Regional water pollution management pathways and effects under strengthened policy constraints: the case of Tianjin, China

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Abstract

In recent years, China's government has attached great importance to pollution management. In 2015, the State Council issued the “Action Plan for Water Pollution Prevention and Control”, proposing the water quality targets of 2020, and deploying 10 important tasks for water pollution reductions. As a result, provinces and cities have conducted water pollution management in order to achieve the expected goals. Although the performance of regional water pollution management directly affects the implementation of national plan, a systematic evaluation of the performance of regional water pollution management has not yet been conducted after ambitious goals were set and strengthened policy constraints were conducted. This paper constructs an evaluation index system based on DPSIR model, and evaluate the performance of Water Pollution Management (WPM) in Tianjin from five aspects as Driver, Pressure, State, Impact and Response (DPSIR). The results show that the performance of WPM in Tianjin has been commendable, resulting in an improvement from 76.15 points out of 100 in 2014 to 90.93 points out of 100 in 2018, with the score rising more rapidly from 2016 to 2018 after the regional policy was implemented. Furthermore, the management system, paths and deficiencies of WPM are analyzed. Under the constraints of River Chief System, pollutant discharge permit and discharge standards, ecological compensation agreements on water pollution and other policies in Tianjin, the effect of pollution source control is obvious, with the water quality obviously improved, and the public satisfaction levels are high.

1. Introduction

Water is needed to support both economic production and biological life. Thus, water pollution is a widespread concern around the world. Preventing and controlling water pollution is an inevitable choice especially under the current shortage of freshwater resources. Therefore, quantifying the effectiveness of water pollution management strategies and measures is a task of great significance.

Since the 1980s, China has experienced extensive economic development dominated by dramatically increased industrial activity (Zhou Y, Zhu S, He C 2017). Accompanied by a series of environmental problems such as frequent air pollution, shortage of water resources and terrible water quality, the environmental quality throughout the country has been significantly degraded, resulting in pernicious public health risks (Li Z 2018; Wang Q, Yang Z 2016). Since 2012, the Chinese government has gradually begun to pay attention to the protection of ecology and environment. This has been demonstrated in the construction of a strict policy system and rigorous punishment against high-pollution events, and gradually set off a revolution towards greener modes of industrial production.

In terms of water pollution management, the newly revised Environmental Protection Law of the People's Republic of China has been in place since 2015 (Ministry of Ecology and Environment of the People’s Republic of China 2014). Under this revised law, the responsibility system for water pollution prevention and control was improved, penalties for illegal pollution discharges were strengthened, and compliance oversight activities were expanded. In 2015, the State Council issued the “Action Plan for Water Pollution Prevention and Control” (Central People's Government of the People's Republic of China 2015), proposing the water quality target of 2020, deploying 10 important tasks and 238 specific measures for water pollution (Han D, Currell MJ, Cao G 2016). In 2017, the goal of “Winning the Battle Against Pollution” by 2020 (PRC, 2017) was set by the national government, further promoting the water pollution management process. The newly revised “Water Pollution Prevention Law of the People's Republic of China” has been implemented since 2018 (Ministry of Ecology and Environment of the People’s Republic of China 2018), in which further restriction was strengthened from the legal level. In order to reach the preset 2020 water environment quality target, the government has carried out a large number of water pollution management measures to achieve a fundamental improvement in the water pollution situation. According to China's Environmental Status Bulletin (Ministry of Ecology and Environment of the People’s Republic of China 2020), proportion of Class I-III water quality sections accounted for 74.9% in 2019, while the amount was 64.5% in 2015. It is noteworthy that China's water pollution management has achieved such good results in a short period of time. Corresponding to the strict water pollution management system at the national level, local governments have been empowered with greater responsibilities in the effort to combat water pollution. As the entities responsible for the management and enforcement of water pollution, local governments of provinces and cities actively carry out regional water pollution prevention and control work (Wu Z, Ye Q 2020). Up to now, several provinces and cities have issued water pollution prevention and control regulations (Chen Z, Kahn ME, Liu Y, Wang Z 2018), which put forward comprehensive and systematic requirements for water pollution management practices.

Due to differences in natural endowments and production structure, water resources and water pollution situations in different regions of China are varied. Among them, Tianjin, a municipality directly under the central government and a neighboring municipality of Beijing, has experienced rapid economic development and despite having relatively stringent environment requirements, while its per capita water resources are low and the availability of freshwater supplies have been quite limited. This combination of attributes makes the area well suited as a subject for more in-depth research. “Water Pollution Prevention and Control Regulations of Tianjin” was implemented in March 2016 (Tianjin Municipal People’s Congress 2016). After several revisions, it has so far covered 99 articles in nine chapters, including general principles, joint prevention and control of water pollution, protection of drinking water sources, prevention and control of industrial water pollution, urban water pollution, and agricultural and rural water pollution, prevention and disposal of water pollution accidents, cooperation in regional water pollution prevention and control, and legal liability. So far, the work has been steadily carried out and the water quality is showing a good trend (The Bureau of Water Affairs of Tianjin 2019).

Previous scholars have analyzed China's water pollution prevention and control process, laws and regulations, and water pollution control measures from the perspective of different industries (Zhai X, Xia J, Zhang Y 2017). In other studies, some scholars have selected typical cities for water pollution related research (Yuan F, Wei YD, Gao J, Chen W 2019). However, there is still a lack of research on the evaluation of water pollution management policy effects from the perspective of provinces and municipalities. It is of great practical significance to evaluate the implementation effect in terms of adjusting policies, strengthening national adjustment, and providing experiences for other regions. Tianjin, with its constrained water supply and large water pollution management burden due to its location at the mouth of the sea, is suitable for study as a typical and rapidly developing city in China.

The structure of this article is as follows: The second section introduces Tianjin's water pollution management mechanism; The third section describes the composition of DPSIR framework, further constructs an index system for evaluation of WPM based on the framework; The fourth section shows the evaluation results and the effects of WPM; The fifth section discusses the paths of water pollution management in Tianjin; and finally draws conclusions.

2. Water Pollution Management Mechanism Of Tianjin

2.1 Study area

Tianjin, lies between 116°43' E - 118°04' E and 38°34' - 40°15' N, is a municipality directly under the Central Government of the People's Republic of China and the largest coastal city in North China, is located adjacent to

Beijing, covers an area of 11,946.88 km^2, making it slightly smaller in size than the state of Connecticut, US (Fig. 1). As of the end of 2018, the resident population was 15.62 million, with a GDP of 1336.292 billion yuan (about 188.47 billion USD). In 2018, the water resources per capita in China was 1971.85 m^3 (National Bureau of Statistics 2019), meanwhile the number in Tianjin was 112.93 m^3, less than one seventeenth of the whole country, showing significant pressure both in water resources and water pollution.

* The original remote sensing images in Figure 1 were captured by the American Landsat8 satellites in April 2018.

2.2 Multi-level structure of water pollution management

Water pollution management agencies in China have a multi-level vertical structure, which extends from the whole country down to the provinces, cities, and then to the districts. In general, high-level government departments are responsible for formulating emission standards and limits, while low-level government departments carry out specific work in order to meet relevant expectations.

The Tianjin municipal government must comply with relevant national laws and arrange water pollution prevention and control work to ensure the provision of water quality for the whole city. The municipal government can formulate more stringent local standards than the national standards, once the approval were made by the National Ministry of Ecology and Environment (MEE), local standards can be implemented in Tianjin. The Bureau of Ecology and Environment of Tianjin, together with relevant municipal departments are responsible for compiling Tianjin's water pollution prevention and control plan. Furthermore, Bureau of Ecology and Environment of Tianjin allocates pollutant emission quotas for all of the 16 districts, organizes, and urges the implementation of the targets. According to Tianjin's water pollution prevention and control plan, the district governments shall formulate measures and implementation plans for improving water environment situation within their jurisdiction. After developing pollutant emission quotas, Bureau of Ecology and Environment in district governments implement planned emission controls for key water pollutants within their administrative region (Fig. 2).

