Sea-Land Integrated Pollution Control Mode applied to Beidaihe Offshore Area

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Abstract

A Sea-Land Integrated Pollution Control Mode(SLIPCM) is extremely needed as the Beidaihe offshore area experiences the deterioration of water environmental quality and degradation of ecosystem service functions. In this study, a retrospective analysis was used to review the total discharge amount of major pollutants and quality of water environment over the past five years. And it further identified the major water environmental problems and screened out the primary pollution sources. According to lower level of socio-economic development and less power of regional pollution control within the catchment, a set of practical targets regarding freshwater and marine environment protection were made out. Furthermore the SLIPCM was proposed to meet above targets and countermeasures were presented in three dimensions, namely non-point source pollution control, point source pollution control, and water ecological protection and restoration. Moreover, a SWAT model was established to predict the SLIPCM performance in three scenarios. The results showed that the effect of sea-land integrated pollution control scheme was the best and almost can meet the Ⅰ class of water quality standard.
Keywords: offshore, retrospective analysis, SLIPCM, SWAT, Beidaihe

1 Introduction

In recent years, marine and freshwater in the Beidaihe offshore areas have been heavily polluted with the increasing of land-source pollutants. Part of the ecological and economic service functions fell sharply, which severely restricted the development of economy（Li *et al*.,2008;Liu *et al*.,2013）. Currently, the pollution control in offshore areas focuses on either the land-source pollutants reduction or the end treatment of marine pollution, while ignoring the essence of offshore pollution. In the meanwhile, the implement effect is not obvious. Sea-Land integrated pollution control mode is based on the offshore pollution generation chain system, which consists of pollution source, pollution transportation, pollution acceptance, pollution field and pollution effect(Wang *et al*.,2001). It is a overall process pollution control mode, which reflects the geographical spatial linkage effect of pollution and the generation essence of offshore pollution, namely the space-shifting of economic activity externality. Moreover, its implement effect proves to be good and it is a effective way to improve the environmental quality in offshore areas.

In this study, a retrospective analysis method was used to screen out the major environmental problem and analyse the main reasons in Qinhuangdao offshore areas. Furthermore, the reduction rate of pollution sources were set and the framework of sea-land integrated pollution control countermeasures was made out, which mainly according to the level of socio-economic development in all zones and the state of water quality in all basins. Finally, a SWAT model was established to predict implement effect in three scenarios, namely non-point source pollution control scheme, point source pollution control scheme, and comprehensive pollution control scheme.

2 Materials and Methods

2.1 Study area

The main catchment city of Beidaihe offshore areas is Qinhuangdao. It is located in the east of Hebei province, adjacent to Bohai in the south, in 118°33'～119°51'E,39°23'～40°37'N. It belongs to the warm temperate semi-humid continental monsoon climate. The whole year features with rainless, drought and constant warmer. The basin area above 30 km^2 is 51 rivers, above 100 km^2 is 21 rivers. There are 15 rivers into the Bohai sea such as Luanhe river, Yanghe river, Daihe river,Yinmahe river, Shihe river. Yinmahe river and Man-made river are heavily polluted in Qinhuangdao.

In 2011, its permanent population is 3.0062 million, the GDP is 106.403 billion.The industries are mainly distributed in Lulong county, Changli county and Qinglong county. It features with ferrous metal minerals mining, agricultural and sideline food processing, and non-metallic mineral product. Land-source pollutants are the main reason of pollution in offshore areas, especially urban living pollutants and livestock breeding pollutants. In all kinds of marine pollution sources, the mariculture pollution source is the largest contributor to the total nitrogen and total phosphorus.

2.2 Materials

In retrospective analysis, the data of pollution source and water environment quality is from Qinhuangdao city environment condition bulletin, Qinhuangdao city marine condition bulletin, the 12th five-year plan of Qinhuangdao city environmental protection, Qinhuangdao city sewage outlet into the sea monitoring report .

Reduction rate setting mainly refers to the water pollution prevention plan of key water basin(2011-2015), the overall planning of environmental protection in Bohai sea,the 12th five-year plan of Qinhuangdao city environmental protection, the implementation scheme of Bohai sea environmental protection in Hebei province.

In constructing SWAT model, Qinhuangdao DEM(30*30), Qinhangdao land-use digial map(shp), Qinhuangdao soil type map(shp), Hebei province meteorological data(1989-2011) and Qinhuangdao hydrologic data（2005-2012）were used.

2.3 The retrospective analysis Method

Current research and application of retrospective analysis method are mainly divided into verified retrospective analysis and cumulative retrospective analysis. This study focuses on the former, which is also called post-project environmental impact analysis. It is a research and management process, in order to check the actual environmental impact and the validity of mitigation measures, and also to supervise the activities and behaviors that may damage to the environment （Zhao and Yan,1997）.

