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Preliminary Assessment of Human Inpacts on Water Qualities (Nutrient Concentration) of the Han River on the Korean Peninsula, Based on a Mathematical Model

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數學 model에 依한 漢江의 水質(營養素濃度)에 미치는 人間의 影響에 關한 豫察

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ABSTRACT

Near future dynamics of water qualities (nutrient concentration) of the Han River was predicted, based on a mathematical model representing the relationship between the nutrient concentration in the river water and environmental factors (population density, land-use types, rock compositions and nutrient accumulation) in the basin. The population density and land-use types were forecasted to change distinctly in the downstream area, especially in Seoul City area in 1985~1990 whereas any environmental factor was not expected to change its level significantly in both upstream and middle reaches areas. It was indicated by the model that the nutrients concentration in the up- and mid-streams would keep its level in future as it was, but it would increase drastically in the downstream area. For the preservation of the water qualities in the downstream at least to keep its level as it was in 1980, practical countermeasures were proposed, based on the assessment of the contribution of each environmental factor to the water qualities.

INTRODUCTION

It is not recent that the pollution of the Han River has drawn much attention of public (National Environmental Research Institute, 1980).

The level of water qualities of the river, especially in the downstream (Seoul City) area, seems to drop year by year, because few steps have been taken to conserve the river and its basin, especially domestic and industrial waste water treatment, inface of rapid industrial development and population rush in this region during the last decade.

An emergency policy is needed to stop the more contamination of the Han River, which is the most utilized riparian water source in Korea and has innegligible influence on sea water qualities of the northeastern part of the Yellow Sea.

For planning scientific and accurate countermeasures for the pollution of the river, the assessment of human impacts on the river water qualities should be carried out, based on the results of the quantitative analysis of the relation between the water quality of the river and its basin ecosystems or human activities.

Fortunately, Nakane *et al.* (1984) proposed the mathematical model representing the relationship between nutrients concentration in the Han River water and environmental factors (population density, land-use types, rock compositions, accumulation of nutrient) in the basin, based on the data obtained in the field.

Thus, in this study we tried to predict the future dynamics of each environmental factor in the basin based on its statistical data during the last one or two decades, and then to forecast the water qualities in the Han River in near future by the model. By judging the contribution level of each environmental

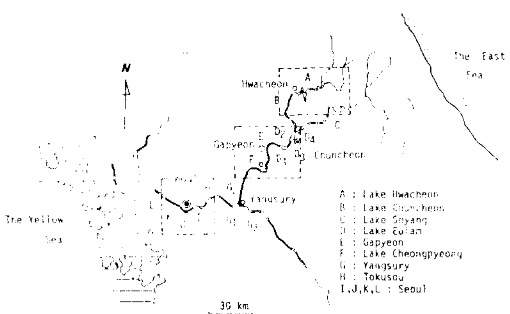

Fig. 1. Sampling sites of water of the Han River (Nakane *et al.*, 1980) and selected areas for analysis of land-use types in the up-, mid- and downstreams basins.

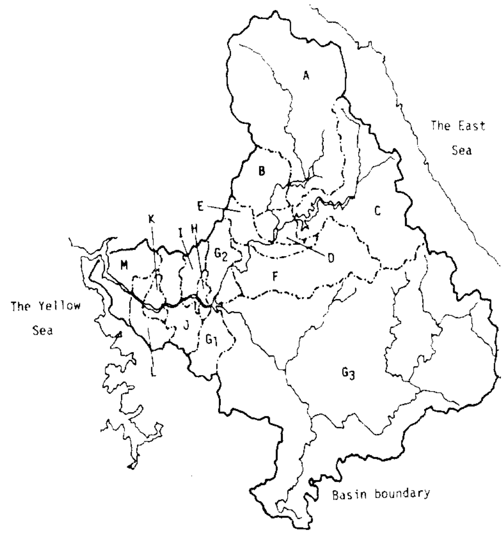

Fig. 2. Map of water catchment areas (Basins A-L), correspond to the sampling sites in the Han River (Nakane *et al.*, 1980).

factor to the change in the water qualities, most effective and practical countermeasures to keep the river water qualities were proposed.