Under the clear vertical management structure of water pollution, for better achievement in water pollution management, many regions in China began to establish the River Chief System, which entrusts certain management responsibilities to individual government officials (She Y, Liu Y, Jiang L, Yuan H 2019) at all levels, and linking the water pollution state with their achievements. The River Chief System is a very important innovation in water resource and water environment management. At the same time, it makes full use of supervision and assessment, so that these individuals remain accountable in a timely manner so as to achieve better results (Li J, Shi X, Wu H, Liu L 2020; Liu X, Pan Y, Zhang W, Ying L, Huang W 2020). The main tasks stipulated by the policy include:

- Strengthen the protection of water resources;
- Reasonable development and utilization of water resources;
- Strengthen the management and protection of the coastline of rivers and lakes;
- Strengthen the safety construction of flood control and waterlogging elimination;
- Implement the action plan for water pollution prevention and control;
- Strengthening water environment management;
- Strengthen law enforcement and supervision.

Article 7 of “Water Pollution Prevention and Control Regulations of Tianjin” stipulates that Tianjin shall establish a four-level river (lake) chief system. Under this system river chiefs are designed at the city, district, township (street), village levels. Tianjin government promulgated and began to implement the River Chief System in May 2017. Till July 2019, 5884 river and lake chiefs have been set up at various geographic levels.

2.3 Multi-department collaboration of water pollution management

Water pollution management touches numerous aspects of a society, its economy, and its citizens' daily lives. It is precisely because of these wide-ranging impacts that it is necessary to coordinate and dispatch pollution management measures from multiple departments.

Generally, the Bureau of Ecology and Environment (BEE) of Tianjin undertakes the core responsibilities. According to the regulations, BEE implements unified management and supervision of water pollution prevention and control measures. The main duties include: Organizing the formulation and supervision of related policies, plans and standards; Controlling the discharge of water pollution sources and reducing the discharge of pollutants; Supervision and management of drinking water sources environmental protection, etc. The Bureau of Water Affairs (BWA) of Tianjin also plays an important role, it’s responsible for the protection of water resources, manages and supervises urban drainage and centralized sewage treatment.

As for the other 12 municipal departments, they carry out correlative work within the scope of duties, providing auxiliary support for water pollution management. The detailed coordination mechanisms of industrial water pollution, urban water pollution and rural water pollution management practices are shown in Fig. 3. Among the industrial pollution management system, pollutant emissions from industrial sources are the most important indicators, which are supervised by the BEE, with other two departments paying more attention to adjusting the industrial structure and water use efficiency. Urban water pollution management focuses on sewage treatment and black and odorous water bodies, the BWA works in cooperation with the Commission of Housing and Construction and the Commission of City Management towards these matters. For rural water pollution management, the Commission of Agriculture and Rural Affairs undertakes wider responsibilities, coordinates with the BEE and the BWA. The specific contents of departmental collaboration include joint formulation of plans, mutual exchange of data, and unified implementation of actions.

3. Evaluation Methods

3.1 DPSIR framework

DPSIR is a widely recognized analytical framework, which specifically addresses a sequence of steps for analyzing environmental disturbances: Driver (D), Pressure (P), State (S), Impact (I), and Response (R) (Apostolaki S, Koundouri P, Pittis N 2019; Vannevel R 2018). The DPSIR framework was developed from the pressure-state-response (PSR) model that was initially used by the Organization of Economic Cooperation and Development in 1993 (OECD 1993). Then further improved by the European Environmental Agency (European Environment Agency 1999) and scientists to construct an integrated framework that was primarily used to assess causes, impacts, outcomes, and responses. This framework has been demonstrated to be effective in addressing environmental issues at global and sectoral scales (Ramos-Quintana F, Ortíz-Hernández ML, Sánchez-Salinas E, Úrsula-Vázquez E, Guerrero JA, Zamorano M 2018), and has been used widely in researches about water resources (Zare F, Elsawah S, Bagheri A, Nabavi E, Jakeman AJ 2019; Liu WX, Sun CZ, Zhao MJ, Wu YJ 2019), water quality (Gari SR, Ortiz Guerrero CE, A-Uribe B, Icely JD, Newton A 2018), water pollution (Apostolaki S, Koundouri P, Pittis N 2019) and water accidents (Yang Y, Lei X, Long Y, Tian Y, Zhang Y, Yao Y, Hou X, Shi M, Wang P, Zhang C, Wang H, Quan J 2020). Therefore, DPSIR framework is used here to evaluate the performance of water pollution management (WPM) in Tianjin, and the final results could truly reflect the effects of social, economic, public management and other components on water pollution management. With the coordination of society, economy and water, important foundation can be laid for sustainable development (Luo Z, Zuo Q 2019). Furthermore, clarifying Driver, Pressure, State, Impact and Response is crucial to identify shortcomings in water pollution prevention and control of Tianjin. Thus, policy implications with important value can be put forward. The details of the five components in the framework are as follows.

3.1.1. Driver

Drivers are high level factors that compel changes in the quality and availability of water in profound and fundamental ways (Liu WX, Sun CZ, Zhao MJ, Wu YJ 2019). They usually include factors relating to the productivity of the economy and the activities of society. Population growth and demand increases are the most fundamental drivers in this regard.

3.1.2. Pressure

Pressures are influences which can be exerted on water pollution and water environment management from numerous different types of human activities. These pressures usually exist in the form of consequences produced in the industrial production and household consumption process, and can be divided into water use pressure and water environment pressure.

3.1.3. State

States describe the physical attributes of the water environment at different levels of ecosystem, mainly including hydrological characteristics, water resources sustainability, water quality and other water environment factors.

3.1.4. Impact

Impacts include qualitative and quantitative indices that promote changes in water, production, life, and environment after the water environment state has played its role. Generally, socio-economic impact, ecological and environmental impact and public impact are significant factors under the framework.

3.1.5. Response

Responses are defined as management and control measures enacted to deal with multiple factors of water environment, including the driver component, pressure component, state component and impact component. It contains the most descriptive indices of governance behavior, and can be considered from the aspects of environment response and management response (Posthuma L, Backhaus T, Hollender J, Bunke D, Brack W, Müller C, Gils J, Hollert H, Munthe J, Wezel A 2019).

There is complex interaction between the five elements of DPSIR model, and the specific influence mechanism of various components and the contents of components can be seen in Fig. 4. It is because of this correlation mechanism between the five modules that we hope to use this model framework to understand and assess regional water pollution management more comprehensively and systematically, and then to identify the shortcomings of water pollution management and the room for improvement by comparing the scores of different modules, thus providing a valuable reference basis for the next water pollution management policy formulation.

3.2 Development of the index system based on the DPSIR framework

In order to construct a scientific, representative, and comprehensive evaluation index system, “Water Pollution Prevention and Control Regulations of Tianjin” (Tianjin Municipal People's Congress 2016) was selected as the policy basis. The proposed index system fully took seven chapters of the regional policy into consideration, and representative indices were chosen according to the specific requirements of the regulations, so as to fully feedback the actual situation and facilitate more reasonable evaluation of the regulations.

Additionally, relevant literatures were investigated (Lu W, Xu C, Wu J, Cheng S 2019; Sun C, Wu Y, Zou W, Zhao L, Liu W 2018; Vannevel R 2018; Zare F, Elsawah S, Bagheri A, Nabavi E, Jakeman AJ 2019). Based on the literature review for water management indices (Apostolaki S, Koundouri P, Pittis N 2019; Liu X, Liu H, Chen J, Liu T, Deng Z 2018; Xiao Z, Gao J, Su Y 2019; Yang W, Xu K, Lian J, Bin L, Ma C 2018) and the peculiar situation of Tianjin's water pollution management, the final index system was determined through on-the-spot investigation and demonstration by many experts in the field, which comprised four layers (target layer, component layer, factor layer, index layer) and thirty indices (Table 1).