2.4 Sea-Land integrated pollution control mode

The sea-land integrated pollution control mode was first proposed by Wang Maojun in 2000(Wang and Luan,2000; Wang *et al*.,2001).The offshore areas has the the diversity of coastal zone resources, natural geographical characteristics of sea and land interaction, along with significant socio-economic characteristics. These composite characteristics form the basis of a marine pollution generation chain system which consists of pollutants generation system, pollutants transport system, pollutants acceptance system, marine pollution field and marine pollution effect, shown in Figure1. The pollutants generation system is the regional economic system. The pollutants transport system includes land migration and marine migration, which consists of sewage rivers, piping and other drainage ways. Especially in urban areas, space configuration of sewage outlets directly affect the degree of pollution and regional differences. Pollutants acceptance system consists of land and marine acceptanc system. Pollutants that transport into the offshore areas will cause a series of physical, chemical and biological process, then may lead to the structure and function damage of environment system. Moreover, some abnormal areas namely marine pollution field will occur and interact with the whole socioeconomic system. Finally, a series of social, economic and environmental problems are triggered, namely marine pollution effect.

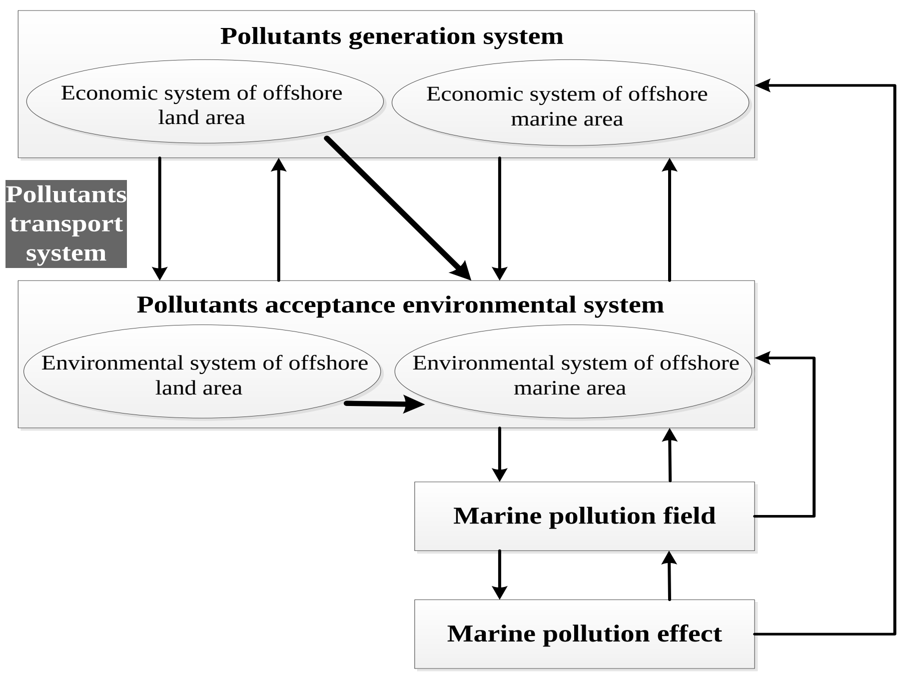

Figure 1. The mechanism of sea-land integrated pollution control mode.

2.5 SWAT model

The Soil and Water Assessment Tool (SWAT) is a hydrologic/water quality model developed by United States Department of Agriculture-Agricultural Research Service(USDA-ARS)(Arnold et al.,1998). It is a continuous time, spatially semi-distributed model. The objective in model development was to predict the impact of management decisions on water, sediment and agricultural chemical yields in river basins in relation to soil, land use and management practices. To satisfy the objective, the model is (a)physically based;(b)uses readily available inputs;(c) is computationally efficient to operate on large basins in a reasonable time; and (d) is continuous in time and capable of simulating long periods for computing the effects of management changes(Santhi,2001). It is suitable for large watershed and can model in insufficient data areas, especially with effectiveness in modelling non-point pollution.

SWAT uses a command structure for routing runoff and chemicals through a watershed similar to the structure of HYMO(Williama and Hann,1973)**.**Commands are included for routing flows through streams and reservoirs, adding flows, and inputting measured data on point source (Santhi,2001;Arnold *et al*.,1998).Using the routing commands have been developed to allow measured and point source data to be input to the model and routed with simulated flows.

