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Study on synthetic evaluation of lakes water quality improvement policies in Wuhan City in China

Xuebo Zhan, Jingjing Yan, Yoshiro Higano, Huanzheng Du

Abstract:

Wuhan City is located in the central part of China, which is an import foothold of the transportation, manufacturing industry, commerce and education in China. Chinese government appointed Wuhan City as a national pilot reform area of resource-saving and environmentally friendly society at the end of 2007. There is a great deal of fresh water resources in Wuhan City, and Wuhan City is known as “the city with 100 lakes”. However, about 60% of the lake water resources have become seriously polluted in Wuhan City.

The most important reason for water degradation of Wuhan City is the imbalance between rapid economic development and the environment load capacity. In this study, we raised synthetic policies to reduce amount of lake water pollutants and realize the harmonious development between regional economy and water environment.

In this paper, we focused on three contamination materials (COD, T-N and T-P) and constructed a model from environmental load, socio-economy and water quality improvement policies. We performed optimization simulation based on linear programming to maximize gross regional production (GRP) and reduce environmental load, and finally we suggested proper policies to improve water quality in this area.

Key words:

Environmental policy, lakes water quality improvement, Modeling, Simulation

1. Introduction

Wuhan is the capital of Hubei province, People's Republic of China, and is the most populous city in central China. Because of the economic prosperity, Wuhan city had been called "Chicago in east Asia" since the latter half of the Qing dynasty. Nowadays, Wuhan is an important center for economy, trade, finance, transportation, information technology, and

education in Central China. Its major industries include optic-electronic, automobile manufacturing, steel manufacturing, new pharmaceutical sector, biology engineering, new materials industry and environmental protection.

Hubei Province has been positioned as the transportation and industrial "hub" of central China. Given its unique geographic importance to implement China's "Central Rise Strategy", in December 2007, the State Council officially approved Wuhan together with its neighboring city circle and Changsha, Zhuzhou and Xiangtan city group of Hunan Province to become a nation-level reform and demonstration zone for "Two-oriented Society". The state policy is a strong stimulus for the area to find an innovative "green" road in the progress of fast industrialization and urbanization. However, the scarcity of successful pilot projects in Hubei to demonstrate "resource-saving and environment-friendly society" as well as imbalance between accelerated economic boom and deteriorating environmental conditions continuously pose pressing challenges for the society transformation.

Some researches of China and Japan were investigated in this study. Some typical research related to this study as follows.

There are many researches to lakes environmental problems of Wuhan City which from single respects. The relation between the development of the city and the transition of lakes in Wuhan city has been attracted in some researches such as Liu [1] and Zeng [2]. They focused on how the change in the land use influence to lakes in Wuhan City, and suggest to solve the reduction problem of the area of lakes by the administrative management and the law. Most of the other researchers are focused on the situation of chemical feature of lakes water pollutant such as Song [3] and Hu[4]. In study of Yan [5], the costs of the construction of the sewerage system for Wuhan City and the operation and maintenance has been simulated it by the price enactment model. The result shows that the drainage charge will increase greatly according to the increase of population in Wuhan City.

In Japan there are many studies integrates environmental problems and the socioeconomic activity such as Higano [6][7], Takagi [8], Hirose [9] and Nakamura [10]. Higano evaluates the policy that achieving purpose under the given restriction condition to solve problems related to socioeconomic activities and the environmental load. In study of Takagi et al. Spatial Computable General Equilibrium (SCGE) model are the used to evaluate the water

quality improvement policy.

In Hirose's study linear optimization simulation models are used to solve the eutrophication problem of Kasumigaura Lake, and optimization simulation is clarified effective technique meet the situation. Nakamura proceeded with Hirose's study to divide Kasumigaura Lake into several blocks to focus on the form of pollutants inflow.

After consideration of the local situation and latest study results in Japan, this study aim to build a comprehensive evaluating system to evaluate the lakes water improvement policy in Wuhan city. The model of this study has imitated the model in existing studies of Higano and Hirose. However, the reliability of adapting those existing model to Chinese city are not verified because of regional difference. So, in this study we modeling the emission structure of the water pollutant caused by the socioeconomic activity of Wuhan City, constructing the optimize simulation model that can identify the trade-off between the emission restriction target and the amount of regional total production, and evaluating the effectiveness of a variety of lakes water quality improvement policies.

In this paper, we focused on three contamination materials (COD, T-N and T-P) and constructed a model from environmental load, socio-economy and water quality improvement policies. We performed optimization simulation based on linear programming to maximize gross regional production (GRP) and reduce environmental load, and finally we suggested proper policies to improve water quality in this area.

2. Simulation Model

2.1 Classifications about target area

Because of the complicated basin structure, it's unable to divide the Wuhan city by river and sub-basin, so we divide the target area by administrative district in Wuhan city.