This attempt may be very few one as a quantitative assessment of human impacts to the river water qualities in Korea, Japan and even in any other country.

We express our sincere thanks to Professor F. Takahashi of Hiroshima University and T. Kira, Director of Lake Biwa Reserach Institute of Shiga Prefecture for their encouragement during the course of this study.

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METHODS

Model used for analysis

Nakane *et al.* (1980) and Nakane & Hong (1983) measured the nutrients concentration (K, Na, Mg, Ca and P) from August of 1978 till May of 1981 simultaneously at seventeen sampling sites (Sites A-L, see Fig. 1) from upstream to downstream in the North Han River and Han River on the Korean Peninsula. They also researched the environmental factors (population density, land-use types, rock compositions, accumulation of nutrients) in the water catchment areas (Basins A- L, see Fig. 2) corresponding to the sampling sites (Nakane *et al.*, 1980 and 1984).

Based on the results obtained in these studies, Nakane *et al.* (1984) proposed the model representing the relationship between the concentration of nutrients in the river water and the environmental factors in the basin, as follows:

$$C=\alpha\cdot B^{\beta}+\gamma\cdot M \quad \cdots\cdots(1)$$

where C is the annual mean concentration of nutrients (mg/l) at a given site, D and M are the mean population density (person/km^2) and mean accumulation of nutrients (kg/ha·30cm soil depth) in the water catchment area (basin) corresponding to the site, respectively. α, β and γ are coefficients.

M was calculated by the following equation,

$$M=\frac{1}{A_T}\sum_{i=1}^{n}(m_{fi}\cdot A_{fi}+m_{ci}\cdot A_{ci}+m_{ui}\cdot A_{ui})\cdots(2)$$

where A_T is the water catchment area (km^2), A_f, A_c, and A_u are the forest, cultivated land and urban or suburban areas in the water catchment area (km^2), and m_f, m_c, and m_u stand for the mean accumulation of nutrients in the forest, cultivated land and urban or suburban soils (kg/ha·30cm), respectively. i represents kinds of rock material, e. g., granite, gnesis, limestone and alluvial soil. That is, where $n=4$. A_{fi}, A_{ci} and A_{ui}, which denote A_f, A_c and A_u of each kind of rock material, respectively, were calculated from geological and land-use maps. m_{fi}, m_{ci}, and m_{ui}, which also denote m_f, m_c and m_u of each rock material, respectively, were estimated from the data obtained by the field survey.

As mentioned above, major environmental factors, which may affect significantly to nutrient concentration (qualities) of the river water, are taken into consideration in Eq. (1).

The concentration of nutrients in the river water observed and calculated by Eq. (1) were closely coincided with each other, e. g., the correlation coefficients(r) between them were more than 0.98 in all cases of nutrients (Nakane *et al.*, 1984; unpublished).

Therefore, it is reasonable to predict the river water qualities (nutrient concentration) by this model when the level of environmental factors (e. g., population density and land-use types) in the basin change in future. For details of the explanation of the model, refer to Nakane *et al.* (1984). Data of phosphates, however, takes its source from Nakane *et al.* (unpublished).

Population, land-use types

Population data used for the population dynamics analysis in the basin of the Han River during two decades (1960~1980) was quoted from population census published in Korea Statistical Yearbook, 1979 and Preliminary Count of Population and Housing Census, 1980 (National Bureau of Statistics Economic Planning Board, Republic of Korea, 1979 and 1980).