SWAT model contains 701 equations and 1013 intermediate variables, along with complex physical mechanism. The subbasin components of SWAT can be placed into eight major components — hydrology, weather, erosion/sedimentation, soil temperature, plant growth, nutrients, pesticides, and land management. Structurally, it can be divided into hydrology model, soil erosion model and waste load model. This study mainly on the hydrology model and waste load model of SWAT. The hydrologic model is based on the water balance equation in the soil profile where the processes simulated include precipitation, infiltration, surface runoff, evapotranspiration, lateral flow and percolation(Bouraoui *et al*.,2005). The water balance equation is shown below.

$$\mathrm{SW_t} = \mathrm{SW} + \sum_{t=1}^{t}(R_i - Q_i - ET_i - P_i - QR_i)$$

Where SW is the soil water content minus the 15-bar water content, t is time in days, and R, Q ,ET ,P, and QR are the daily amounts of precipitation, runoff, evapotranspiration, percolation , and return flow; all units are in mm(Arnold *et al.*,1998). The watershed hydrological processes of SWAT modelling consist of land surface part of the water cycle（namely runoff and confluence slope section）and water surface part of the water cycle（namely river confluence part）. The former controls the input quality of water, soil, nutrients and chemicals in main riverway, the later determines the movement and transformation of water, oil and other materials from river network to basin outlet(Wang *et al.*,2003).

SWAT simulates the movement and transformation of nitrogen (N) and phosphorus (P) in the watershed. Basic processes simulated are mineralisation, denitrification , volatilisation, plant uptake for N, and mineralisation, immobilisation and plant uptake for P. Plants uptake of nitrogen and phosphorus is estimated using a supply and demand approach. The demand is determined daily based on the optimal N and P crop concentration for each growth stage. For the present study, default values provided by SWAT crop database (Arnold *et al.*, 1998) were used. Nitrogen and phosphorus can be lost in both particulate and dissolved forms. Additional details are given by Arnold *et al*.(1998).

3 Results and Discussion

3.1 The retrospective analysis of the water environment quality

3.1.1 The existing major problems

In the aspect of water quality in reservoirs and rivers, water quality of centralized source of drinking water was good expect that Yanghe reservoir was in the state of primary eutrophication due to algae bloom in 2007. The proportion of inferior V class of river sections decreased, shown in Figure 2, while the downstream of Man-made river and Yinma river were still severely contaminated.

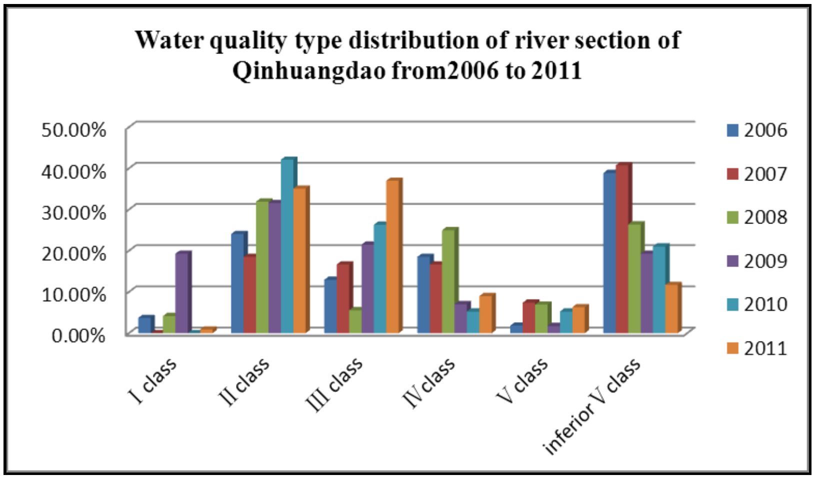

Figure 2. Water quality type distribution of river section of Qinhuangdao from2006 to 2011.
Data sources：2006-2010 Qinhuangdao city environment condition bulletin

In the aspect of water quality in offshore areas, the areas that can't meet clean sea water quality standard increased, shown in Figure3. The marine ecosystem of offshore areas was in the sub-health state, the area and types of red tide were becoming more and more, shown in Figure4. In addition that the environment of mariculture zones deteriorated, the eutrophication problem become prominent.

