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Dynamic Simulation Analysis of the Environmental Policy and Impact on Regional Economy in the Basin

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Subject area: Sustainability, environment and natural resources.

Abstract: The aims of this study are to develop the environmental policy evaluation model and analye the environmental and economic impacts on the regional economy in the Mikawa Bay Basin, Aich Prefecture, Japan. The basin has an area of 724 square kilometers, which spreads from the urban, bay area in the south the rural, mountainous area of the north. Particularly the southern area of the basin has been developed ever since the water for the household, agricultural, and industrial use has been supplied from the Toyogawa River. Today, this development includes the high value-added agricultural systems in the cities of Toyohashi and Tahara, and the manufacturing base, which includes the automobile industry, around the beyond the Mikawa Port. We analyse the regional economic and environmental data of the Mikawa Basin, and construct the system model to clarify the interaction between the regional economy and the water environment in the basin, which model describes the socio-economic activities and its impact on the water environment in the area. The model is mainly considered the water quality and environment as maximum restrictions and has the aim at the purpose of maximizing the GDP of the basin area with consideration for the transportation structure of the water pollutant in the area. Our model is the regional model to evaluate the watershed policy in the basin area, which is defined as the simulation model. The simulation model is for example to evaluate the land use conversion and industrial subsidy policy as a water environmental measure in the river basin. Of course, we assume other environment policies to evaluate by the model simulation. We can analyse the relationship between the regional economy and water environment and estimate the impacts of the regional economic activities on the water environment in the basin. Finally, we evaluate the regional economic and the water environmental policy in the basin by the model simulation.

Keywords: Dynamic simulation analysis, Regional economy, Water-environment policy, Water Pollutants
JEL: Q51 Valuation of Environmental Effects, Q58 Government Policy

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1. Introduction

In recent years, water resource management has become an essential feature of both social and economic activities. Water availability is closely related to the spatial characteristics of regional and urban economies. Many firms involved in the automobile industry are concentrated in the Toyogawa Basin, which is the eastern area of Aichi Prefecture, Japan, and they use industrial water as an inter-mediate input. Figure 1 shows the Toyogawa Basin area that faces several policy issues including environmental preservation in Mikawa Bay, highway construction, consolidation of municipalities, and the aging and depopulation of communities in the northern mountain area. The problem of water quality is of increasing importance in this area.

A wide-ranging analysis of urban and regional issues facing the Toyogawa Basin, which is in the East Mikawa area, has been undertaken by the Institute of Regional Research of Chubu (1998) and the East Mikawa Development Council (1994). Esaki (1992) and Makino (1997) analyzed the economic impact of the Toyogawa waterway in East Mikawa. Sakatou et al. (1990) investigated the relationship between water demand and land use in the Toyogawa Basin. Matsukura et al. (1998) explored environmental issues such as the quality of water in the Toyogawa River and Mikawa Port. Yamaguchi and Shibusawa (2006) focused on the water resources and regional economy by an econometric model of East Mikawa area (Toyogawa basin). Shibusawa and Yamaguchi (2014) analyzed the impact of water demand and supply on the social and economic structure in East Mikawa using our multi-regional econometric model. Most of these previous studies simply relied on regional statistical data and a questionnaire. There have been few attempts to examine the interaction between the regional economic system and the water environment using the dynamic optimization approach.