Landsat M. S. S. data was applied to estimate the area of each land-use type in the basins. The change in the area of each land-use type (forest, cultivated land and urban or suburban) between in 1972 and 1983 was estimated at the selected areas, as shown in Fig. 1, and based on the estimation at the selected areas, the change in land-use types per ten years or one year was calculated in up-, mid- and downstreams areas, respectively.

A image map analyzer, Nac Model 4200 F, was used for the analysis of Landsat data.

Chemical fertilizer consumption in the cultivated land during the last decade in Korea was refered to Korea Statistical Yearbook, 1979.

Based on the change in the environmental factors during the last one or two decades, their future dynamics was predicted under the assumption that the tendency of their change in the past would go on in near future as it was.

RESULTS AND DISCUSSION

Prediction of change in population and land-use types

Change in population in Seoul City, Gyeonggi-Do,

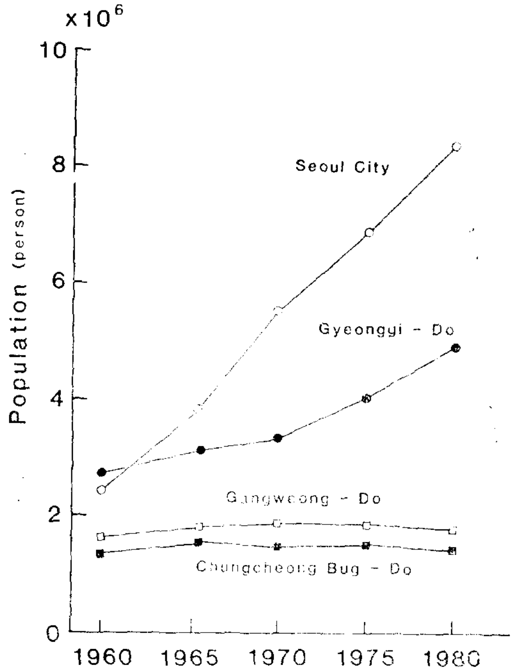

Fig. 3. Population dynamics in 1960~1980 in the basin of the Han River, Seoul City, Gyeonggi-Do, Gangweon-Do and Chungcheong Bug-Do (Data source: National Bureau of Statistics Economics Planning Board, 1979 and 1980).

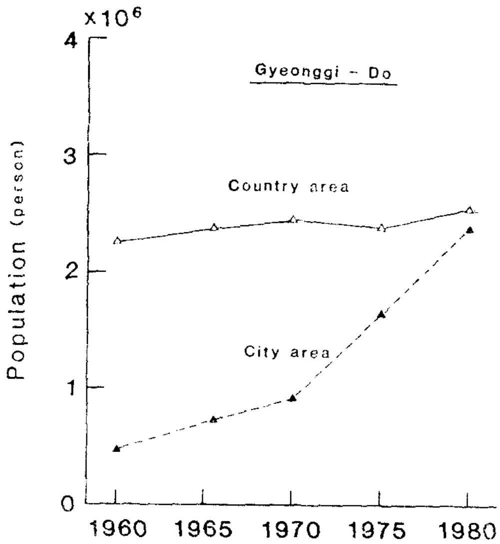

Fig. 4. Population dynamics in country and city areas in Gyeonggi-Do (Data source: National Bureau of Statistics Economics Planning Board, 1979 and 1980).

Gangweon-Do and Chungcheong Bug-Do, most area of which are belong to the basin of the Han River, is shown in Fig. 3.

Fig. 3 shows that population increased rapidly in the downstream area of the Han River, in particular in Seoul City area during the past two decades whereas there was little change in population in the upstream and middle reaches areas, i. e., Gangweon-Do and Chungcheong Bug-Do.

The increase of total population in Gyeonggi-Do in the same duration was deeply depended on that in the city areas in it, e. g., Incheon, Suweon, Seongnam, Euijeongbu, Anyang and Bucheon Cities, as shown in Fig. 4. These cities locate in the downstream area except for Incheon and Suweon Cities which locates outside of the Han River basin.

