (Fig. 7,8).
- In the dry season in particular a very serious situation occurred because the methane fermentation occurred in the bottom at the inlet area, and the surface of the water was covered with methane gas bubbles.
- In the rainy season, the DO concentration rises with the increase of the inflow rate in the inlet area because agitation occurred.
- In the dry season, the photosynthesis in the surface becomes active and DO becomes super saturated. At this time, water-blooming was observed.
- The water temperature changes because of meteorological conditions in the range of 20 - 30℃, however, the substratum shows a constant value through the year at 25 ℃.
- pH is also shown at a high value in the surface, pH 8 - 9, compared with the lower the layer, pH less than 7. This is due to lively photosynthesis. This tendency is almost the same as chlorophyll-a.
- COD shows approximately 10 mg/l and there is no significant change in the vertical distribution.
- TN and TP have changed in the range of approximately 3 - 8 mg/l, 0.2 - 0.7 mg/l, respectively, and no significant change is recognized in the vertical distribution.
- As for the ratio of TP per TN that shows more than 10, the limiting factor seems to be nitrogen according to the Redfield formula.
- The concentration of SS is more than 20 mg/l at the inlet area, however, it shows a value that is less than 10 mg/l in the lower layer. The reason for this phenomenon is that phytoplankton increases in the surface layer, and a great deal of earth and sand flow into the inlet area.

Table 2 The result of the analyzed water quality in the Saguling Reservoir

[No.1]

St.	Depth (m)	Transparency (m)				Temp. (°C)				ORP (mV)				Cond (μS/cm)			
		1996			1997	1996			1997	1996			1997	1996			1997
L1	4～19	0.5	0.2	0.5	0.6	26.4	27.6	25.4	25.3	145	181	151	—	428	560	236	223
L2	16～30	0.6	0.3	0.7	0.8	26.0	27.3	25.3	25.1	203	158	164	—	388	459	216	203
L3	32～47	1.2	0.5	0.7	0.8	25.3	26.3	25.6	24.3	282	197	164	—	296	427	229	201
L3-a	22～37	1.0	0.5	0.8	0.9	25.7	26.2	25.8	24.8	273	155	162	—	323	394	311	273
L4	32～51	1.1	0.7	0.6	1.4	25.3	26.4	25.5	24.6	273	156	167	—	310	321	246	180
L5	16～44	1.3	1.0	0.5	1.2	26.2	26.1	25.6	24.5	318	162	147	—	272	280	262	181
L5-a	28～41	—	0.6	0.6	1.3	—	26.6	25.8	24.4	—	174	154	—	—	220	227	170
L6	31～63	1.1	0.6	0.6	1.4	25.0	25.8	25.3	24.0	331	158	150	—	261	266	243	190

[No.2]

St.	Depth (m)	PH				Turbidity				SS (mg/l)				DO (mg/l)			
		1996			1997	1996			1997	1996			1997	1996			1997
L1	4～19	7.68	7.34	6.95	7.68	12	54	48	27	6	18	21	10	3.5	1.2	6.0	6.2
L2	16～30	7.52	7.66	7.27	7.48	7	27	28	13	5	7	21	7	2.5	4.1	6.4	5.1
L3	32～47	7.31	7.52	7.27	7.25	3	12	21	8	3	4	4	6	2.2	3.2	4.9	3.0
L3-a	22～37	7.55	7.72	7.65	7.56	4	6	107	12	5	1	2	12	3.1	3.0	3.2	2.5
L4	32～51	7.27	7.45	7.32	7.00	3	10	15	6	5	9	4	6	2.0	2.4	3.4	2.7
L5	16～44	7.50	7.36	7.63	7.22	4	23	15	7	2	3	1	6	4.4	2.6	3.9	3.6
L5-a	28～41	—	7.31	7.26	6.92	—	37	22	5	—	3	3	6	—	2.4	3.3	2.0
L6	31～63	7.12	5.72	8.45	7.10	3	32	165	6	3	11	6	6	1.7	0.9	2.9	2.0

[No.3]