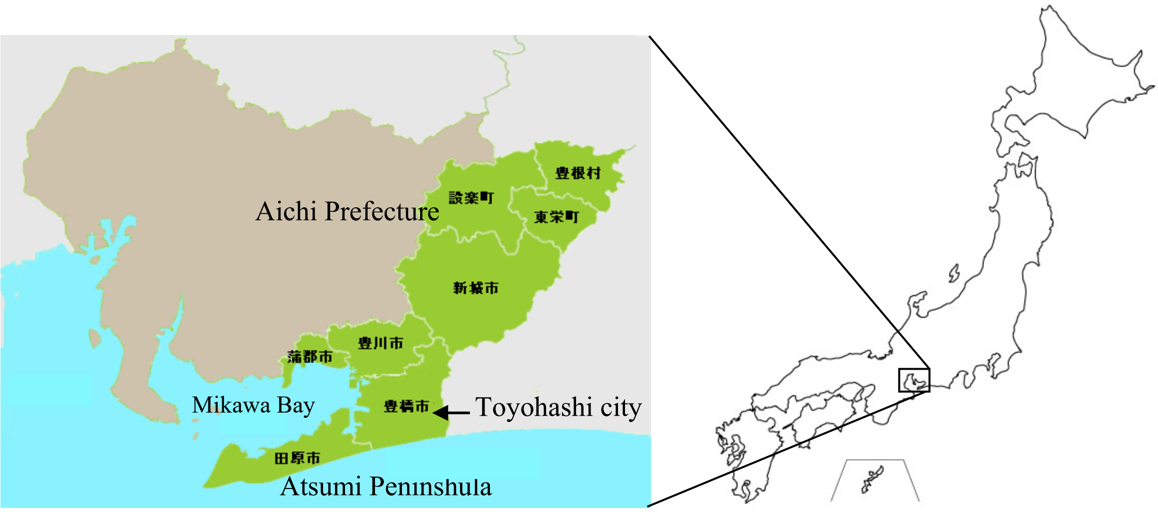

Figure 1. Toyogawa Basin in Japan

2. Research purpose and target area

The purpose of our study is to construct a dynamic model including regional socio-economic activities and water pollution in the Toyogawa Basin. Moreover, we also try to analyze the impacts of the environmental management policy on the regional economy and water environment.

The population of the Toyogawa Basin is about 770,918 (2009), which is 10.4% of the population of Aichi Prefecture. The central city in East Mikawa is Toyohashi, whose population is about 375,000. This area is home to the largest share of Aichi Prefecture's primary industry. There is also an advanced agricultural area that has a high-value-added system. Land mainly used for agriculture ex-tends over the Atsumi area in Toyohashi city. Atsumi Peninsula is home to Ja-pan's largest-scale agricultural cooperative association. This area's main agricultural products are vegetables, fruits, flowers, and livestock. The agricultural sector strongly depends on the waterways in the Toyogawa Basin. Three channels, namely the eastern, western, and Muro/Matsubara channels, go through this area.

The east side of the target area has a superior forest zone in its northeastern mountains. The main industries are involved in the manufacturing, for example, of transport equipment, electrical machinery, and general machinery.

The target area has several regional issues. This area sometimes faces water shortage problems, especially in summer. Balancing water supply and demand is an important regional issue. Aging and depopulation are general problems not only in the Toyogawa area but also in other regions of Japan. The Toyogawa River goes through Mikawa Bay. Mikawa Bay is a closed area of the sea and the water depth is shallow.

Water pollution in Mikawa Bay is feared.

Figure 2 shows the main indicators in the Toyogawa Basin and the average growth rate from 1985 to 2005. Most indicators have positive average growth rates. Agricultural output shows 0.7% growth, whereas manufacturing sales grew by 4.5%.