It indicates that most the increment of population in the basin in 1960~1980 immigrated to the downstream area and also the immigration from the other river basins concentrated into the same area, especially in Seoul City area. This is the reason that there was little variation in population in the up-and mid-stream areas but remarkable increase of population in the downstream area of the Han River.

It is reasonable to forecast that the population dynamics will go on in the same rate and same way within the near future (1985~1990) because the increasing rate of population in the downstream area (Basins I-L) was nearly constant. The rate ranged from 1, 700, 000 to 2, 000, 000 persons/5 years or from 340, 000 to 400, 000 persons/year.

The results of analysis of the land-use types in the basin of the Han River by using landsat data in 1972 and 1983 are given in Table 1.

Table 1 suggests that the land-use types in the basin changed little during about ten years except those in the downstream area, in particular in Seoul City area. The change in land-use types between 1972 and 1983 in the downstream area was chara-

Table 1. Change in land-use types during eleven years (1972~1983) at the selected areas in up-, mid- and downstreams basins of the Han River

Land-use types	1972 (%)	1983 (%)	Balance
Upstream area			
Forest	59.0	64.9	
Disturbed forest	28.7	23.7	
	(87.7)	(88.6)	+0.9
Cultivated land	7.7	8.0	+0.3
Suburban	0.1	0.1	
Urban	0.0	0.0	
	(0.1)	(0.1)	+0.0
River and river bank	1.8	1.4	−0.4
Other	2.7	1.9	−0.9
Middle reaches area			
Forest	52.0	59.2	
Disturbed forest	30.5	24.0	
	(82.5)	(83.2)	+0.7
Cultivated land	9.0	8.8	−0.2
Suburban	0.8	0.5	
Urban	0.0	0.0	
	(0.8)	(0.5)	−0.3
River and river bank	3.8	2.9	−0.9
Other	3.9	4.5	+0.6
Downstream area			
Forest	17.2	19.2	
Disturbed forest*	34.7	25.7	
	(51.9)	(44.9)	−7.0
Cultivated land	14.7	7.6	−7.1
Suburban	5.6	8.4	
Urban	17.5	28.0	
	(23.1)	(36.4)	+13.3
River and river bank	3.8	3.6	−0.2
Other	6.5	7.5	+1.0

*: Including rock mountains

cterized by the conversion from cultivated land or forest to urban or suburban, caused by rapid increase of population or development of industry in Seoul City area.

The increment of urban and suburban area is, however, not so large. It was roughly estimated to 10% of total area in the downstream per ten years or 1.0% per year, which correspods to 10% per 3,600,000 persons increment or 2.7×10^{-6} % per person increment.

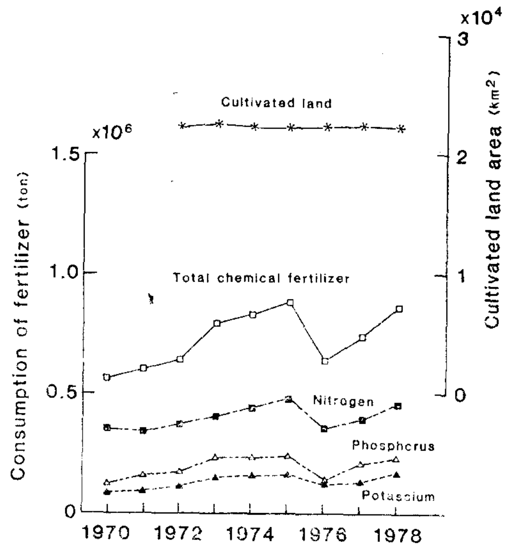

Fig. 5. Change in the consumption of chemical fertilizer in cultivated land and cultivated land area in Korea in 1970~1978 (Data source: National Bureau of Statistics Economics Planning Board, 1979 and 1980).