St.	Depth (m)	Chlorophyll (μg/m^3)				COD (mg/l)				TN (mg/l)				NH_4 (mg/l)			
		1996			1997	1996			1997	1996			1997	1996			1997
L1	4～19	15.2	12.0	12.1	14.2	12.7	14.4	3.4	7.3	3.40	5.60	3.21	3.94	0.80	6.76	0.89	0.50
L2	16～30	10.1	11.6	11.6	25.2	14.0	11.9	7.6	7.9	5.38	4.43	2.25	3.14	4.28	3.83	0.64	0.25
L3	32～47	4.7	9.8	9.8	14.7	13.8	11.1	6.8	5.6	8.13	3.83	2.96	3.88	6.98	1.77	1.02	0.33
L3-a	22～37	2.4	9.5	9.5	18.2	11.4	9.6	8.9	7.6	6.04	2.25	2.43	3.72	6.94	3.62	0.79	0.47
L4	32～51	3.7	4.4	4.4	13.6	10.3	8.8	7.6	6.4	7.59	2.74	2.76	3.27	5.78	2.41	0.88	0.38
L5	16～44	2.4	3.9	3.9	23.6	12.8	7.9	9.0	5.4	5.98	2.76	2.90	3.14	4.78	1.79	1.12	0.58
L5-a	28～41	—	3.7	3.7	11.4	—	6.7	9.5	5.5	—	2.33	2.67	3.71	—	2.12	1.22	0.23
L6	31～63	5.0	7.5	7.5	15.9	10.9	9.2	11.6	5.3	5.82	2.37	2.47	3.85	4.71	2.41	2.30	0.29

[No.4]

St.	Depth (m)	Nitrate (mg/l)				Nitrite (mg/l)				TP (mg/l)				PO_4 (mg/l)			
		1996			1997	1996			1997	1996			1997	1996			1997
L1	4～19	0.13	0.26	1.07	1.31	0.154	0.031	0.024	0.070	0.214	0.293	0.145	0.130	0.198	0.167	0.044	0.062
L2	16～30	0.10	0.11	1.03	1.09	0.092	0.124	0.048	0.074	0.215	0.187	0.145	1.479	0.149	0.139	0.029	0.021
L3	32～47	0.09	0.26	0.87	1.18	0.006	0.118	0.148	0.027	0.458	0.162	0.123	0.079	0.146	0.184	0.034	0.022
L3-a	22～37	0.07	0.77	1.29	1.14	0.017	0.074	0.024	0.057	0.486	0.089	0.136	0.143	0.065	0.079	0.041	0.042
L4	32～51	0.07	0.23	1.10	2.63	0.017	0.150	0.357	0.027	0.233	0.129	0.176	0.870	0.133	0.100	0.049	0.015
L5	16～44	0.13	0.23	1.49	2.60	0.045	0.153	0.373	0.035	0.196	0.121	0.212	0.075	0.118	0.468	0.102	0.010
L5-a	28～41	—	0.07	1.44	2.65	—	0.005	0.353	0.005	—	0.111	0.163	0.081	—	0.575	0.041	0.024
L6	31～63	0.08	0.11	0.56	2.60	0.137	0.030	0.245	0.128	0.050	0.206	0.178	0.704	0.035	0.480	0.021	0.016

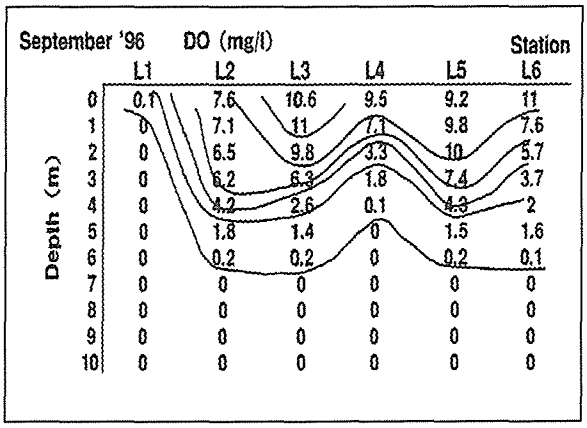


Fig.7 Vertical distribution of DO concentration [Dry-season]

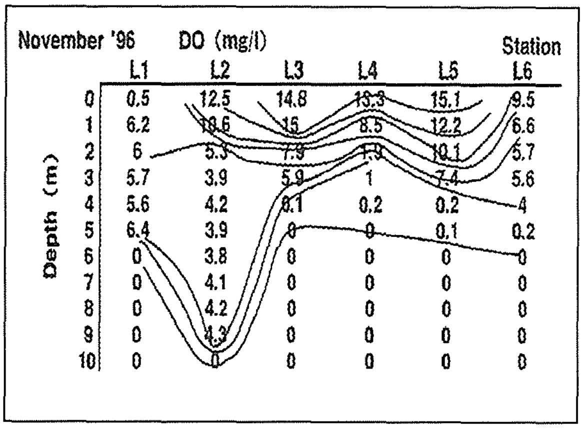


Fig.8 Vertical distribution of DO concentration [Rainy-season]

5. Simulation Model

1) Calculation Model

We constructed a simulation model of Saguling Reservoir and examined some measures for improvement of water quality. Saguling Reservoir was divided into the 500m meshes as shown in Fig. 9. Then, the model was constructed into a 2-dimention multi-layer model[6]. The equation of material balance of DO is shown as below. In this paper, the calculated results related to DO simulation in the rainy season are indicated.