Table 1
Index system for evaluating implementation effect of Water Pollution Management in Tianjin

Target layer	Component layer	Factor layer	Index layer	Unit	Corresponding to the Regulation
Performance of Water Pollution Management (WPM) in Tianjin	Driver (C_1)	Economy (F_1)	Annual GDP growth rate (I_1)	%	Article 14: "…… Economic and social development……"
		Society (F_2)	Natural population growth rate (I_2)	‰	
			Growth rate of water resources per capita (I_3)	%	Article 18: "…… Improve the carrying capacity of environmental resources in river basins……"
	Pressure (C_2)	Water use (F_3)	Total water consumption (I_4)	10^9m³	Article 40: "…… Save water……"
			Water consumption for industrial output value of 10,000 yuan (I_5)	m³	
			Effective utilization coefficient of farmland irrigation water (I_6)	-	Article 58: "…… Encourage water-saving irrigation……"
		Water environment (F_4)	Discharge of domestic waste water from urban residents (I_7)	10^9t	Article 13: "…… Control water pollutant discharge concentration and total discharge of key water pollutants……"
			Discharge of waste water from Industry and Construction Industry (I_8)	10^9t	
			Discharge of Chemical Oxygen Demand (COD) in wastewater (I_9)	10^4t	
			Discharge of Ammonia Nitrogen (NH_3-N) in wastewater (I_{10})	10^4t	
	State (C_3)	Water state (F_5)	Proportion of Class I-III water quality sections in National Examination Sections (I_{11})	%	Article 4: "…… Protect and improve water environment quality……"
			Penetration rate of urban water (I_{12})	%	Articles 46 to 55: "…… Prevent and control urban water pollution……"

Target layer	Component layer	Factor layer	Index layer	Unit	Corresponding to the Regulation
			Growth rate of total water storage of large and medium-sized reservoirs at the end of the year (I_{13})	%	Article 18: "…… Improve the carrying capacity of environmental resources in river basins……"
			Compliance rate of water functional zone evaluation based on full indicators (I_{14})	%	Article 4: "…… Protect and improve water environment quality……"
			Average utilization rate of water resources (I_{15})	%	Article 34: "…… Increase water reuse rate……"
	Impact (C_4)	Socio-economic impact (F_6)	GDP per cubic meter of water (I_{16})	yuan/m³	Article 40: "…… Save water……"
		Ecology and environment impact (F_7)	Green coverage rate of built-up areas (I_{17})	%	Article 18: "…… Ecological environment governance and protection project……"
			Water supplement to ecology and environment (I_{18})	10^9m³	Article 18: "…… Carrying capacity of river basin environmental resources……"
		Public impact (F_8)	Public satisfaction with water environment management (I_{19})	%	Article 10: "…… Public participation……"
	Response (C_5)	Environment response (F_9)	Centralized treatment rate of sewage (I_{20})	%	Article 46: "…… Increase the treatment rate of urban sewage……"
			Water quality compliance rate of discharged sewage (I_{21})	%	Article 50: "…… Ensure that the effluent water quality meets relevant emission standards……"
			Compliance rate of discharged industrial wastewater (I_{22})	%	Article 43: "…… Construct centralized sewage treatment facilities and install automatic online monitoring facilities……"

Target layer	Component layer	Factor layer	Index layer	Unit	Corresponding to the Regulation
			Sewage reuse rate (I_{23})	%	Article 9: "…… Encourage reuse of water……"
			Water quality compliance rate of urban drinking water sources (I_{24})	%	Articles 35 to 39: "…… Protect drinking water sources……"
		Management response (F_{10})	Growth rate of Pollution Discharge Permit issued by Environmental Protection Department to enterprises (I_{25})	%	Article 16: "…… Pollution discharge permit management system……"
			Growth rate of urban sewage network (I_{26})	%	Article 46: "…… Strengthen the planning and construction of urban sewage centralized treatment facilities and pipe networks……"
			The soundness of laws and standards related to water pollution prevention and control (I_{27})	-	Article 11: "…… Formulate environmental management measures, implementation plans and local standards……"
			Improvement rate of water pollution prevention and control management system (I_{28})	-	Article 8: "…… Water Environmental Protection Target Responsibility System and Assessment System……"
			Proportion of investment in water resources (I_{29})	%	Article 5: "…… Irreplaceable financial investment……"

Target layer	Component layer	Factor layer	Index layer	Unit	Corresponding to the Regulation
			Regional water environment management and ecological compensation (I_{30})	-	Article 65: "…… A coordinated watershed environment management mechanism……" Article 68: "…… Ecological protection mechanism for permanent protection of ecological regions……"

3.3 Quantitative evaluation steps of index system

After establishing the index system, a series of assessment tasks were undertaken according to the following stepwise procedure.

3.3.1 Step 1 - Data procurement

In order to reflect the actual effects of the "Water Pollution Prevention and Control Regulations of Tianjin" more accurately, which were implemented in March 2016, researchers evaluated the performance of water pollution management (WPM) in Tianjin on the basis of the regional policy during the period of 2014-2018. Annual data were obtained mainly from the website of China National Bureau of Statistics, the Statistical Yearbook of Tianjin, the Water Resources Bulletin of Tianjin and so on. The exact sources of index data are enumerated in Table 2.

Additionally, researchers visited the major reservoirs, rivers and lake basins in Tianjin, interviewed the staff of Tianjin Water Bureau and Ecology and Environment Bureau in April 2019, successfully obtained internal data and their thoughts.

For the policy implementation survey, researchers focused not only on the tangible effects but also assessments of public satisfaction and opinion (Fu J, Geng Y 2019; Li L, Xia XH, Chen B, Sun L 2018). To this end, we developed a public opinion survey which asked questions about the levels of public satisfaction with water pollution management in Tianjin. 345 valid submissions were collected and the complete questionnaire is provided in Appendix A.

3.3.2 Step 2 - Calculation of indicator score

Because of the distinctive indicator measuring units, it's necessary to transfer and calculate original data for subsequent assessments. Owing to the differences between the properties of different indicators, we divided the thirty indicators into three types, with the indicator score of each type being generated according to separate methods.

- **Graded scoring method**

Graded scoring method means set four grades (Grade I/ II/ III/ IV) for potential performance of indicators. The boundary values for four grades are decided according to relevant laws, regulations and regional targets, together with literature views(Yang W, Xu K, Lian J, Bin L, Ma C 2018). We then compare index data with four boundary values, ensure grade of each index, then calculate exact score as follows:

$$\mathbf{S_i} = \frac{\mathbf{X^i} - \mathbf{X^{ib}_{min}}}{\mathbf{X^{ib}_{max}} - \mathbf{X^{ib}_{min}}} \cdot \mathbf{P_{ib}} + \mathbf{S^{ib}_{min}}$$

1

where S_i is the score of ith index (I_i); X^i is the actual data of I_i; b is the grade number ranks 1 to 4, and the value of X^i belongs to grade b; X^{ib}_{min} is the minimum value of grade b of I_i; X^{ib}_{max} is the maximum value of grade b of I_i; P_{ib} is the score interval of grade b; S^{ib}_{min} is the minimum score of grade b.

Twenty of the thirty indicators used in the index system were calculated according to this method.

- **Median-based standardized calculation method**

Median-based standardized calculation method means calculating the score according to the median between five years. This method applied to six of thirty indicators in the index system. Due to the differences in natural resources endowment, population, economic development level and other factors, these values cannot be directly compared with the national and global average level. Therefore, it was deemed more judicious to reflect the growth or decline of the data obtained for Tianjin across a sample of multiple different years. The specific calculation method is therefore as follows:

$$\mathbf{S_i} = \mathbf{S}_0 \cdot (1 \pm \frac{\mathbf{X^i} - \mathbf{X^i_{median}}}{\mathbf{X^i_{median}}}) \quad (2)$$

where X^i_{median} is the median of (I_i) during 2014 – 2018; make S_0=80; when the index is positive, use “+” of “ ± ”, and when the index is negative, use “-” of “ ± ”; when the value of S_i > 100, make S_i=100.