The amount of fertilizer consumption may affect to the accumulation of nutrients in cultivated lands. Annual amount of chemical fertilizer sowed in the cultivated land was nearly constant in 1970~1978 especially since 1973, and the total area of cultivated land decreased only slightly in Korea (National Bureau of Statistic Economics Planning Board, 1979), as shown in Fig. 5.

It suggests that the amount of fertilizer sowed per unit area (km^2) of cultivated land was also constant during the last decade. If this tendency continues in near future, the accumulation of nutrients will not change drastically at cultivated land in the basin of the Han River in a future decade.

The predicted dynamics of major environmental factors in the basin of the Han River in near future (1985, 1990) is given in Table 2.

Prediction of nutrients concentration in the river water

Fig. 6 shows the concentration of nutrients in the

Table 2. Near future dynamics of environmental factors in the basin of the Han River, predicted based on the dynamics of those during the last one or two decades*

Environmetal factors	1985	1990
Population (person)		
Upstream area	—	—
Middle reaches area	—	—
Downstream area		
Basin (I)	+ 300,000	+ 600,000
(J)	+ 600,000	+1,200,000
(K)	+ 300,000	+ 600,000
(L)	+ 600,000	+1,200,000
Sum	(+1,800,000)	(+3,600,0000)
Land-use type(% of the selected area)		
Upstream area	—	—
Middle reaches area	—	—
Downstream area (Basins I-L)		
Forest	− 2.5	− 5.0
Cultivated land	− 2.5	− 5.0
Urban and suburban	+ 5.0	+10.0
Fertilizer consumption in cultvated land		
Up-, mid- and downsream areas	—	—
Rock compositions		
Up-, mid- and downstream areas	—	—
Accumulation of nutrients in soil at each land-use type		
Up-, mid- and downstream areas	—	—

* The base period is 1980. —; No change

river water at the downstream (Sites I-L) of the Han River in 1985 and 1990, which were calculated by the model (Eqs. 1 and 2) under the predicted level of the environmental factors in 1985 and 1990 (Table 2), respectively.

The concentration in the river water at the up- and mid-stream (Sites A-G) are excluded from Fig. 6 because it is not expected to change within ten years future due to a little change in population density, land-use types and etc. in these areas.

Fig. 6 indicates that the concentration of potassium, sodium and phosphates in five and ten years future increases swiftly in the downstream. These nutrients originate almost from the human activities in the basin.

There are, however, less significant increasing tendency in the cases of magnesium and calcium, which are derived mainly from the rock materials in the basin more than human activities.

The concentrations of potassium, sodium and phosphates in 1985 and 1990 at Site L correspond to 110~125% and 120~150% of their level in 1980, respectively. Total or nitrate nitrogens, heavy metals, SS and etc., which are also derived mainly from human activities, may show the similar behavior in the river water as potassium, sodium and phosphates.

It suggests that the water qualities at the downstream of the Han River will be contaminated at most 1.5 times in 1990 as much as the level in 1980 whereas those at up- and mid-streams will be maintained as they were in 1980. The concentration of nutrients (K, Na, P and N) and heavy metals (Cu, Zn, Pb and Cd) at the lowest site L contaminated 10~50 fold of the upstream area level even in 1978 ~1980 (Hong *et al.*, 1980; Hong and Ra, 1979;