Euphotic Zone

$$\frac{\partial O_2}{\partial t} = -\left(Ux\frac{\partial O_2}{\partial X} + Uz\frac{\partial O_2}{\partial Z}\right) + \frac{\partial}{\partial X}\left(Kx\frac{\partial O_2}{\partial X}\right) + \frac{\partial}{\partial Z}\left(Kz\frac{\partial O_2}{\partial Z}\right)$$
$$+ \sigma p - \alpha p - \beta z - \gamma D + k(DOS - O_2)$$

Uneuphotic Zone

$$\frac{\partial O_2}{\partial t} = -\left(Ux\frac{\partial O_2}{\partial X} + Uz\frac{\partial O_2}{\partial Z}\right) + \frac{\partial}{\partial X}\left(Kx\frac{\partial O_2}{\partial X}\right) + \frac{\partial}{\partial Z}\left(Kz\frac{\partial O_2}{\partial Z}\right) - \gamma D - S$$

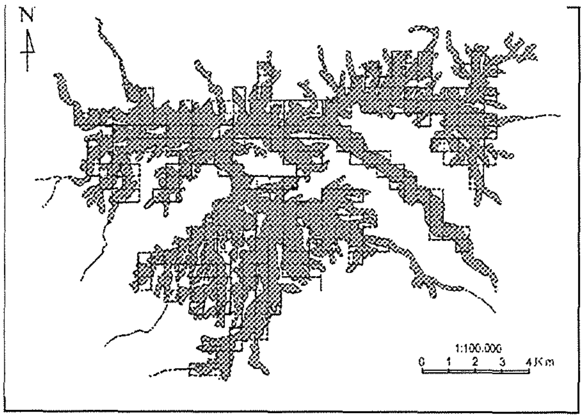


Fig.9 Area of calculation in the Saguling Reservoir

σ : Primarily production rate of a phytoplankton
α : Respiration rate consumption velocity of a phytoplankton
p : Density of phytoplankton
β : Respiration rate of a zooplankton
z : Density of zooplankton
γ : Oxygen consumption velocity of organic detritus
D : Concentration of organic detritus
DOS : Saturated concentration of Oxygen
k : Reaeration coefficient
Sc: Consumption velocity of Oxygen on sediment

2) Results

The results of our numerical simulation such as current velocity and concentration of dissolved oxygen are shown in Fig. 10 and 11. The calculated horizontal current velocity indicates approximately 0.1-3.0 cm/sec in the center of Saguling Reservoir. The vertical distribution of DO concentration that is described by the result of the calculation represents the present situation well.

Moreover, the measure for improvement of water quality was examined by using the simulation model. Three scenarios were calculated as shown in the following cases.

- -25% decrease of pollution load
- -50% decrease of pollution load
- -75% decrease of pollution load

The result of the calculated DO is shown in Fig. 12. This case study demonstrates, to say the least, that the pollutant load must be reduced by more than 25% from the present state.

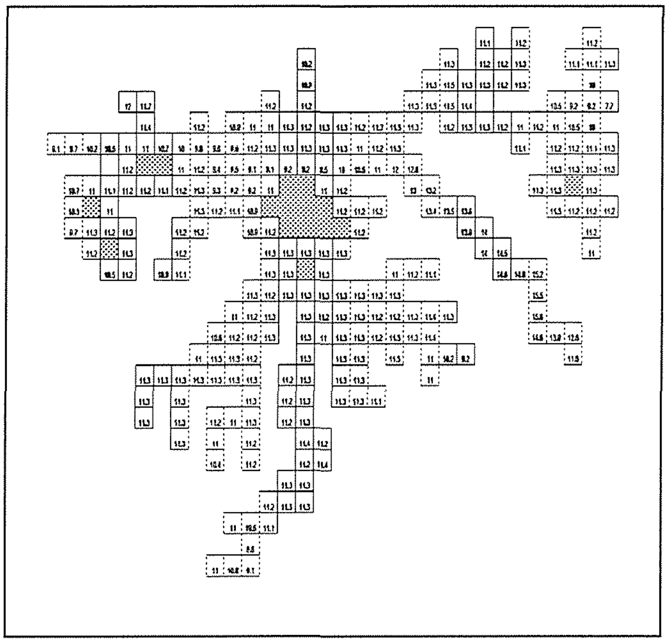


Fig.10 The result of the calculated current velocity (Horizontal current)