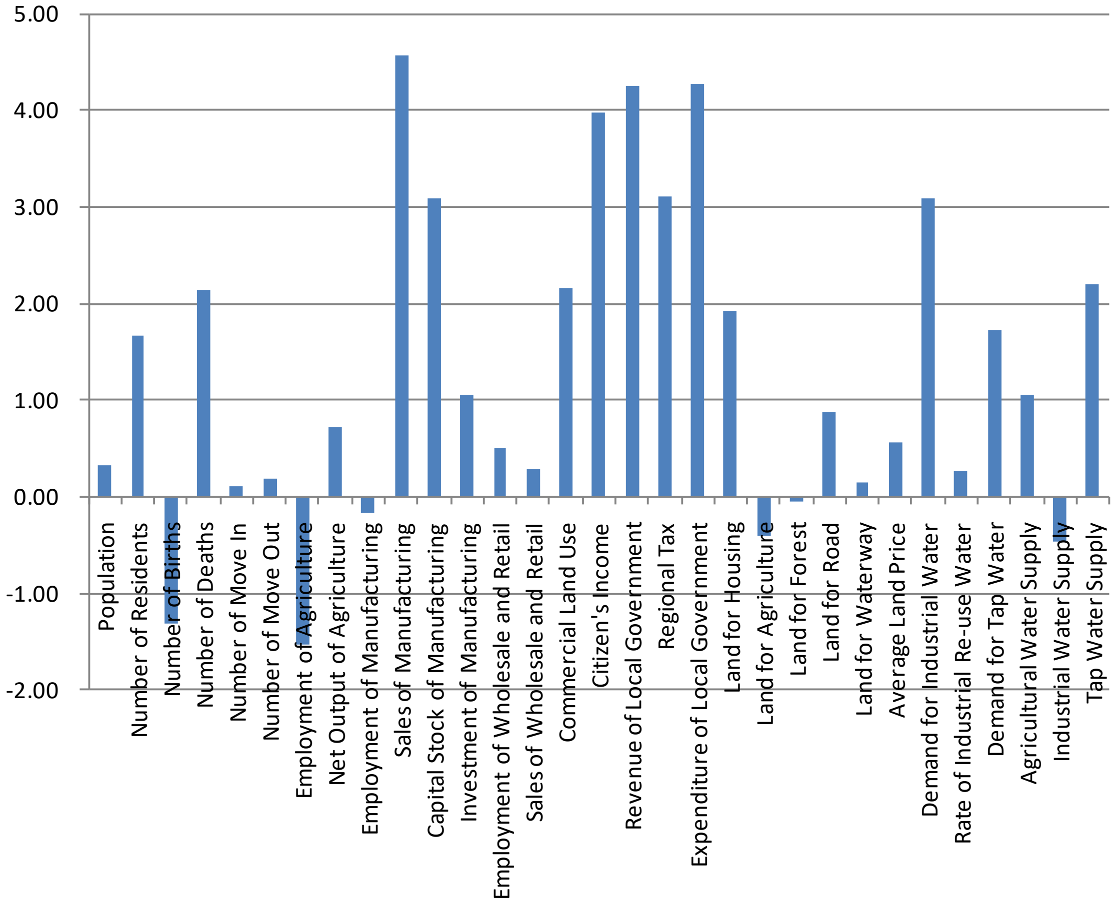

Figure 2. Average growth rate from 1985 to 2005 (%/year)
Reprinted from Shibusawa and Yamaguchi(2014)

Agricultural and tap water supplies also have positive average growth rates. We can thus observe that the regional economic growth and water usage are closely related.

This study explores the relationship between the water quality in Mikawa Bay and the regional economy in the Toyogawa Basin.

3. The model

In this study, we develop a dynamic socio-economic model with water pollutant emissions. Our target area is the Toyogawa Basin, including 5 cities and 1 town. Planning years run from 2005 to 2050.

In our simulation, 1 period is assumed to last 5 years. The method is the dynamic optimization approach. The objective function is GRP and constraints are social, economic, and environmental conditions.

3.1 Amount of water pollutant emission from the target area

The total amount of water pollutant emissions caused by socio-economic activities around the Toyogawa Basin flowing into the Mikawa Bay is calculated as follows:

$$Q^i(t) = \sum_j QS_j^i(t) + QR^i(t) \tag{1}$$

where

$Q^i(t)$: Total amount of water pollutant emission i from the Toyogawa Basin at period t;

t : Time period of the model simulation;

$QS_j^i(t)$: Amount of water pollutant emission i from municipality j in the basin at period t;

$QR^i(t)$: Amount of water pollutant by rainfall at period t; and

i = 1: T-N, 2: T-P, 3: COD.