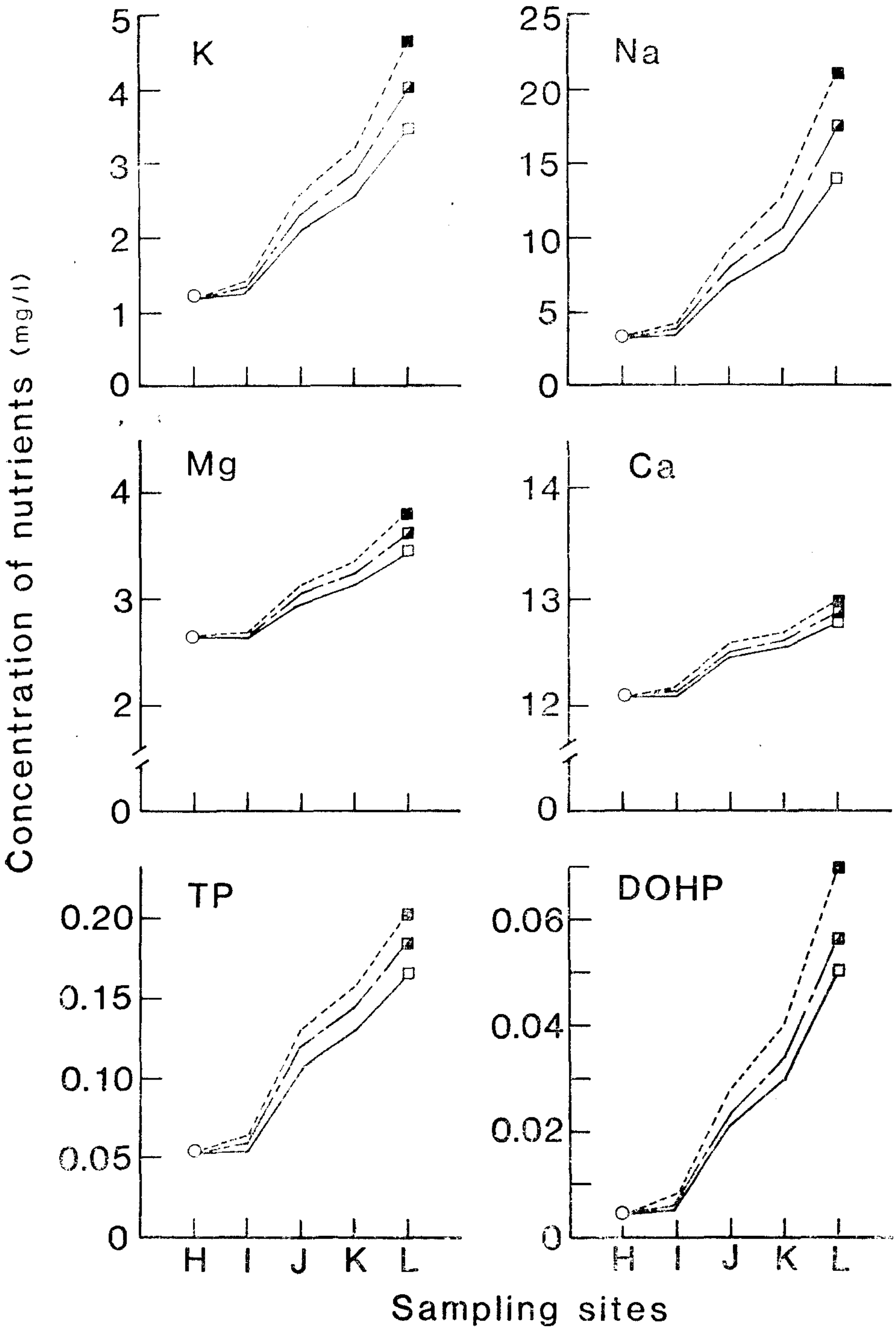

Fig. 6. Near future dynamics of the nutrient concentration in the river water of downstream (Sites I-L), forecasted by the model (Eqs. 1 and 2) under the condition of predicted level of the environmental foctors (population density, land-use types, rock compositions and accumulation of nutrients) in the basin.
——□ : 1980, ——◪ : 1985, ——■ : 1990. K : Potassium, Na : Sodium, Mg : Magnesium, Ca : Calcium, TP : Total phosphate, DOHP : Dissolved ortho & hydrolizable phosphate