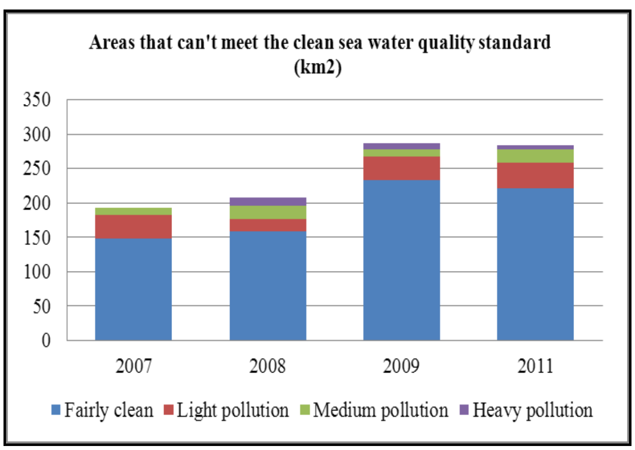

Figure 3. Areas that can't meet the clean sea water quality standard .
Data source: 2006-2011 Qinhuangdao city marine condition bulletin

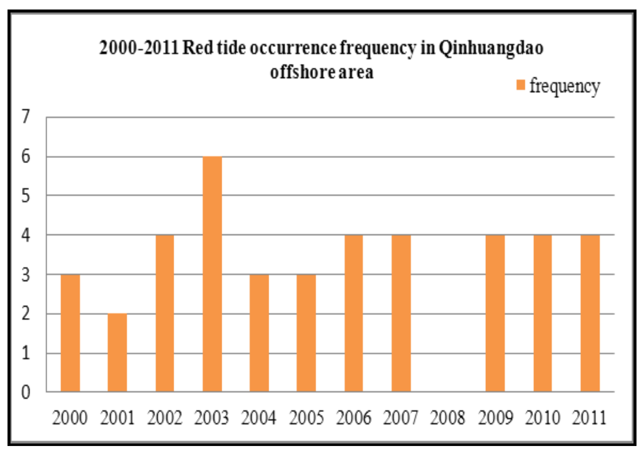

Figure 4. 2000-2011 Red tide occurrence frequency in Qinhuangdao offshore area.
Data source:2000-2011 Qinhuangdao city marine condition bulletin

3.1.2 The analysis of main reasons

Noneffective control on land-source pollutants was the vital reason to result in pollution above. The total amount of waste water emission and discharge into the sea increased from 2008 to 2010 comparing to 2007 in Qinhuangdao, shown in Figure5. The COD almost accounts for 97% of the total, followed by nutrient and oils. Land-source pollutants have not yet been under effective control.

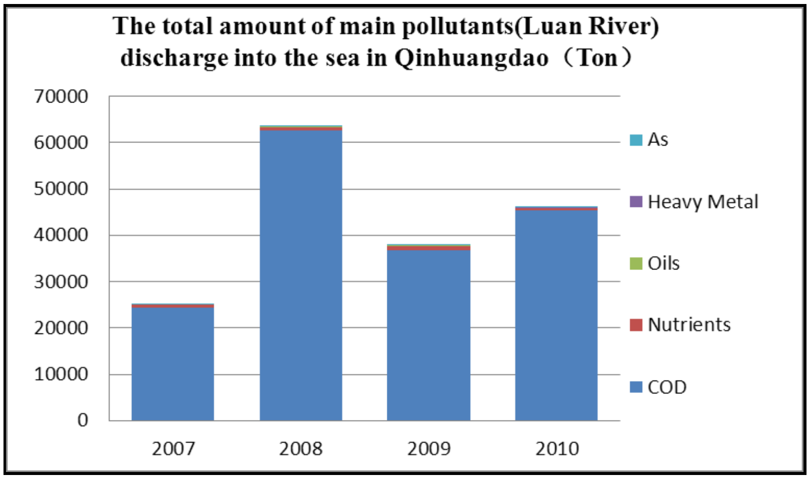

Figure 5. The total amount of main pollutants discharge into the sea （Luanhe）in Qinhuangdao.
Data source：2006-2010 Qinhuangdao city environment condition bulletin

Over standard discharge problems and the lack of effective control measures especially on nitrogen and phosphorus were another important reason. According to 2007-2011 Qinhuangdao city sewage outlet into the sea monitoring report, the excessive discharge ratio of all sewage outlets increased year by year, respectively 55.6%, 66.7%, 75%, 87.8% from 2008 to 2011. In the meanwhile, the excessive discharge problem of total phosphorus was obvious, respectively 56.6%, 63.0%, 77.8% of the sewage outlets had this problem from 2009 to 2011. Moreover, the proportion of nutrients in pollutants total amount increased and sewage factory lacked of corresponding treatment measures, which meant the possibility of water eutrophication greatly increase.

3.2 Reduction scheme and Pollution control scheme

3.2.1 Reduction targets setting

According to level of socio-economic development in all zones, based on the pollutants discharge condition, pollution situation in all basins and related environmental protection planning above, a series of reduction targets were set.