3.2 Amount of water pollutant emissions from socio-economic activities

Water pollutants from socio-economic activities in the Toyogawa Basin consist of emissions from households, the industry sector, land use, and a sewage-treatment plant as follows:

$$QS_j^i(t) = QZ_j^i(t) + QL_j^i(t) + QX_j^i(t) + \sum_d QD_d^i(t) \tag{2}$$

where

$QZ_j^i(t)$: Amount of water pollutant emission from household of the municipality j in the basin at period t (excluding sewage system);

$QL_j^i(t)$: Amount of water pollutant emission from land use area of the municipality j in the basin at period t;

$QX_j^i(t)$: Amount of water pollutant emission from industry of the municipality j in the basin at period t; and

$QD_d^i(t)$: Amount of water pollutant emission from the sewage-treatment plant d in the basin at period t.

3.3 Amount of water pollutant emissions from households

The amount of water pollutant emissions from household activities in the Toyogawa Basin is calculated as follows:

$$QZ_j^i(t) = \sum_{\Delta} E^{\Delta} \cdot z_j^{\Delta}(t) \tag{3}$$

where

E^h : Water pollution coefficient by water pollutant treatment facility h; and

$z_j^h(t)$: Numbers of users of water pollutant treatment facility h of the municipality j in the basin at period t.

3.4 Amount of water pollutant emissions from land use

The amount of water pollutant emissions from land use in the Toyogawa Basin is calculated as follows:

$$QL_j^i(t) = \sum_l G^l \cdot L_j^l(t) \tag{4}$$

where

G^l : Water pollution coefficient by land use l; and

$L_j^l(t)$: Area of land use l of the municipality j in the basin at period t.

3.5 Amount of water pollutant emissions from industry

The amount of water pollutant emissions from the industrial sector in the Toyogawa Basin is calculated as follows:

$$QX_j(t) = \sum_m P^m \cdot x_j^m(t) \tag{5}$$

where

P^m : Water pollution coefficient by industry m; and

$x_j^m(t)$: Production of industry m of municipality j in the basin at period t.

3.6 Population in the basin

The population in the Toyogawa Basin is calculated as follows:

$$z_j(t) = z_j(t-1) + \Delta z_j(t-1) \tag{6}$$

where

$z_j(t)$: Population of municipality j in the basin at period t; and

$\Delta z_j(t)$: Population change of municipality j in the basin at period t.

3.7 Finance of municipality in the basin

The finance of the municipality in the Toyogawa Basin is calculated as follows:

$$R_j(t) = \rho_j \cdot z_j(t) \tag{7}$$

where

$R_j(t)$: Revenue of municipality j in the basin at period t; and

ρ_j : Local government tax per capita of municipality j in the basin.

3.8 Restriction of financial expenses

We introduce a restriction whereby the subsidy expense for the water-environment policy to control water pollutant emissions is less than the total tax revenue.

$$wep_j(t) \leq \omega_j R_j(t) \tag{8}$$

$wep_j(t)$: Subsidy for water-environment policy by municipality j at period t; and

ω_j : Ratio of financial expenses for water-environment policy.

3.9 Users of household wastewater treatment facility

The total number of users of water pollutant treatment facility h is equal to the total population of municipality j in the Toyogawa Basin. Changes in users depend on the construction investment made in the wastewater treatment facility.

$$z_j(t) = \sum_{\acute{A}} z_j^{\acute{A}}(t) \tag{9}$$

$$z_j^{\acute{A}}(t) = z_j^{\acute{A}}(t-1) + \Delta z_j^{\acute{A}}(t-1) \tag{10}$$

$$\Delta z_j^{\acute{A}}(t) \le \Gamma_j^{\acute{A}} \cdot i_j^{\acute{A}}(t) \tag{11}$$

where

Γ_j^h : Ratio of investment made in construction for water pollutant treatment facility and increase of users; and

$i_j^h(t)$: Investment in construction of water pollutant treatment facility .