- **Expert scoring method**

In addition to the above two calculation methods, there are four indicators related to the perfection of water pollution management system and public satisfaction in the proposed index system, which need to be assigned quantitatively. According to the expert scoring method, indicator values are decided by numerous experts in water management field based on extensive and in-depth investigation and the collection of relevant supporting materials.

3.3.3 Step 3 - Calculation of indicator weight

The relative weighting of different indicators is an important concern which can have a significant impact on the overall index ranking of the study area and subsequent policy decisions. This is because relative indicator weights may significantly differ depending on the chosen weighting procedure (Mikulic J, Kožic I, Krešić D 2015). According to the results of most studies, common weighting methods can be segregated into two categories: subjective weighting and objective weighting. In order to address the presence of extreme values for several indicators in various years without unduly skewing the overall results, we chose analytic hierarchy process (AHP) to calculate each indicator’s weight.

The AHP is a methodology created by Saaty TL (2004), where an importance level is selected according to a comparison between parameters (Sun S, Wang Y, Liu J, Cai H, Wu P, Geng Q, Xu L 2016). The AHP provides a framework to handle decisions without making assumptions about the independence of higher-level elements from lower-level elements or about the independence of the elements within a level (Do HT, Lo S, Thi LAP 2013; Saaty TL 2002).

In this paper we conducted AHP twice among Component layer and Index layer in the same Component layer. The importance levels were chosen by water management experts according to the requirements in water pollution prevention and control. The main calculation processes are as follow:

First, construct an evaluation matrix. An n-criteria evaluation matrix **A** in which every element a_{ij}(i, j = 1, 2, ..., n) is the quotient/ratio of the preference values attached to the criteria as shown in the following matrix (Gao L, Hailu A 2013):

$$\mathbf{A} = \begin{pmatrix} 1 & \cdots & \mathbf{a}_{1\mathbf{n}} \\ \vdots & \ddots & \vdots \\ \mathbf{a}_{\mathbf{n}1} & \cdots & 1 \end{pmatrix} = (\mathbf{a}_{\mathbf{ij}})_{\mathbf{n}*\mathbf{n}}$$

3
where a_{ij}>0; $a_{ij}=1/a_{ji}$; a_{ii}=1.

Next, derive criteria weight. The consistency index (CI) is used to determine whether and to what extent decisions violate the transitivity rule, the equation provides optimal results when CI < 0.1 (Feng L, Zhu X, Sun X 2014; Saaty TL 2006):

CI = (λ_{max}-n)/(n-1) (4)

where λ_{max} is the largest eigenvalue of matrix a, n is the order of matrix **A**, and λ_{max} is calculated as follows (Feng et al., 2014; Sun S, Wang Y, Liu J, Cai H, Wu P, Geng Q, Xu L 2016):

$\boldsymbol{\lambda_{max}} = \frac{1}{n}\sum_{i=1}^{n}\frac{(A\omega)_i}{\omega_i}$ (5)

The weight of an index was calculated using the importance scales in the second and fourth layers. For this process, the square-root method was used as follows (Feng L, Zhu X, Sun X 2014; Saaty TL 2006; Sun S, Wang Y, Liu J, Cai H, Wu P, Geng Q, Xu L 2016):

$m_i = \prod_{j=1}^{n} a_{ij}$, i = 1,2, ..., n (6)
$\overline{\boldsymbol{\omega}_i} = \sqrt[n]{\mathbf{m}_i}$, i =1, 2, ..., n (7)
$\boldsymbol{\omega}_i = \overline{\boldsymbol{\omega}_i} / \sum_{k=1}^{n} \overline{\boldsymbol{\omega}_k}$ (8)

The calculation result of indicator weight can be checked in Table 2. The above results have passed the consistency test.

Table 2
Index weights and calculation method

Index layer	Weight (relative to the component layer)	Weight (relative to the target layer)	Positive or negative	Grading standard				Data source
				Grade IV (<60 points)	Grade III (60-80 points)	Grade II (80-100 points)	Grade I (=100 points)	
I_1	0.2857	0.0244	P	<0	0~5	5~10	≥10	C
I_2	0.2857	0.0244	P	<0	0~0.5	0.5~1	≥1	C
I_3	0.4286	0.0366	P	<-40	-40~0	0~40	≥40	C
I_4	0.1208	0.0190	N	Median-based standardized calculation method				D
I_5	0.1453	0.0228	N	>20	20~10	10~5	≤5	D
I_6	0.0996	0.0156	P	<0.64	0.64~0.68	0.68~0.72	≥0.72	F
I_7	0.1208	0.0190	N	Median-based standardized calculation method				D
I_8	0.1577	0.0248	N	Median-based standardized calculation method				D
I_9	0.1779	0.0279	N	Median-based standardized calculation method				A
I_{10}	0.1779	0.0279	N	Median-based standardized calculation method				A
I_{11}	0.2230	0.0558	P	<15	15~25	25~40	≥40	C
I_{12}	0.1609	0.0403	P	<90	90~95	95~98	100	A
I_{13}	0.1982	0.0496	P	<0	0~5	5~10	≥10	D
I_{14}	0.2356	0.0590	P	<5	5~20	20~40	≥40	D
I_{15}	0.1823	0.0456	P	<90	90~95	95~100	≥100	G
I_{16}	0.2128	0.0426	P	<500	500~600	600~800	≥800	F
I_{17}	0.2374	0.0475	P	<25	25~35	35~45	≥45	A
I_{18}	0.2653	0.0531	P	Median-based standardized calculation method				D
I_{19}	0.2844	0.0569	P	Expert scoring evaluation method				I
I_{20}	0.0738	0.0227	P	<80	80~90	90~98	≥98	C
I_{21}	0.0894	0.0275	P	<80	80~90	90~98	≥98	E
I_{22}	0.0983	0.0302	P	<60	60~80	80~100	≥100	G

Index layer	Weight (relative to the component layer)	Weight (relative to the target layer)	Positive or negative	Grading standard				Data source
				Grade IV (<60 points)	Grade III (60-80 points)	Grade II (80-100 points)	Grade I (=100 points)	
I_{23}	0.0808	0.0248	P	<15	15~30	30~40	≥40	D
I_{24}	0.1078	0.0331	P	<90	90~95	95~100	≥100	B&C
I_{25}	0.0706	0.0217	P	≤0	0~50	50~100	≥100	G
I_{26}	0.0867	0.0266	P	<0.4	0.4~1.2	1.2~2	≥2	C
I_{27}	0.1058	0.0325	P	Expert scoring evaluation method				H
I_{28}	0.1058	0.0325	P	Expert scoring evaluation method				H
I_{29}	0.0855	0.0263	P	<1	1~1.5	1.5~3	≥3	C
I_{30}	0.0957	0.0294	P	Expert scoring evaluation method				H

*****Data source:

A. Website of China National Bureau of Statistics

B. Website of Tianjin Eco-Environment Bureau
C. Statistical Yearbook of Tianjin (2013-2018)
D. Water Resources Bulletin of Tianjin (2013-2018)
E. Environmental Status Bulletin of Tianjin (2013-2018)
F. Calculated from statistical yearbook data
G. Obtained from relevant government departments
H. Scored by experts
I. Scored according to Public Satisfaction Questionnaire Survey

3.3.4 Step 4 - Calculation of annual scores of WPM in Tianjin

After indicator weights have been computed according to the AHP method, comes the calculation of annual scores of WPM in Tianjin. It’s inevitable for missing values to occur within the underlying data supporting such an index system, and there were still three vacancies out of 150 pieces of data. Consequently we calculated the scoring rate as a reasonable approach to avoid unbalance due to blank in specific years and indicators. Finally, we regard the rate calculated as annual scores of regulations implementation.

$$S_{WPM} = \sum_{i=1}^{n} \frac{S_i * W_{ic} * W_{ct}}{100 * W_{ic} * W_{ct}} * 100\%, \ i=1, 2, \ldots, n, \text{ when } I_i \text{ isn't missing value} \quad (9)$$

where W_{ic} is the weight of the ith index relative to component layer; W_{ct} is the weight of the cth component relative to target layer; and n is the number of indicators.