For the non-point source in rural areas, the reduction from 20% to 70% was set, show in Figure 6. Five types of pollutants were taken into account, namely the rural life, solid waste, fertilizer runoff , livestock and poultry breeding , water and soil loss, the average reduction rate distribution is shown in Figure 6. The urban non-point source pollution average reduction rate is shown is Figure 6. In Figure 6 and Figure 7, Z1 is Haigang district, Z2 is Shanhaiguan district, Z3 is Beidaihe district, Z4 is Qinglong county, Z5 is Changli county, Z6 is Funing county, Z7 is Lulong county.

For point source, the reduction from 15% to 40% was set, Figure8 is the distribution of the 50 sewage outlets discharge into the sea in all basins, Figure9 is the average reduction rate distribution of point source. In Figure8 and Figure9, R1 is Xin river,R2 is Yinma river,R3 is Shi river,R4 is Dongsha river,R5 is Qinglong river, R6 is Yang river, R7 is Xinkai river, R8 is Man-made river, R9 is Tang river, R10 is Xinkai river, R11 is Luan river,R12 is Dai river.

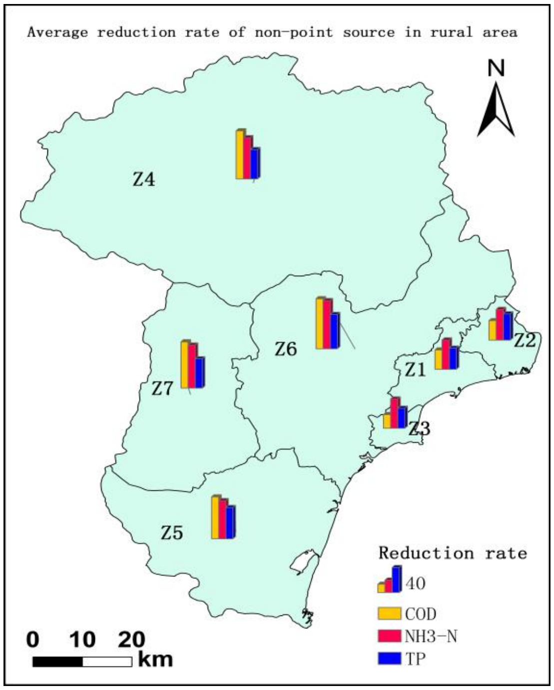

Figure 6. The average reduction rate distribution of non-point source in rural area.

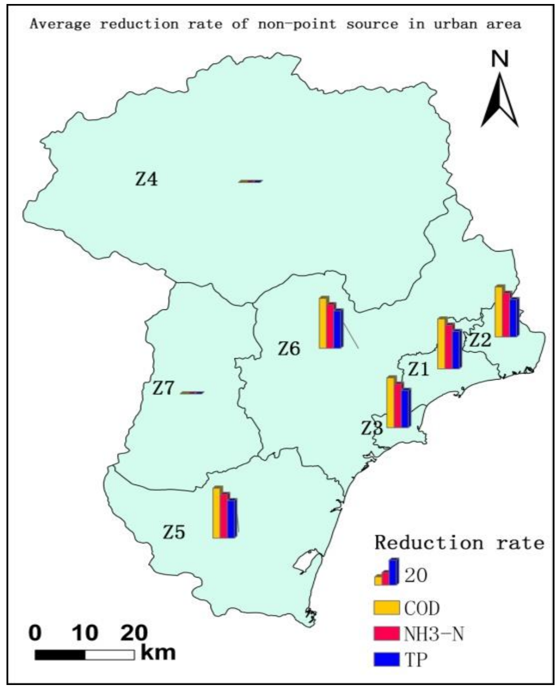

Figure 7. The average reduction rate distribution of non-point source in urban area.

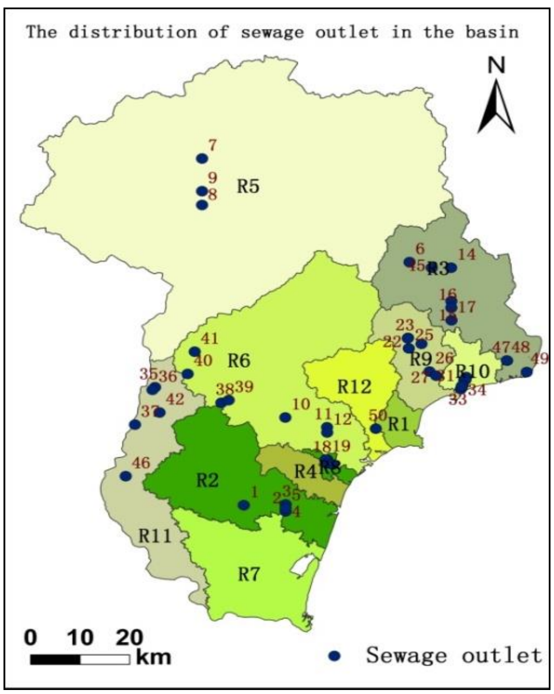

Figure 8. The distribution of sewage outlet discharge into the sea in all basins.