3.10 Production function

The amount of production is dependent on capital accumulation of production, as follows:

$$x_j(t) \le \omega_j k_j^P(t) \tag{12}$$

where

ω_j : Proportion coefficient of production to capital stock; and

$k_j^P(t)$: Capital accumulation of industrial production.

3.11 Capital accumulation

The accumulation of capital by the water pollutant treatment facility is defined as follows:

$$k_j^{mP}(t) = k_j^{mP}(t-1) + i_j^{mP}(t-1) - d^m \cdot k_j^{mP}(t-1) \tag{13}$$

where

$k_j^{mP}(t)$: Accumulation of capital for production of industry m of the municipality j in the basin;

$i_j^{mP}(t)$: Investment for production of industry m of the municipality j in the basin; and

d^m : Discount rate of industry m.

3.12 Flow condition of production market

$$x(t) \ge Ax(t) + C(t) + i^P(t) + B^S\{i^1(t) + i^2(t)\} + B^C \cdot \delta \cdot \Delta Z^3(t) + e(t) \tag{14}$$

where

$x(t)$: Industrial production vector;

A : Input coefficient matrix;

$C(t)$: Consumption vector;

$i^P(t)$: Production investment vector ($P \neq 1, 2$);

B^s : Production inducement coefficient matrix by investment in the sewage system and rural community’s sewage system;

$i^1(t)$: Investment in the sewage system;

$i^2(t)$: Investment in the rural community’s sewage system;

B^c : Production inducement coefficient matrix by investment in combined treatment septic tanks;

$\delta \cdot \Delta z^3(t)$: Total cost of installing a combined treatment septic tank; and

$e(t)$: Exports.

3.13 Restriction of consumption

Consumption in municipality j is determined by the municipality’s population.

$$C_j(t) \le k_j z_j(t) \tag{15}$$

where

k_j : Consumption coefficient vector.

3.14 Regional economy

GRP in the basin is determined by the rate of added value and amount of production:

$$GRP(t) = v \cdot x(t) \tag{16}$$

where

$GRP(t)$: Regional GDP; and

v : Added value rate.

3.15 Water-environment policy

We try to evaluate the impact and effect of plant factory construction on the regional economy and water environment in the target area as a water-environment policy.

$$PF_j(t) \le wep_j(t) \tag{17}$$

where

$PF_j(t)$: Subsidy for construction of plant factory in municipality j at period t.

3.16 Objective function

We define the objective function in the model, which maximizes GRP in the simulation terms with a restriction on the amount of water pollutant emissions from the Toyogawa Basin flowing into the Mikawa Bay as follows:

$$max \sum_{t=1} \frac{1}{(1+\rho)^{(t-1)}} GRP(t) \tag{18}$$

$$\text{subject to} \quad Q^i(t) \le \overline{Q^i(t)} \tag{19}$$

where

ρ : Social discount rate (=0.04); and

$\overline{Q^i(t)}$: Restriction on amount of water pollutant emission i from the Toyogawa Basin at period t.

4. Dynamic simulation

4.1 Study area and environmental index

The study area of our study is the Toyogawa Basin, which contains five cities and one town, as shown in Table 1. We simulate the model using the dynamic optimization approach and maximizing GRP with restrictions on social, economic, and environmental conditions.

The planning years range from 2005 to 2050 (10 periods, 1 period = 5 years). The pollution indices analyzed in the simulation are Total Chemical Oxygen De-mand, Total Nitrogen, and Total Phosphorus (Table 2).