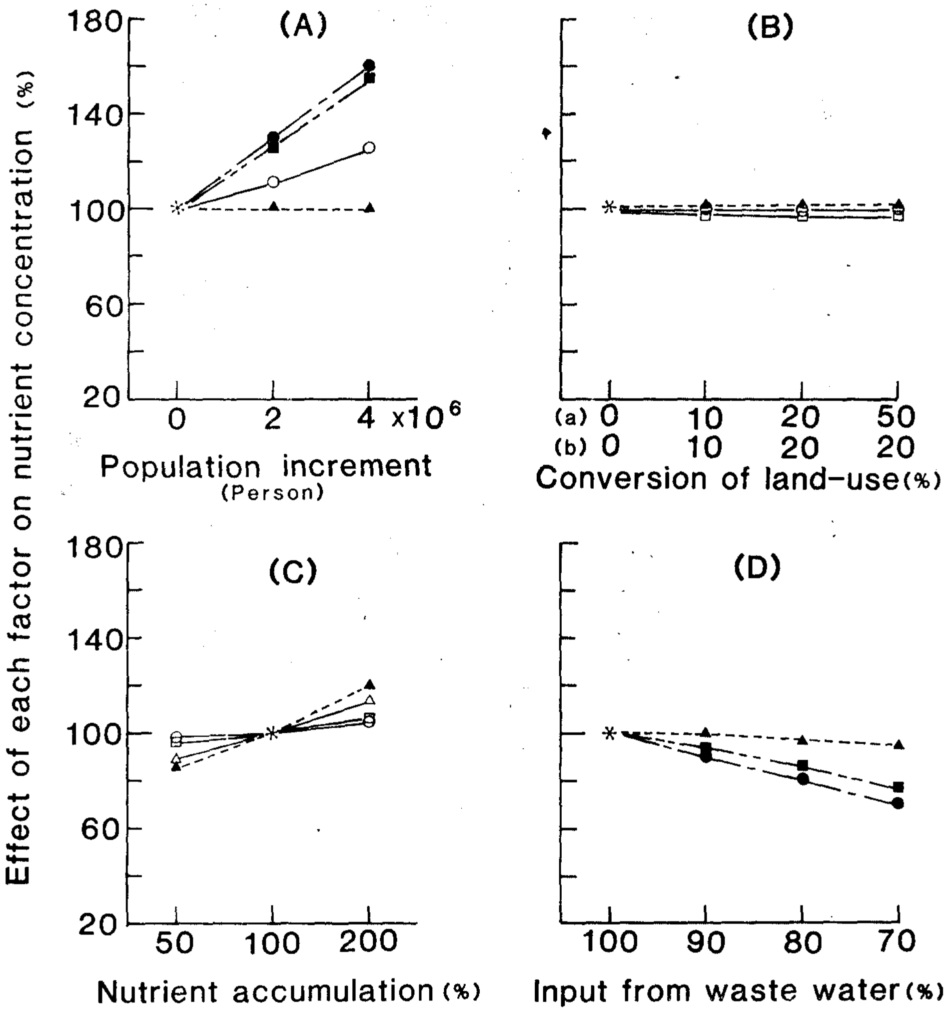

Fig. 7. Contribution of each environmental factor to the nutrient concentration in the river water, assessed by the term $\alpha \cdot D^{\beta}$ in Eq.(1) under the condition of the fixation of any other environmental factors level in the basin.

The base period of 100 is 1980 on the vertical axis.

(A) : Effect of population increment in the downstream.
The base population of 0 is that in 1980 on the horizontal axis.

(B) : Effect of land-use type conversion in the downstream.
(a) : Ratio of conversion from cultivated land to urban or suburban.
(b) : Ratio of conversion from forest to urban or suburban.
The horizontal axis represents the ratio to the level in 1980(%).

(C) : Effect of change in nutrient accumulation in cultivated land.
The horizontal axis respresents the ratio to the accumulation in 1980(%).

(D) : Effect of diminution of nutrient input from waste water.
The horizontal axis represents the ratio to the input in 1980(%).