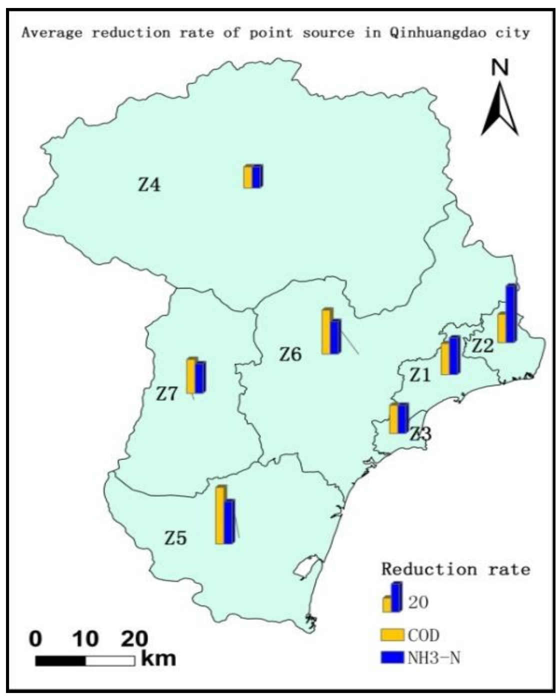

Figure 9. The average reduction rate distribution of point source .

3.2.2 Sea-Land Integrated Pollution Control Countermeasures framework

Based on the Sea-Land Integrated Pollution Control Mode mechanism, pollution control system was divided into pollutants generation system, pollutants transport system and pollutants acceptance environmental system. Pollution control countermeasures were composed of non-point source pollution control, point source pollution control, protection and restoration of the waters ecology. Moreover, the main control aspects and key control districts were screened out, shown in Figure10. In Figure, PCR is short for prior control rank.

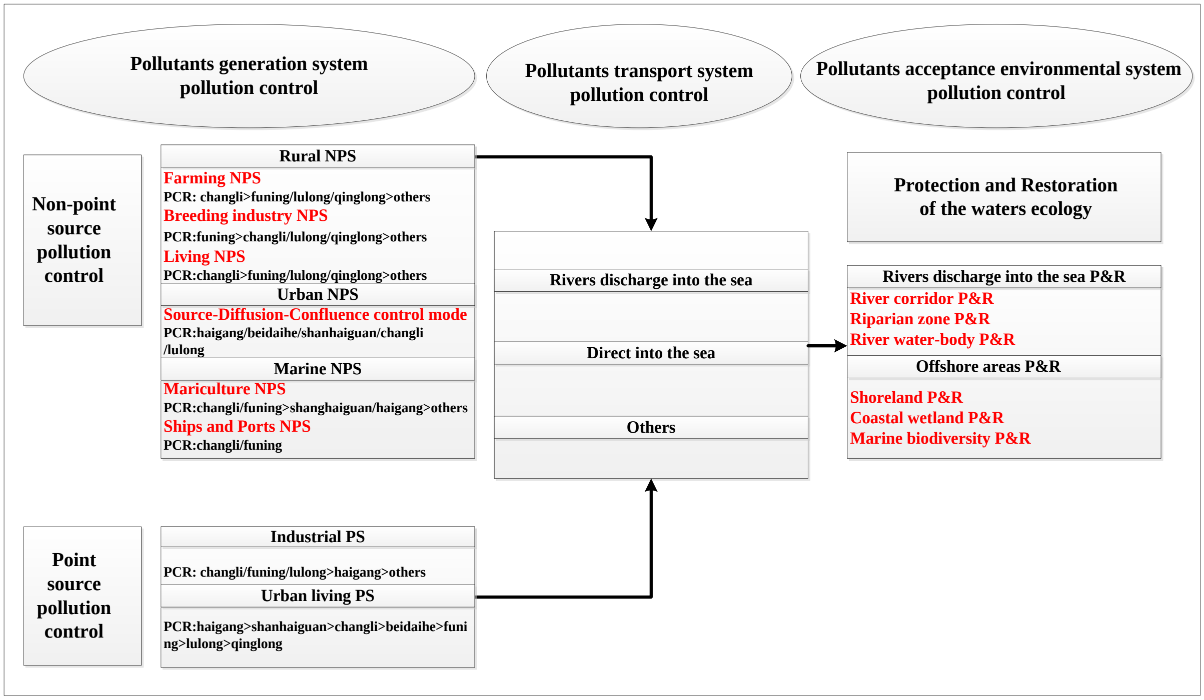

Figure 10. The Sea-land integrated pollution control countermeasures framework .