Table 1. Target area

Index	Municipality	
1	Toyohashi	city
2	Toyokawa	city
3	Gamagori	city
4	Tahara	city
5	Shinshiro	city
6	Shitara	town

Table 2. Water pollutant index

Index	Water Pollutant	
1	T-COD	(Total Chemical Oxygen Demand)
2	T-N	(Total Nitrogen)
3	T-P	(Total Phosphorus)

4.2 Classifications and Variables

In our simulation model, industry is classified into 22 sections, which are shown in Table 3. Table 4 shows the land use in the model, which covers a range of uses such as paddy fields, rice fields, mountain forests, city area, other, and plant factory sites. This model includes the household wastewater disposal system, which is shown in Table 5 and comprises the sewage system, rural community sewage, combined treatment septic tanks, single treatment septic tank, and night soil septic tank. The amount of water pollutant emissions, which refers to three kinds of pollutants (T-COD, T-N, and T-P), is estimated by our simulation model. The water pollutant emission coefficients are shown in Table 6, and the pollutants are generated from non-point sources (land use), production sources (production activities), and household wastewater generation sources.

Table 3. Industry sector

Index	Industry	Index	Industry
1	Manufacture of Food	12	Manufacture of Rubber Products
2	Manufacture of Feed	13	Manufacture of Leather Products
3	Manufacture of Textile Mill Products	14	Manufacture of Ceramic, Stone and Clay Products
4	Manufacture of Apparel	15	Manufacture of Iron and Steel
5	Manufacture of Lumber and Wood Products	16	Manufacture of Non-ferrous Metals and Products
6	Manufacture of Furniture and Fixtures	17	Manufacture of Fabricated Metal Products
7	Paper Products	18	Manufacture of General Machinery
8	Printing	19	Manufacture of Electrical Machinery, Equipment and Supplies
9	Manufacture of Chemical and Allied Products	20	Manufacture of Transportation Equipment
10	Manufacture of Petroleum and Coal Products	21	Manufacture of Precision Instruments and Machinery
11	Manufacture of Plastic Products	22	Others

Table 4. Land use

Index	Land use
1	Paddy Field
2	Rice Field
3	Mountain Forest
4	City Area
5	Other
6	Plant Factory

Table 5. Classification of household wastewater disposal system

Index	Household Wastewater Disposal System
1	Sewage system
2	rural community sewage system
3	combined treatment septic tank
4	single treatment septic tank
5	nigh soil septic tank

Table 6. Pollutant emission coefficient (g/ha/day)

Index	Emission Source	COD	T-N	T-P
1	Paddy Field	208.2	28.2	1.9
2	Rice Field	304.4	94.4	8.5
3	Mountain Forest	58.9	9.9	0.8
4	City Area	386.3	54	7.4
5	Other	58.9	9.9	0.8
6	Plant Factory A	42.6	6.3	0.5
7	Plant Factory B	84.1	17.9	1.1

4.3 Simulation cases

The base year was set up as 2005, and Aichi Prefecture Statistical Yearbook and other statistics were used as initial data (Aichi Environment Department water ground Environment Division (2006), Aichi Construction Department Sewer Division: Sewer of Aichi HP, Aichi Prefectural life part Statistics Division (2006), and Aichi Prefectural life part Statistics Division (2010)). The following four cases were examined. The simulation was performed for 10 units (5 years as a unit) per dynamic.

(1) **Case 1**: Maximize GRP not considering environmental measures.
(2) **Case 2**: Maximize GRP with setting a 3% reduction of pollutant load as a constraint. Assume receipt of a grant from the national government, thus prompting changes of land use and economic activity.
(3) **Case 3**: Maximize GRP with setting a 3% reduction of pollutant load as a constraint as in Case 2. Assume receipt of a grant from the national government, thus prompting change of existing farmland to advanced agriculture facilities (Sunlight-use type plant factory; Plant Factory A).
(4) **Case 4**: Maximize GRP with setting a 3% reduction of pollutant load as a constraint as in Case 2. Assume receipt of a grant from the national government, thus prompting change of existing farmland to advanced agriculture facilities (Full-control type plant factory; Plant Factory B).