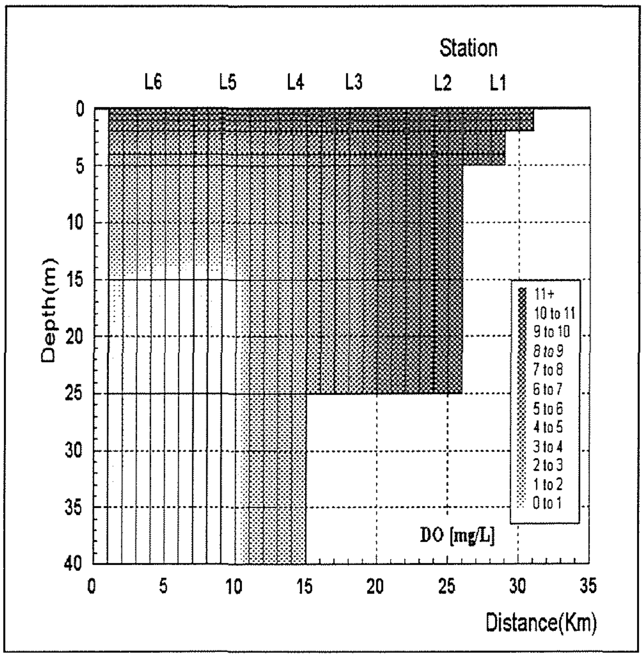


Fig.11 The result of calculated vertical DO concentration

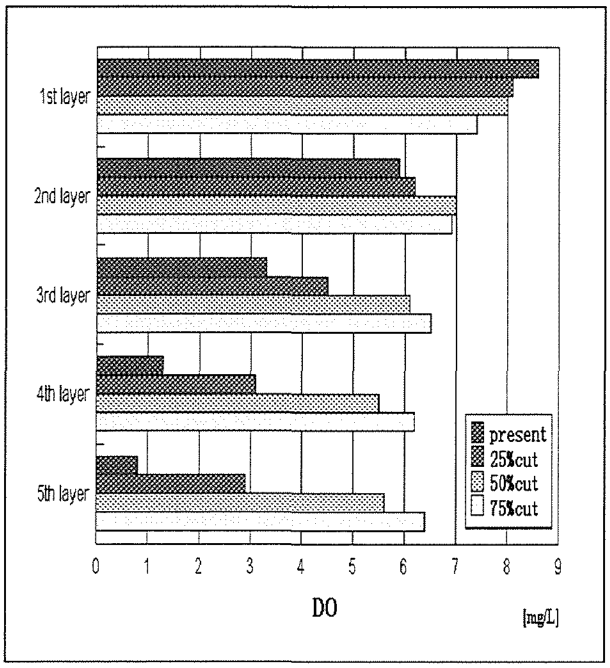


Fig.12 The result of the case study related to measure of Improvement for the water body

6. Discussion

The research demonstrates the present situation in the Saguling catchment area such as social conditions, pollutant inflow load and mechanisms of water pollution. As we have mentioned about the characteristic of water quality, a lack of dissolved oxygen is a very serious problem in this water body. Under such an anaerobic condition, when it rains, a high density of surface water flows down to the lower layer, and thus, upwelling occurs. At the same time, there appears a milky turbidity on the surface water cased by hydrogen sulfide, and tons of fish die due to lack of oxygen every year. This situation must be settled immediately. Then, we constructed a 2-dimensional multi-layer model for improvement of water quality based on the results of the research. Moreover, a case study was examined for improvement of environmental disruption by a numerical model of DO. Additionally, we pointed out that the pollutant load must be reduced more than 25% from the present state in order to improve the water body. However, it will be not easy to carry out effective measures. It seems to be an administration and social system problem instead of a scientific one. This research has just been started. We hope that a realistic way for the improvement of environmental disruption will be dynamically discussed in the future.

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