3.3 The scenario setting and model simulation

3.3.1 The scenario setting

According to the level of socio-economic development in all zones and the state of water quality in all basins, three scenarios were set to simulate and demonstrate the implementation effect of pollution control countermeasures, as shown below.

Scenario1: Non-point source pollution control

Scenario2: Point pollution source control

Scenario3: Pollution comprehensive control. Integrating non-point pollution control with point source pollution to control offshore pollution comprehensively, namely sea-land integrated pollution control countermeasures

3.3.2 The effect of SWAT model simulation in three scenarios

Comparing the simulation results of concentration with the current concentration, shown in Table1, it get the reduction degree of main pollutants, then the effect of model simulation was analysed below.

After implementing scenario 1 countermeasures. the concentration of NH_3-N reduced largely in most rivers, and the TP of R1,R4,R7,R8,R12 reduced largely. However, only the water quality of R6,R12,R9,R10,R3 can meet the requirement(GB 3838-2002).

After implementing scenario2 countermeasures, the concentration of COD in R1,R4 and R8 reduced largely, while the concentration of COD, NH_3-N and TP in R2,R3 and R10 didn't reduce obviously, this might have relation with the small proportion of point source. Only the annual average concentration of R3,R6,R9,R10 and R12 could reach the water quality standard. The COD, NH_3-N and TP of R2 was too high to meet the requirement(GB 3838-2002).

After implementing scenario3 countermeasures, the water quality of all rivers improved with different levels, and almost all met the requirement of functional zone.

Table1. The comparision of simulation concentration and current concentration .

Name	Scenario 1			Scenario 1			Scenario 1		
	NH3-N	COD_{Cr}	TP	NH3-N	COD_{Cr}	TP	NH3-N	COD_{Cr}	TP
R1	0.37	0.70	0.62	1.00	0.76	0.92	0.29	0.69	0.58
R2	1.00	1.00	1.00	1.00	0.85	1.00	0.40	0.66	1.00
R3	0.92	0.95	1.00	1.00	0.86	1.00	0.73	0.75	1.00
R4	0.25	0.36	0.39	1.00	0.76	0.92	0.16	0.35	0.35
R6	0.60	1.00	1.00	0.86	1.00	1.00	0.53	1.00	1.00
R7	0.64	0.41	0.50	1.00	0.75	1.00	0.56	0.40	0.47
R8	0.08	0.67	0.03	0.13	0.50	0.05	0.06	0.41	0.02
R9	0.63	0.90	0.90	0.03	0.90	0.54	0.49	0.73	0.81
R10	0.99	0.86	0.96	1.00	0.84	1.00	0.79	0.81	0.80
R12	0.38	0.61	0.50	0.69	1.00	0.87	0.37	0.59	0.50

3.3.3 The comparative analysis of three pollutants in three ecenarios

According to the simulation results of the three scenarios, considering present pollution situation to carry on the comparative analysis. The results of simulation concentration divided by current concentration in offshore 1 and offshore 2 are shown in Figure 11 and Figure 12, and offshore 2 is farther than offshore1.The results were all below 1.00,which indicated the main pollutants reduced to different extent in three scenarios. The comparative analysis results indicated that scenario 1 had the obvious advantages over reducing the NH_3-N and TP, scenario 2 had the obvious advantages over reducing the COD in offshore areas. After implementing the scenario three, water quality improvement effect was the best, annual average water quality of all pollutants could reach Ⅰ class of water quality standard in offshore1 and offshore2.

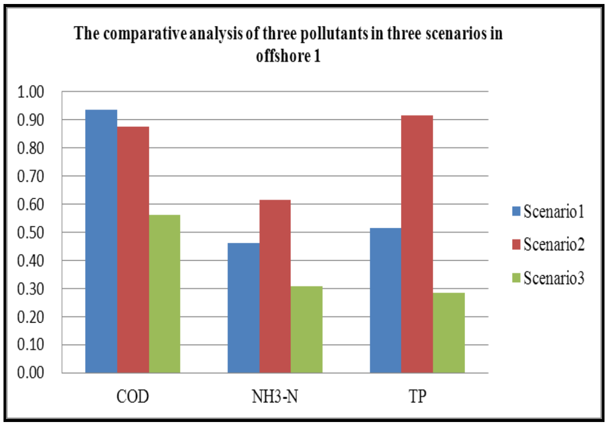

Figure 11. The comparative analysis of three pollutants in three scenarios in offshore1.