4. Results

4.1 Results of indicator system assessment

4.1.1 Results of Factor Layer and Component Layer

Results of Factor Layer and Component Layer are shown in Fig. 5 and Fig. 6. When it comes to scores of Factor Layer, inter-annual fluctuations are common, such as Society Factor, Environment Response Factor and so on. However, the scores for each element layer vary slowly from year to year. Further, the Component Layers provide clearer feedback on the change in scores. The score of Driver Component (C_1) fluctuated wildly from 2014 to 2018, with the maximum value 95.67 in 2016 and minimum value 77.82 in 2017. The performance of Pressure Component (C_2) increased gradually during the study period. The situation in 2014 and 2015 was nearly the same, with scores between 75 and 76. After that, the Pressure Component became better, and finally reached 85.81 in 2018. Similar to Pressure Component, State Component (C_3) also increased greatly as time went on, from 74.58 in 2014 and improved until 96.02 in 2018. As for Impact Component (C_4), the highest mark 89.88 was achieved in 2018, 1.01, 4.00, 6.55 and 2.75 score of improvement was made in 2015, 2016, 2017 and 2018. Responses consist of two factors, eleven indicators, and nearly 30% of the total weight within the whole index system.

4.1.2 Inter-annual variation in Target Layer scores

Finally, a comprehensive assessment was undertaken to evaluate the overall change in scores of WPM in Tianjin across the study years (Fig. 7). From 76.15 in 2014 and 76.62 in 2015, the water pollution situation improved slightly and the rate of this improvement was calculated as 0.47 index units per year. However, after the implementation of “Water Pollution Prevention and Control Regulations of Tianjin”, sharp growth occurred in 2016, which then was followed by sustained increases in scoring levels. Finally, the overall score in 2018 was founded to be 90.93. During these three years, the rate of improvement was 4.36 index units per year, more than twice of that during the 2014 to 2015 period. In general, the implementation of “Water Pollution Prevention and Control Regulations of Tianjin”, together with water management efforts made these years have turned out to be effective.

4.2 Actual improvement of water pollution

From the results presented in Fig. 6, the Water State (F_5) layer index score emerged as the most prominent component. Separate from the inter-annual fluctuation of scores in other index layers, the Water State Component scores have maintained a growth trend of more than 5 points per year since 2016. Current scores for this component are relatively ideal, with the score achieving a level of 96.0 by 2018. This outstanding performance is mainly attributed to the improvement of water pollution statement in Tianjin.

The indicator of "Proportion of Class I-III water quality sections in National Examination Sections" is an important indicator of water quality in China, which includes ph value, COD, BOD, ammonia nitrogen, total phosphorus, heavy metal concentration, etc. The water quality is best represented by one category, and different categories become worse in turn until the worst water quality of poor V. Since 2016, the annual value of this indicator has increased from 10–25% to 40% in 2018. value from 10–25%, and has risen to 40% by 2018. From the different categories of water quality measurement standards, it means that 40% of the water bodies have reached the standard of "secondary protected areas of centralized surface water sources for living drinking water, fish and shrimp overwintering grounds, swimming channels, aquaculture areas and other fishing waters and swimming areas", which greatly meets the production and living water needs of Tianjin residents.

Meanwhile, “Penetration rate of urban water”; “Growth rate of total water storage of large and medium-sized reservoirs at the end of the year”; “Compliance rate of water functional zone evaluation based on full indicators”; “Average utilization rate of water resources” these indicators also showed good improvements over the five years of the study period, which implies that water pollution control in Tianjin has indeed achieved good results.

5. Discussion

Based on the evaluation results of the index system under the DPSIR model in this paper, several deep-seated challenges to water pollution management have been identified which are worth analyzing further. These include improvement reasons of State Component (C_3), water pollution management situation, as well as public satisfaction and participation phenomena. Furthermore, as a representative of cities in China which are experiencing water shortages and related pressures, or even similar cities within other developing countries, Tianjin’s experience with implementing water pollution management measures have particular research value.

5.1 Key measures to reduce emissions and improve water quality

5.1.1 Closure and remediation of industrial high pollution and high emission enterprises

Pollutants discharged from industrial sources have been reduced significantly, and the main paths of source emissions reductions in Tianjin are quite clear. Industry and Construction activities are currently the main sources of waste water in Tianjin, accounting for more than 40% of the whole city's waste water emissions over the study years. In terms of industrial pollutant emissions, the chemical oxygen demand and ammonia nitrogen showed similar trends of change. They both plummeted to less than 40% from the previous year in 2016, and have maintained significant declining trends ever since. The specific pollutants data can be checked in Table 4.

To achieve these gains, the Tianjin municipal government mainly shut down and renovated several industries and developed centralized sewage treatment plants within industrial agglomeration areas. In response to the national requirements, the Tianjin municipal government completely banned 10 types of small-scale industries such as miniature paper making, leather making, printing and dyeing, dyes, coking, sulfur refining, arsenic refining, oil refining, electroplating, pesticides, etc. At the same time, the government also formulated special treatment plans for the industries of paper making, coking, nitrogen fertilizer, non-ferrous metals, printing and dyeing, leather making, etc. and implemented cleaner renovation for the above-mentioned enterprises. From 2015 to 2019, more than 21,900 scattered and high-pollution enterprises have been comprehensively reformed, an effort which significantly contributed to the overall progress of the region’s water pollution management program. In order to promote waste water centralized treatment, Tianjin municipal government encouraged scattered enterprises to move into industrial parks, which is also quite common in China. It is more convenient for supervision and easier to meet the requirements of relevant standards (Amiri S, Mazaheri M, Samani JMV 2019). By the end of 2016, a total of 60 nationaland municipal industrial clusters in Tianjin had completed the construction of centralized sewage treatment facilities and installed automatic online monitoring devices, leading to improved discharge performance.

Table 3
Discharge of waste water from different sources in Tianjin

	2015		2016		2017		2018	
	Volume (m^3)	Proportion (%)	Volume (m^3)	Proportion (%)	Volume (m^3)	Proportion (%)	Volume (m^3)	Proportion (%)
From urban residents	1.8463	30.8	2.3382	34.5	2.4308	34.5	2.7935	35.6
From industrial and construction	3.3996	56.8	3.5969	53.2	3.5510	50.3	3.4764	44.2
From tertiary industry	0.7406	12.4	0.8315	12.3	1.0703	15.2	1.5882	20.2
From the whole city	5.9865	100.0	6.7666	100.0	7.0521	100.0	7.8584	100.0
*Data source: Water Resources Bulletin of Tianjin (2013-2018)								

Table 4
Discharge of COD and NH_3-N from industrial and agricultural sources in Tianjin

	2014	2015	2016	2017	2018
COD discharged from industrial source (ton)	28269	28058	11023	9041	6795
NH_3-N discharged from industrial source (ton)	3707	3501	1139	620	507
COD discharged from agricultural source (ton)	105058	102468	14749	11842	10886
NH_3-N discharged from agricultural source (ton)	5278	5104	89	147	89
*Data source: Statistical Yearbook of Tianjin (2013-2018)					

5.1.2 Regulatory management of agricultural aquaculture

After promulgation of the Water Pollution Prevention Regulations of Tianjin, emissions from agricultural sources have also undergone rapid declines through livestock and poultry excrement pollution management and aquaculture pollution controls, similar to other regions in China (Sun X, Hu Z, Li M, Liu L, Xie Z, Li S, Wang G, Liu F 2019; Zou L, Liu Y, Wang Y, Hu X 2020) . According to Tianjin Statistical Yearbook, the discharge of chemical oxygen demand (COD) and ammonia nitrogen from agricultural sources dropped sharply in 2016, with the emissions of COD being only 14.93% of that in 2015 and ammonia nitrogen being only 1.74% of that in 2015. Relevant departments have carried out a great deal of work. Tianjin designated a livestock and poultry breeding exclusionary zone in 2016, closed or relocated livestock and poultry farms in the exclusionary zone, and assisted farms with pollution treatment. By 2018, the matching rate of excrement treatment facilities for large-scale livestock and poultry farms in Tianjin had reached 75%, and the utilization rate of excrement resources has reached 76.5%.As for aquaculture pollution control, more than 66.7 million m^2 of freshwater aquaculture ponds were renovated, and individual aquaculture farmers who failed to meet the sewage treatment standards were shut down or relocated in 2016. The municipal government actively promoted the recycling of aquaculture waste water, which can be discharged only after it reaches permissible quality standards, thus greatly reducing pollutant discharge.