Figure 3. Sunlight use type (Plant Factory A; Case 3)

Figure 4. Full control type (Plant Factory B; Case 4)

5. Simulation result

Figure 5 shows GRP of each case in 2050 and the percentage rates as compared with Case 1 needed to maintain the status quo. In Case 2, which takes measures to protect the environment, GRP decreased by 1.28% compared with Case 1. Meanwhile, in Cases 3 and 4, which aggregate subsidy uses from countryside to advanced agriculture facility development, GRP increased 1.54% and 3.24% respectively compared with Case 1 despite the environmental measures being in place. In these cases, percentages of advanced agricultural facilities in 2050 were 1.75% and 0.94% respectively; from these changes, agricultural production values increased 3.3% and 8.4% respectively. Agricultural water usage decreased 0.8% and 0.6%, respectively, compared with initial values. In turn, GRP increased by approximately 1.5 and 3 times compared with the amount of subsidies received. From these results, Cases 3 and 4 were considered effective policies to achieve both environmental and economic benefits. In all cases, though GRP decreased in 2050 compared with the base year, the main reason is population decline. Furthermore, despite the decreased overall GRP, per capita GRP increased in all cases other than the base year. From this, we can conclude that stemming population decline will bring about increases in total GRP.

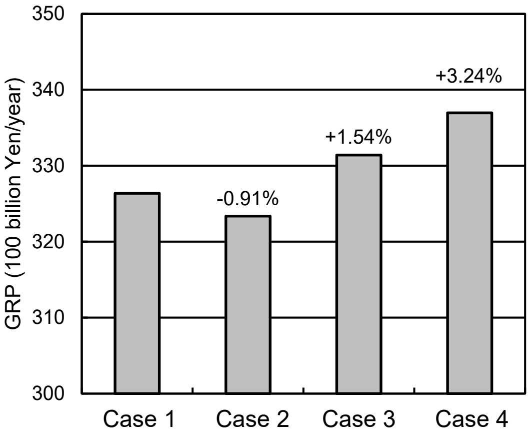

Figure 5. GRP of each case in 2050 and percentage rates as compared with Case 1

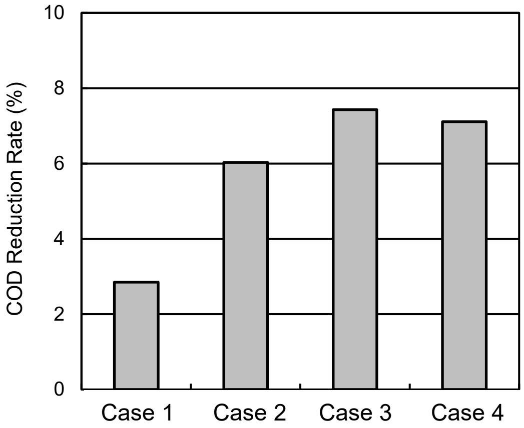

Figure 6. Reduction rates of COD load of each case in 2050 compared with base year (2005)

Figure 6 shows reduction rates of COD load for each case in 2050 compared with the base year in order to demonstrate the success of the proposed environ-mental measures. COD load decreased approximately 3% even in Case 1, which did not impose intentional environmental measures. This is also because of population decline, and per capita COD was the same as the initial value. On the other hand, the reduction rate of COD load increased 6% to 7.5% from Case 2 to Case 4. These cases were estimated as offering effective environmental-protection policies. However, it is difficult to bring about such improvements solely through hu-man actions. Thus, more drastic measures are necessary to significantly improve the target area's water quality.