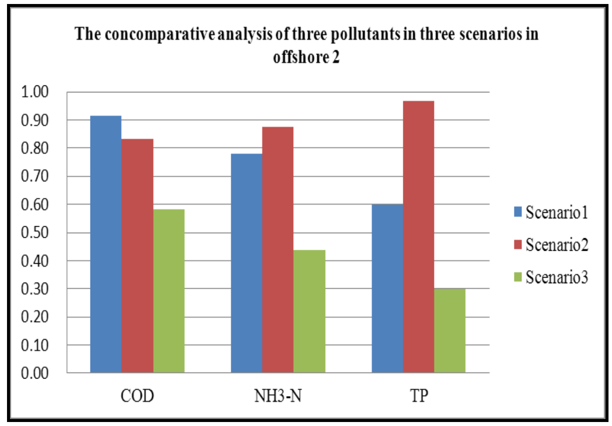

Figure 12. The comparative analysis of three pollutants in three scenarios in offshore2.

4 Conclusion

The retrospective analysis was used to the screen out the major environmental problems.The downstream of Man-made river and Yinma river were still severely contaminated. The water quality and ecosystem in offshore areas deteriorated. Areas that can not meet the water quality standard of clean sea increased. The eutrophication problem in offshore areas and Yanghe reservoir become prominent. Furthermore, the main reasons were analysed. Noneffective control on land-source pollutants, over standard discharge problems and the lack of effective control measures especially nitrogen and phosphorus were three most important reasons.

The reduction targets of non-point source and point source were set to control pollution mainly according to the economic level and pollution situation. Sea-Land integrated pollution control countermeasures framework, namely non-point source pollution control, point source pollution control and ecological restoration was made out to achieve those reduction goals.

A SWAT model was construct to model the effect of pollution control schemes in three scenarios, namely non-point source pollution control, point pollution control and pollution comprehensive control. The results showed that the effect of pollution comprehensive control (scheme 3)was the best, the concentration of three main pollutants reduced the most in all rivers and offshore areas. In the meantime, the annual average water quality of three pollutants in offshore1 and offshore2 could reach Ⅰ class of water quality standard. Therefore, sea-land integrated pollution control mode is the powerful and effective tool to improve the environmental quality in Beidaihe offshore areas.

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References

Arnold J G., Srinivasan R., Muttiah R S. and Williams J R. (1998).Large area hydrologic modeling and assessment part Ⅰ:model development. *Journal of the American Water Resources Association*,34(1):73-89.

Bouraoui F, Benabdallah S, Jrad A. and Bidoglio G. (2005). Application of the SWAT model on the Medjerda river basin (Tunisia).*Physics and Chemistry of the Earth*, Parts A/B/C,30(8): 497-507.

General Bureau of China National Environmental Protection.(2002).Environmental Quality Standard for Surface Water, GB 3838-2002, General Bureau of China National Environmental Protection, China.

Li Z.W., Cui L.T, Lin Z.J. and Xu C.X.(2008). Assessment of water quality in the sea offshore of Hebei province. *Reasearch of Environmental Sciences*,21(6):143-147.

Liu T.T., Peng Y.D. and JiM.T.(2013). Situation of environmental protection in nearshore area and strategies for sustainable development of Qinghuangdao. *Energy Environmental Protection*,27(4):12-15.

Santhi C., Arnold J G., Williams J R., Dugas W.A., Srinivasan R. and Hauck L.M.(2001). Validation of the SWAT model on a large river basin with point and nonpoint sources. *Jouranl of the American Water Resources association*,37(5):1169-1188.

Wang M.J., Luan W.X. ,Song W. and Zhao Y.J.(2001).Preliminary discussion on the sea-land integrated regulation and control of pollution in the coastal sea area. *Marine Science Bulletin*,20(5),65-71.

Wang M.J. and Luan W.X.(2000). A study on zone control and regulation of marine pollution in the coastal area of China’s yellow sea. *Marine Science Bulletin*,19(6),50-56

Wang Z.G., Liu C.M. and Huang Y.B.(2003). The theory of SWAT model and its application in Heibe baisin. *Progress in Geography*,22(1),79-86.

Williams J. R. and Hann R. W..(1973). HYMO: Problem-Oriented Language for Hydrologic Modeling — User's Manual. USDA, ARS-S-9.

Zhao D.F. and Yan L.H.(1997). The study on retrospective environmental impact assessment and its contents. *Environmental Protection of Xinjiang*, 19 (3) : 38～43.