5.2 Pathways and Policies for water pollution management

According to the results presented in Fig. 5, the scores of management response (F_{10}) also exhibited a significant positive growth trend. In 2014-2016, the scores were only slightly higher than 70 points, while in 2017 and 2018, they were significantly higher than before. By 2018, the score was 89.3, which means that there is still room for improvement in response to water pollution management. Still, Tianjin has introduced many important management policies for water pollution prevention and control since 2017. Prominent among these have been the River Chief System, issuance of Pollutant Discharge Permits for heavy pollution industries, development of relevant discharge standards, and Ecological Compensation Agreements. A detailed discussion of these specific management policies is provided in the following sections.

5.2.1 Emission control at source

Currently, the management of water pollution in Tianjin, and in China as a whole, regards source control as the most effective and fundamental means, for which there are relevant pollutant discharge standards and discharge permits and administrative orders. In addition to the aforementioned shutdowns and standardisation, the increase in standards in Tianjin in recent years has also laid a solid institutional foundation for good control at source.

In July 2017, the Ministry of Ecology and Environment issued a List of Classified Management of Pollutant Discharge Permits for Fixed Pollution Sources, stipulating the classified management and orderly issuance of Pollutant Discharge Permits nationwide. Additionally, the List restricted the duration of issued pollutant discharge permits for different industry categories. As one of the key cities, Tianjin had completed the issuance of Pollutant Discharge Permit for enterprises in ten industries with high pollution, such as paper making and coking in 2017, and 20 industries such as starch and built-up area sewage treatment plants by the end of 2018. Furthermore, Pollutant Discharge Permit will cover all fixed pollution sources by 2020 in Tianjin.

In terms of discharge standards, Tianjin issued its Urban Sewage Treatment Plants Pollutant Discharge Standard (DB12/599-2015) in October 2015. Considering the requirements of water functional areas, differentiated emission limits are determined depending upon the design throughput of sewage treatment plants, and the normal concentrations of general pollutants in the wastewater stream (categorized on an A/B/C Level). The standard has been implemented in existing sewage treatment plants since 2018, and 108 sewage treatment plants had been renovated by the end of 2018. In 2018, Tianjin revised the local Comprehensive Sewage Discharge Standard (DB12/356-2008) implemented in 2008, greatly reducing the permissible emissions rates for several major pollutants. For example, the limit of COD_{Cr} in the first-class standard is adjusted from 50mg/L to 30mg/L; Ammonia nitrogen (calculated by N) is adjusted from 5mg/L to 3 mg/L. In addition, similar reductions have also been proposed for other pollutants (such as volatile phenol, sulfide, etc.) After the implementation of the above two standards, the black and odorous surface waters have been effectively been eliminated, with water environment quality on the whole, throughout the city improving distinctly.

5.2.2 Upstream water quality control

The upstream and downstream transfer of pollutants cannot be avoided, and as a downstream city, the state of water pollution in Tianjin is closely linked to the discharge of upstream cities.

Ecological compensation agreements on water pollution are set up to promote the upstream and downstream cooperative management process, which means once upstream provinces meet the agreed water quality requirements, downstream provinces and even the central government will pay them fee (Cheng Y, Wu D, Bian Y 2020; Wang X, Berman EM, Chen D, Niu X 2019). This type of compensation has been used as a tool of water pollution management programs in other areas of China in recent years (Gao X, Shen J, He W, Sun F, Zhang Z, Guo W, Zhang X, Kong Y 2019). As an important drinking water source of Tianjin, water quality of Yuqiao Reservoir is affected by the upstream in Hebei Province. To improve the water quality in this reservoir, a three-year Ecological Compensation Agreements was set in 2016. With a total of 1.5 billion yuan invested by the national government, Tianjin municipal government and Hebei provincial government in 2016-2018, water source protection and water pollution prevention projects were conducted in Panjiakou, Daheiting River Basin, together with the upper reaches along the Luanhe River. Two provincial monitoring stations were set up to measure the concentration levels of pollutants such as permanganate as well as to measure pH levels. From 2016 to 2018, both sections met the requirements of drinking water source, proving that water quality had significantly improved (PRC, 2019).

In addition to ecological compensation between provinces, Tianjin formulated the plan of Measures for the Monthly Ranking of Surface Water Environmental Quality in Districts, which ranks the surface water quality within each district on a monthly basis. The lower-ranking districts need to pay money to compensate the top-ranking districts, forcing the upper and lower-level districts protect the river and harness the water pollution jointly.

6. Conclusions

In order to evaluate the performance of regional water pollution management, the DPSIR framework was used to evaluate the performance of water pollution management. According to the evaluation results, water pollution management situation turned little better from 2014 to 2015. However, after the implementation of the regional policy, sharp growth had been made in 2016, then came with sustained increase, finally the score in 2018 reached 90. During these three years, improvement speed is 4.36 per year, more than 9 times of that during 2014 to 2015. In general, the implementation of “Water Pollution Prevention and Control Regulations of Tianjin”, together with water management efforts made these years have turned out to be effective.

Through the analysis of regional water pollution control policies, pathways and measures we know that good results have been achieved in controlling industrial and agricultural pollution sources, and the main paths of emission reduction in Tianjin are quite clear: renovating industrial enterprises with high pollution discharge, conducting strict livestock and poultry excrement pollution management and aquaculture pollution control. The analysis of the reasons for improvement proves the effectiveness of the regulations and government work, and provides experience for other countries and regions committed to promoting water pollution management. The existing shortcomings and deficiencies identified through the evaluation of the index system, such as inadequate public participation mechanism, will be the focus of the government and scholars in the future.

The index system set up in this paper has comprehensive, systematic, and scientific characteristics by comparing with the contents of “Water Pollution Prevention and Control Regulations of Tianjin”, meaningful for the evaluation of regional water pollution control policies. At the same time, there are still limitations in this study, such as subjective factors in index selection and weight determination, and the index setting is still worth further discussion and refinement. In the future, it is hoped that different evaluation methods can be adopted to analyse the effects of a certain policy implementation, and the credibility of the evaluation results can be improved through a comprehensive and multi-faceted assessment.

Declarations

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Author Contributions

Mo Zhang and Meiting Ju contributed the central idea and design the research. Material preparation, data collection and analysis were performed by Yujia Wang, Yan He and Chonggang Yang. The first draft of the manuscript was written by Yujia Wang. All authors discussed the results and revised the manuscript.