6. Concluding remarks

In this study, we constructed a dynamic environment-economic model to evaluate regional economy and water-environment policies for the Toyogawa Basin in consideration of regional characteristics. Specifically, we analyzed regional economic and environmental data for the Toyogawa Basin and constructed a whole-system model to elucidate the interaction between the regional economy and the water environment in the basin, as the devised model describes the area's socio-economic activities and their impact on the area's water environment. The analysis encompassed the option of vegetable cultivation factory systems, a high-value-added agricultural system, as a choice of environmental improvement technology. Then using this model, we analyzed the relationship between the regional economy and water environment and estimated the impacts of the regional economic activities on the water environment in the Toyogawa Basin. Finally, we evaluated the regional economic and water-environment policies in the basin via a simulation analysis using the developed model.

The analysis results show that the introduction of advanced agricultural facilities is more effective than other policies, as they are projected to decrease pollution load by approximately 7% compared with initial values and further increase GRP by 1.5% to 3% compared with current policies. However, the effects will not be significant in everyday terms. Moreover, from the viewpoint of water resources management, these policies will be able to reduce agricultural water needs by only 0.6%–0.8%. Therefore, we have to conclude that benefits cannot be expected for the flow management of rivers or the habitat improvement of freshwater aquatic organisms.

We considered the effectiveness of advanced agricultural facilities foremost as a preliminary specific positioning. However, radical improvements are not expected to stem from only adding a single change in isolation, regardless of whether that technique meets local characteristics or not. Thus, it is important to clarify the real-life impact of proposed policies as well as determine what policies are effective in practice in order to combine many element organically a unique combined solution that can best meet local characteristics and challenges.

References

Aichi Environment Department water ground Environment Division (2006) 2005 fiscal year water quality survey of public waters and groundwater result, digital data.

Aichi Construction Department Sewer Division: Sewer of Aichi HP, website, (URL: www.pref.aichi.jp/gesuido/), Final accessed date: 6/20/2014

Aichi Prefectural life part Statistics Division (2006) 2006 fiscal published Aichi Statistical Yearbook, digital data

Aichi Prefectural life part Statistics Division (2010) 2005 Aichi industry input-output tables, digital data

East Mikawa Development Council (1994) Regional and Urban Plan for East Mikawa Area (in Japanese)

Esaki K (1992) On the Impact Given by the Water Supply of Toyogawa Irrigation Canal for Local Farm Households Income and Agriculture Management. Bulletin of the Faculty of Agriculture, Meiji University 95: 37-60

Institute of Regional Research of Chubu (1998) Economy and Society of East Mikawa 6, Aichi University

Makino Y ed. (1997) Toyokawa Water and Atsumi Village, Iwata Sho-in (in Japanese)

Matsukura G, Kokugo O, Higuchi Y and Tanaka Y (1998) Environmental Issues of East Mikawa, Okumikawa Shobo (in Japanese)

Ministry of the Environment (2006) Environmental White Paper (2006 fiscal year edition), pp.280

Ministry of Land, Infrastructure and Transport Chubu Regional Development Bureau Toyohashi River Office (2012) Toyogawa river maintenance management plan, digital data

National Institute of Advanced Water Resources Agency Toyogawa-yosui General Division: Toyogawa-yosui General Division, web site (URL: www.water.go.jp/chubu/toyokawa/), Final accessed date: 6/20/2014

Public Interest Incorporated Orchestra corporation Higashi Mikawa Area Studies Center (2009) 2012 fiscal year research study commissioned business report, pp.204

Sakatou K, Yamasaki S and Konno A (1990) A Study of the Water Demand and Land Use of Toyogawa Waterway, Papers on City Planning 25: 133-138 (in Japanese)

Shibusawa H and Yamaguchi M (2014) Evaluating the Social and Economic Impacts of the Water Resources in the Toyogawa Basin. The lark hill, Toyohashi University of Tech-nology , 36: 45-60

Yamaguchi M and Shibusawa H (2006) A Comparative Analysis of Water Resources and Regional Economic Structures in East Mikawa. Studies in Regional Science, 35 (4):1007-1020