Table1. Classification of the target area

No.	District
1	Huangpi
2	Dongxihu
3	Caidian
4	Hannan
5	Jiangxia
6	Hongshan
7	Jiang'an
8	Jianghan
9	Qiaokou
10	Hanyang
11	Wuchang
12	Qingshan
13	Xinzhou

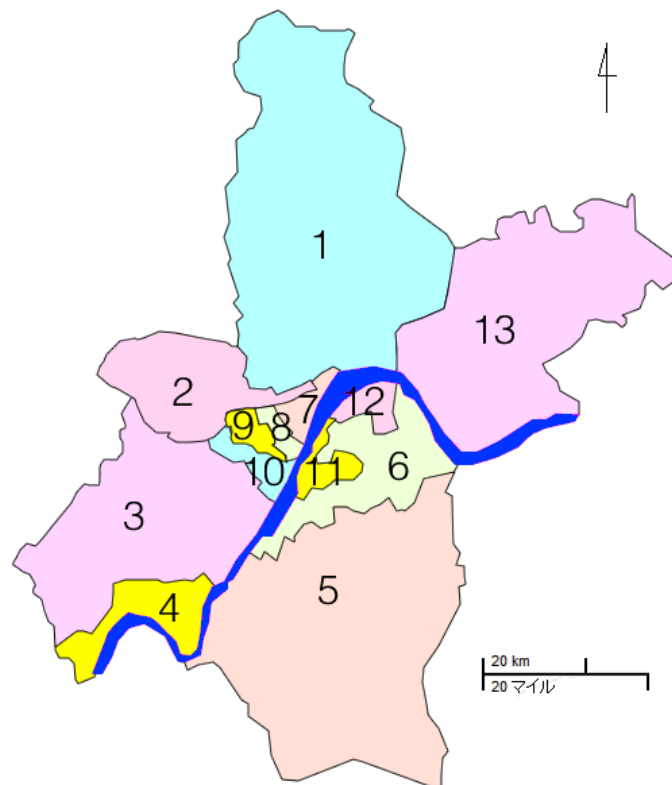


Figure1. Administrative district of Wuhan city[11]

Considering the condition of Wuhan city we divided household waste water treatment into 2 types: sewage plant and untreated water. And we divided land use and industry as follow. The pollutants measured in this study included three water pollutants, T-N (total nitrogen), T-P (total phosphorus) and COD (chemical oxygen demand).

Table2. Classification of household waste water treatment system, land use and industry

Index	Facility	Index	Land Use	Index	Industry
1	Sewage Plant	1	Arable Land	1	Farming Industry
2	Untreated waste water	2	Paddy Field	2	Stockbreeding Industry
		3	Forest Land	3	Fishery
		4	Urban Area	4	Manufacturing Industry
		5	Land For Other Use	5	Other Industries

3. Model Structure

3.1 Water pollutant load of lakes in Wuhan city

$$Q(t) = r_i(t) + Q^M(t) + Q^P(t) + Q^R \quad (1)$$

$Q(t)$: total net load of water pollutant of the lakes at the time t .

$r_i(t)$: load of water pollutant that emitted by socioeconomic activities in area i .

$Q^M(t)$: load of water pollutant by fisheries.

$Q^P(t)$: water pollutant discharged by sewage plant.

Q^R : water pollutant from rainfall that flows into the lakes.

(2) Water pollutant that emitted by socioeconomic activities in Wuhan city

Water pollutant that emitted by socioeconomic activities in Wuhan city was composed of pollutants from households, non-point source and point sources

$$r_i(t) = Ez_i(t) + GL_i(t) + Px_i(t) \quad (2)$$

E : pollutant emission coefficient of sewage plant.

z_i : population that uses sewage plant in area i .

G : coefficient of water pollutant emitted in each land use.

$L_i(t)$: area i of land use that emitted pollutants into lakes.

P : coefficient of water pollutant emitted by each industry.

$x_i(t)$: production of industry in area i .

(3) Load of water pollutant by fisheries

Fishery industry emits water pollutant directly into lakes, so we treat it separately. The load water pollutants emitted by fisheries are decided by production.

$$Q^M(t) = P^3 x^3(t) \quad (3)$$

P^3 : coefficient of water pollutant emitted by fisheries.

$x^3(t)$: production of fisheries in area i .

(4) Water pollutant discharged by sewage plant

$$Q^P = E^1 \sum z_i^1(t) \quad (4)$$

E^1 : pollutant emission coefficient of sewage plant l .

$z_i^1(t)$: population that uses sewage plant l in area i .