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References

1. Amiri S, Mazaheri M, Samani JMV (2019) Introducing a general framework for pollution source identification in surface water resources (theory and application). J Environ Manage 248:109281. https://doi.org/10.1016/j.jenvman.2019.109281
2. Apostolaki S, Koundouri P, Pittis N (2019) Using a systemic approach to address the requirement for Integrated Water Resource Management within the Water Framework Directive. Sci Total Environ 679:70–79. https://doi.org/10.1016/j.scitotenv.2019.05.077

3. Central People's Government of the People's Republic of China (2015) Water Pollution Prevention and Control Action Plan (in Chinese). Available online: http://www.gov.cn/zhengce/content/2015-04/16/content_9613.htm
4. Central People's Government of the People's Republic of China (2017) Report of the 19th National Congress of the Communist Party of China (in Chinese) Avaiable online: http://www.gov.cn/zhuanti/2017-10/27/content_5234876.htm
5. Central People's Government of the People's Republic of China (2019) Tianjin has allocated a total of 300 million yuan of horizontal ecological compensation funds to Hebei Province (in Chinese). Available online: http://www.gov.cn/xinwen/2019-06/16/content_540075
6. Chen Z, Kahn ME, Liu Y, Wang Z (2018) The consequences of spatially differentiated water pollution regulation in China. J Environ Econ Manage 88:468–485. https://doi.org/10.1016/j.jeem.2018.01.010
7. Cheng Y, Wu D, Bian Y (2020) A systematic approach of determining compensation and allocation for river basin water environment based on total pollutants control. J Environ Manage 271:110896. https://doi.org/10.1016/j.jenvman.2020.110896
8. Do HT, Lo S, Thi LAP (2013) Calculating of river water quality sampling frequency by the analytic hierarchy process (AHP). Environ Monit Assess 185:909–916. https://doi.org/10.1007/s10661-012-2600-6
9. European Environment Agency (1999) Environmental Indicators: Typology and Overview, Report No. 25. European Environment Agency, Copenhagen
10. Feng L, Zhu X, Sun X (2014) Assessing coastal reclamation suitability based on a fuzzy-AHP comprehensive evaluation framework: A case study of Lianyungang, China. Mar Pollut Bull 89:102–111. https://doi.org/10.1016/j.marpolbul.2014.10.029
11. Fu J, Geng Y (2019) Public participation, regulatory compliance and green development in China based on provincial panel data. J Clean Prod 230:1344–1353. https://doi.org/10.1016/j.jclepro.2019.05.093
12. Gao L, Hailu A (2013) Identifying preferred management options: An integrated agent-based recreational fishing simulation model with an AHP-TOPSIS evaluation method. Ecol Modell 249:75–83. https://doi.org/10.1016/j.ecolmodel.2012.07.002
13. Gao X, Shen J, He W, Sun F, Zhang Z, Guo W, Zhang X, Kong Y (2019) An evolutionary game analysis of governments' decision-making behaviors and factors influencing watershed ecological compensation in China. J Environ Manage 251:109592. https://doi.org/10.1016/j.jenvman.2019.109592
14. Gari SR, Ortiz Guerrero CE, A-Uribe B, Icely JD, Newton A (2018) A DPSIR-analysis of water uses and related water quality issues in the Colombian Alto and Medio Dagua Community Council. Water Sci 32:318–337. https://doi.org/10.1016/j.wsj.2018.06.001
15. Han D, Currell MJ, Cao G (2016) Deep challenges for China's war on water pollution. Environ Pollut 218:1222–1233. https://doi.org/10.1016/j.envpol.2016.08.078
16. Li J, Shi X, Wu H, Liu L (2020) China Economic Review Trade-o ff between economic development and environmental governance in China: An analysis based on the e ff ect of river chief system. China Econ Rev 60:101403. https://doi.org/10.1016/j.chieco.2019.101403
17. Li L, Xia XH, Chen B, Sun L (2018) Public participation in achieving sustainable development goals in China: Evidence from the practice of air pollution control. J Clean Prod 201:499–506. https://doi.org/10.1016/j.jclepro.2018.08.046
18. Li Z (2018) A health-based regulatory chain framework to evaluate international pesticide groundwater regulations integrating soil and drinking water standards. Environ Int 121:1253–1278. https://doi.org/10.1016/j.envint.2018.10.047

19. Liu WX, Sun CZ, Zhao MJ, Wu YJ (2019) Application of a DPSIR Modeling Framework to Assess Spatial–Temporal Differences of Water Poverty in China. J Am Water Resour Assoc 55:259–273. https://doi.org/10.1111/1752-1688.12724
20. Liu X, Liu H, Chen J, Liu T, Deng Z (2018) Evaluating the sustainability of marine industrial parks based on the DPSIR framework. J Clean Prod 188:158–170. https://doi.org/10.1016/j.jclepro.2018.03.271
21. Liu X, Pan Y, Zhang W, Ying L, Huang W (2020) Achieve Sustainable development of rivers with water resource management - economic model of river chief system in China. Sci Total Environ 708:134657. https://doi.org/10.1016/j.scitotenv.2019.134657
22. Lu W, Xu C, Wu J, Cheng S (2019) Ecological effect assessment based on the DPSIR model of a polluted urban river during restoration: A case study of the Nanfei River, China. Ecol Indic 96:146–152. https://doi.org/10.1016/j.ecolind.2018.08.054
23. Luo Z, Zuo Q (2019) Evaluating the coordinated development of social economy, water, and ecology in a heavily disturbed basin based on the distributed hydrology model and the harmony theory. J Hydrol 574:226–241. https://doi.org/10.1016/j.jhydrol.2019.04.042
24. Mikulic J, Kožic I, Krešić D (2015) Weighting indicators of tourism sustainability: A critical note. Ecol Indic 48:312–314. https://doi.org/10.1016/j.ecolind.2014.08.026
25. Ministry of Ecology and Environment of the People’s Republic of China (2014) Environmental Protection Law of the People’s Republic of China (in Chinese). Availabe online: http://www.mee.gov.cn/ywgz/fgbz/fl/201404/t20140425_271040.shtml
26. Ministry of Ecology and Environment of the People's Republic of China (2018) Water Pollution Prevention Law of the People’s Republic of China (in Chinese). Available online: http://www.mee.gov.cn/ywgz/fgbz/fl/200802/t20080229_118802.shtml
27. Ministry of Ecology and Environment of the People’s Republic of China (2020) China’s Environmental Status Bulletin 2019 (in Chinese). Available online: http://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/202006/P020200602509464172096.pdf
28. National Bureau of Statistics (2019) Available online: http://data.stats.gov.cn/easyquery.htm?cn=E0103
29. OECD (1993) OECD core set of indicators for environmental performance reviews,OECD Environmental Directorate Monographs No.83
30. Posthuma L, Backhaus T, Hollender J, Bunke D, Brack W, Müller C, Gils J, Hollert H, Munthe J, Wezel A (2019) Exploring the ‘solution space’ is key: SOLUTIONS recommends an early-stage assessment of options to protect and restore water quality against chemical pollution. Environ Sci Eur 31. https://doi.org/10.1186/s12302-019-0253-6
31. Ramos-Quintana F, Ortíz-Hernández ML, Sánchez-Salinas E, Úrsula-Vázquez E, Guerrero JA, Zamorano M (2018) Quantitative-qualitative assessments of environmental causal networks to support the DPSIR framework in the decision-making process. Environ Impact Assess Rev 69:42–60. https://doi.org/10.1016/j.eiar.2017.11.004
32. Saaty TL (2002) Decision making with the Analytic Hierarchy Process. Sci Iran 9:215–229. https://doi.org/10.1504/ijssci.2008.017590
33. Saaty TL (2004) Decision making — the Analytic Hierarchy and Network Processes (AHP/ANP). J Syst Sci Syst Eng 13:1–35. https://doi.org/10.1007/s11518-006-0151-5
34. Saaty TL (2006) Rank from comparisons and from ratings in the analytic hierarchy/network processes. Eur J Oper Res 168:557–570. https://doi.org/10.1016/j.ejor.2004.04.032