□——□ : Potassium, ■……■ : Sodium, △——△ : Magnesium, ▲——▲ : Calcium,
○——○ : Total P. ●……● : Dissolved ortho & hydo. P.

Nakane *et al.*, 1980 and 1983; Nakane and Hong, 1983). Therefore, the more contamination of the downstream water should be avoided.

Contribution of each environmental factor to water quality

The contribution of each environmental factor to water qualities (nutrients concentration) of the river was tested in the downstream area by the model (Eqs. 1 and 2). Namely, by changing the level of concerned environmental factor under the fixation of other factors one, its effect on the nutrient concentration was assessed at the lowest site L by the model (Eqs. 1 and 2) (Fig. 7).

Fig. 7 suggests that the change in population density affects intensively to the concentration of nutrients in particular potassium, sodium and phosphates whereas that of land-use type slightly affects to them, when these environmental factors change their level within the predicted ranges.

There is not a small influence of fertilizer consumption on the concentration of magnesium and calcium in the river water, when the accumulation (consumption) of nutrients decreases to a half or increases to twice as much as it was in 1980.

On the other hand, the term $\alpha \cdot D^{\beta}$ in Eq.(1) represents the influence on nutrients concentration in a river water by domestic and industrial waste water. It suggests that the influence of the change in input of nutrients through the waste water on the concentration in the river can be assessed, based on the term $\alpha \cdot D^{\beta}$ in Eq. (1).

The effects of decrease of the input by 10% or 20% on the nutrient concentration in the river correspond to that of the diminution of one or two million people in the basin, as shown in Fig. 7.

CONCLUSION (ASSESSMENT)

It is obvious that the concentration of nutrients in the river water, which originate from human activities, will increase to 1.2～1.5 times as much as in 1980, at the downstream of the Han River within a few years owing mainly to the rapid increase of population in this area.

The more contamination of the river water in the downstream of the Han River means not only the death of its aquatic ecosystem but also tremendous damage to fishes and shells living in its estuary and near sea.

It is, however, very difficult to stop the centralization of population into Seoul City area or to reduce much chemical fertilizer consumption in cultivated land in near future.

A possible emergency measure is to reduce the input of nutrients through domestic and industrial waste water in the downstream area by constructing more sewage disposal works plants or by controlling the consumption of synthetic detergents and salts at home.

For example, if the treatment capacity of waste water by the plants goes up from 17% to 50% of total waste water in Seoul City area till 1990, water quality of the downstream may be preserved its level in 1990 as it was in 1980.

摘　要

漢江의 水質과 流域의 人口密度, 土地利用型, 岩石의 組成, 營養堆積物 등 環境要因과의 關係를 나타내는 數學 model에 의거하여, 가까운 將來의 水質營養濃度의 動態를 豫測하였다.

1985～1890年 사이에, 漢江의 下流, 특히 서울特別市地域에서는 人口密度와 土地利用型이 뚜렷이 變할 것으로 豫想된데 (1980年 基準으로 1.2～1.5倍) 反하여 上流와 中流域에서는 어느 環境要因도 有意한 水準으로 變化할 것으로 期待할 수 없었다. model에 의하면 營養素濃度는 上·中流에서는 가까운 將來에도 1980年 水準으로 維持될 것이나 下流에서는 크게 增加할 것으로 나타났다. 下流의 水質을 最小限 1980年水準으로 維持하기 위하여, 水質에 對한 各環境因子의 貢獻度에 關한 評價(assessment)에 立脚하여 實際的인 方案을 提示하였다. 이를테면 工場廢水의 處理量을 서울市의 總廢水處理量의 17에서 50%로 하면 下流의 水質은 1990年에도 1980年의 水準을 維持할 수 있을 것으로 期待된다. 이것은 現在進行中에 있는 漢江綜合開發事業에 參考가 될 것으로 본다.

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