(5) Water pollutant from rainfall that flows into the lakes

$$Q^R = \Phi \sum L_l \quad (5)$$

Φ : coefficient of water pollutant discharged by rainfall.

L_l : area of lakes in Wuhan city.

3.2 Treatment policy for water pollutant by household

As the treatment policy for water pollutant by household, the construction and maintenance of sewage system are suggested. By this policy the population, the scale of government finance, the amount of user of sewage system in Wuhan City was calculated, then we know financial budget for treatment policy for water pollutant by household.

(1) Population of administrative district of Wuhan city

$$z_i(t + 1) = z_i(t) + \Delta z_i \quad (6)$$

Δz_i : change of population.

(2) Financial budget of administrative district

The scale of government finance of the area is proportional to the population.

$$R_i(t) = \rho_i z_i(t) \quad (7)$$

$R_i(t)$: scale of financial budget.

ρ_i : financial budget for a resident in area i.

(3) Amount of sewage treatment facility user

The total of each sewage treatment facility user is equal to the population of the administrative district.

$$z_i(t) = z_i^1(t) + z_i^2(t) \quad (8)$$

1= sewage system, 2= untreated waste water.

(4) Alteration of sewage treatment facility user

An increase in the drainage employee entrance is decided by investing the administrative area in each facilities.

$$\Delta z_i(t) \leq \Gamma_i i_i(t) \quad (9)$$

$i_i(t)$: investment of sewage treatment facility construction.

Γ_i : parameter of sewage treatment facility construction.

(5) Financial budget of sewage treatment facility construction

$$k_i(t + 1) = k_i(t) + i_i(t) \leq TB_i \quad (10)$$

$k_i(t)$: financial budget of sewage treatment facility construction.

TB_i : financial budget of Wuhan city.

(6) Construction investment

The construction investment is depending on the subsidy from the country and financial budget of each administrative area.

$$I_i(t) = \left(\frac{1}{1-M_i} \right) cc_i(t) \quad (11)$$

M_i : construction subsidy ratio by country.

$cc_i(t)$: construction budget of Wuhan city.

(7) Construction budget of Wuhan city

The construction budget of Wuhan City is proportional to the scale of government finance of Wuhan City.

$$cc_i(t) = \xi R_i(t) \quad (12)$$

ξ : parameter.

(8) Management and maintenance expense

Wuhan City bears for the management and maintenance expense of the sewage treatment facilities. It is proportional to the scale of government finance.

$$mc_i(t) = v R_i(t) \quad (13)$$

$mc_i(t)$: management and maintenance expense.

v : parameter.

(9) Financial restriction

$$I_i(t) + mc_i(t) \leq \omega R_i(t) + s_i^1(t) \quad (14)$$

ω : ratio of household waste water treatment policy.

$s_i^1(t)$: subsidy of household waste water treatment policy.

3.3 Treatment policy for water pollutant by non-point sources

It is important to understand the land use situation of the object area on the characteristic (area and usage) for the non-point sources. Here, we tries to investigate the change in the amount of the non-point source load by investigate the change in the land use.

(1) Area of land use

$$\bar{L}_i = \sum L_i^k(t) \quad (15)$$

\bar{L}_i : area of administrative district i.

$L_i^k(t)$: area of land use k in administrative district i.

(2) Conversion of land use

The land use change increases and decreases by converting each land use.

$$L_i^k(t+1) = L_i^k(t) + \sum_{k \neq l} L_i^{lk}(t) - \sum_{l \neq k} L_i^{kl}(t) \quad (16)$$

$L_i^{lk,lk}(t)$: conversion from land use l to k.

(3) Farmland reduction measures

$$L_i^{k5} \geq \lambda^k s_i^m(t) \quad (17)$$

λ^k : parameter.

(4) area of land use of urban area and other usage

$$L_i^{54}(t) \geq \gamma \Delta z_i(t) + \varphi^4 \Delta i_i^{4p} + \varphi^5 \Delta i_i^{5p} \quad (18)$$

γ : demand coefficient of housing.

$\varphi^{4,5}$: demand coefficient of business.

$\Delta i_i^{4p,5p}$: expansion production investment of manufacturing and of other industries

(5) area of land for other use

$$L_i^5(t+1) = L_i^5(t) + L_i^{15}(t) + L_i^{25}(t) - L_i^{5p}(t) \quad (19)$$

3.4 Treatment policy for water pollutant by manufacturing industry

(1) Production restriction

The level of production depends on the capital accumulation. In agriculture, the farmland is considered to be the capital.

$$x_i^n \leq \alpha^n k_i^{np}(t) \quad (20)$$

α^n : coefficient of production restriction

n=11: farming in arable land

n=12 : farming in paddy field

n=2 : stockbreeding industry

n=3 : fisheries

n=4 : manufacturing industry

n=5 : other industries

(2) Capital accumulation and production amount adjustment

The capital accumulation is decreased by the subsidy, and the amount of production is adjusted. As a result, pollutant load is reduced.

Agriculture

$$k_i^{np}(t) = k_i^{np}(t-1) - d^n x_i^n(t-1) + i_i^{np}(t) - \theta^n L_i^{nz}(t) - f^n s_i^m(t) \quad (21)$$

Other industries except agriculture

$$k_i^{np}(t) = k_i^{np}(t-1) - d^n x_i^n(t-1) + i_i^{np}(t) - f^n s_i^m(t) \quad (22)$$

$k_i^{np}(t)$: the production capital accumulation of each industry

$i_i^n(t)$: production investment of each industry

d^n : depreciation ratio of each industry

$s_i^m(t)$: subsidy to each industry

θ^n, f^n : parameter

3.5 Total treatment policy cost

Here, the total lakes water quality improvement measures cost of the Wuhan City whole is calculated.

$$y(t) = s_i^l(t) + \sum_i \sum_m s_i^m(t) \quad (23)$$

$y(t)$: lakes water quality improvement policy cost

3.6 Economic indicator

(1) Flow balance in commodity market

The amount of production of each industry follows flow balance in commodity market.

$$x(t) \geq Ax(t) + C(t) + i^P(t) + B^s i^1(t) + e^{(t)} \quad (24)$$

$x(t) = \sum_i x_i(t)$: column vector of the total production of each industries.

$i^P(t) = \sum_i i_i^P(t)$: column vector of the total investment of each industries.

A : input-output coefficient matrix.

$C(t)$: total consumption at time t .

B^S : column vector of the coefficient that induced production in industry by construction of sewage plant.

$e^{(t)}$: column vector of net export.

(2) Restriction of consumption

$$C(t) \geq H \sum_i z_i(t) \quad (25)$$

H : column vector of the consumption coefficient

(3) Restriction of export

$$e_{\min} \leq e^{(t)} \leq e_{\max} \quad (26)$$

e_{\min}, e_{\max} : maximum and minimum of net export

(4) Gross regional production

The gross domestic production (GDP) of Wuhan city is considered as the gross regional production (GRP) in this model.

$$GRP(t) = vx(t) \quad (27)$$

v : row vector of added value

3.7 Objective function

The quantity of pollutant that flows in the lakes of the city been set under the target value and the maximization of GRP is requested that fills the restriction condition.

$$\max GRP(T) \quad (28)$$

$$\text{subject to } Q(t) \leq Q^*(t) \quad (29)$$

$Q^*(t)$: target value of pollutant emission

4. Conclusion

The conclusion of this study includes the following.

1. Based on the previous study that related to the lakes water quality management of the China and Japan, we analyzed the feature, approach and the result of those study, and the lack point was examined. To found the comprehensive evaluation system as our target has been clarified.

2. The distribution and the feature of the water system in Wuhan city were analyzed. We found that it is difficult to analyze every basin in Wuhan city, so the approach that to control the gross pollutant emission of the Wuhan city is considered for this study.

3. According the analyze on the population, land use and social economy of the city[12], the economic and population of Wuhan city will growing rapidly, and the land use of the city will be advancing. in the future large amount of population flow in is considered by the promotion policy of the government, and an advanced land use and advanced economic growth are expected.

4. The source of the pollutant emission was classified, and the amount of the pollutant emission emitted by the each source was calculated [13][14]. According the result, in the year of 2007, the T-N, T-P and COD emission were 8,016t, 410t, and 17,819t, because of increase of population and the delay of sewage plant construction. In industry system, the emission of T-N, T-P and COD were 8,796t, 1,572t, and 21,537t, high production of agriculture, livestock industry, and the fishing industry which belongs to primary industry with highly emission factor. In case of non-point source system ,the emission of T-N, T-P and COD were 5,611t, 287t, and 16,560t.

5. As the proposal of this study, to promote the construction of the advanced waste water processing facilities to the household system, to give the subsidy to building waste water treatment facilities and the drain recycling facilities to the manufacturing industry, to control the use of the chemical fertilizer to agriculture are considered. According those policies, the achievement of sustainable social development that unites economic development of Wuhan City to the lakes environmental preservation is expected.

Because the model in this study quotes a lot of models from existing study, it is hard to apply to the situation completely of local region in Wuhan city. And the social economic of

Wuhan city will grow rapidly as well as China economy. It is necessary to update latest information into this study when the study is continued. And in addition, use this study as a foundation, add various conditions such the economic policies, activity of the air and fluvial, emissions trading, environment tax etc. to enhance the model, and make the lakes water quality improvement policy of Wuhan city to become concrete is expected.

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