35. She Y, Liu Y, Jiang L, Yuan H (2019) Is China's River Chief Policy effective? Evidence from a quasi-natural experiment in the Yangtze River Economic Belt, China. J Clean Prod 220:919–930. https://doi.org/10.1016/j.jclepro.2019.02.031
36. Sun C, Wu Y, Zou W, Zhao L, Liu W (2018) A Rural Water Poverty Analysis in China Using the DPSIR-PLS Model. Water Resour Manag 32:1933–1951. https://doi.org/10.1007/s11269-017-1819-y
37. Sun S, Wang Y, Liu J, Cai H, Wu P, Geng Q, Xu L (2016) Sustainability assessment of regional water resources under the DPSIR framework. J Hydrol 532:140–148. https://doi.org/10.1016/j.jhydrol.2015.11.028
38. Sun X, Hu Z, Li M, Liu L, Xie Z, Li S, Wang G, Liu F (2019) Optimization of pollutant reduction system for controlling agricultural non-point-source pollution based on grey relational analysis combined with analytic hierarchy process. J Environ Manage 243:370–380. https://doi.org/10.1016/j.jenvman.2019.04.089
39. The Bureau of Water Affairs of Tianjin (2019) Bulletin on the Status of Water Resources in Tianjin in 2018 (in Chinese). Available online: http://swj.tj.gov.cn/gztb_17212/201912/t20191214_1714584.html
40. Tianjin Municipal People's Congress (2016) Water Pollution Prevention and Control Regulations of Tianjin (Revised Version) (in Chinese). Available online: http://www.tjrd.gov.cn/flfg/system/2018/12/17/030011284.shtml
41. Vannevel R (2018) Using DPSIR and balances to support water governance. Water (Switzerland) 10. https://doi.org/10.3390/w10020118
42. Wang Q, Yang Z (2016) Industrial water pollution, water environment treatment, and health risks in China. Environ Pollut 218:358–365. https://doi.org/10.1016/j.envpol.2016.07.011
43. Wang X, Berman EM, Chen D, Niu X (2019) Strategies to improve environmental networks for pollution control: Evidence from eco-compensation programs in China. J Environ Manage 234:387–395. https://doi.org/10.1016/j.jenvman.2018.12.080
44. Wu Z, Ye Q (2020) Water pollution loads and shifting within China's inter-province trade. J Clean Prod 259:120879. https://doi.org/10.1016/j.jclepro.2020.120879
45. Xiao Z, Gao J, Su Y (2019) China's water risk assessment and industrial source analysis based on the localization of WWF water risk assessment tools. Environ Impact Assess Rev 78:106285. https://doi.org/10.1016/j.eiar.2019.106285
46. Yang W, Xu K, Lian J, Bin L, Ma C (2018) Multiple flood vulnerability assessment approach based on fuzzy comprehensive evaluation method and coordinated development degree model. J Environ Manage 213:440–450. https://doi.org/10.1016/j.jenvman.2018.02.085
47. Yang Y, Lei X, Long Y, Tian Y, Zhang Y, Yao Y, Hou X, Shi M, Wang P, Zhang C, Wang H, Quan J (2020) A novel comprehensive risk assessment method for sudden water accidents in the Middle Route of the South–North Water Transfer Project (China). Sci Total Environ 698:134167. https://doi.org/10.1016/j.scitotenv.2019.134167
48. Yuan F, Wei YD, Gao J, Chen W (2019) Water crisis, environmental regulations and location dynamics of pollution-intensive industries in China: A study of the Taihu Lake watershed. J Clean Prod 216:311–322. https://doi.org/10.1016/j.jclepro.2019.01.177
49. Zare F, Elsawah S, Bagheri A, Nabavi E, Jakeman AJ (2019) Improved integrated water resource modelling by combining DPSIR and system dynamics conceptual modelling techniques. J Environ Manage 246:27–41. https://doi.org/10.1016/j.jenvman.2019.05.033
50. Zhai X, Xia J, Zhang Y (2017) Integrated approach of hydrological and water quality dynamic simulation for anthropogenic disturbance assessment in the Huai River Basin, China. Sci Total Environ 598:749–764. https://doi.org/10.1016/j.scitotenv.2017.04.092

51. Zhou Y, Zhu S, He C (2017) How do environmental regulations affect industrial dynamics? Evidence from China's pollution-intensive industries. Habitat Int 60:10–18. https://doi.org/10.1016/j.habitatint.2016.12.002
52. Zou L, Liu Y, Wang Y, Hu X (2020) Assessment and analysis of agricultural non-point source pollution loads in China: 1978–2017. J Environ Manage 263:110400. https://doi.org/10.1016/j.jenvman.2020.110400

Figures

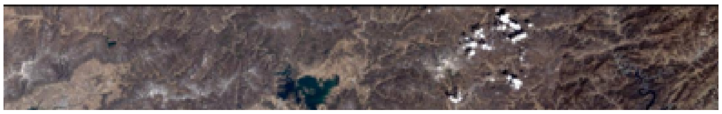

Figure 1

Location of the study area

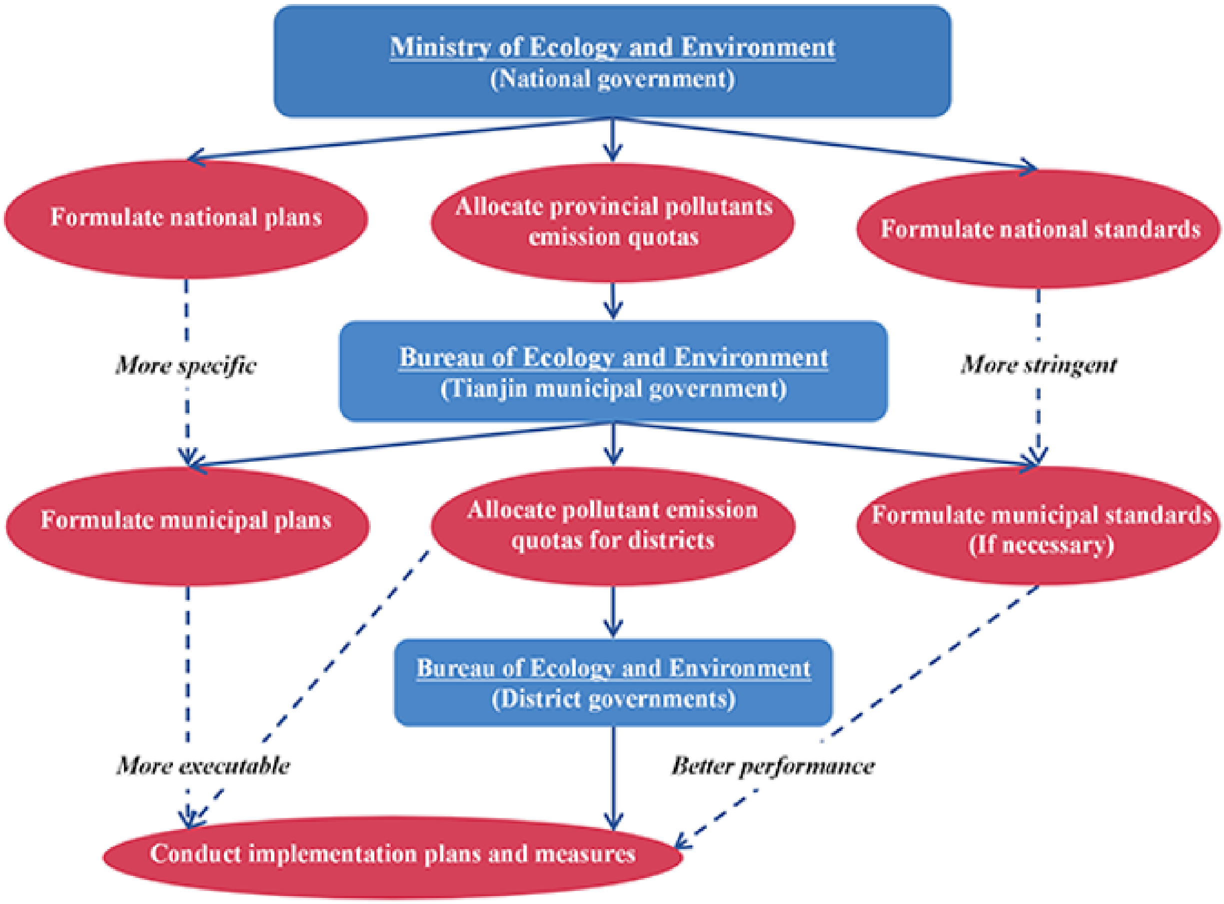

Figure 2

Multi-level structure of water pollution management in Tianjin

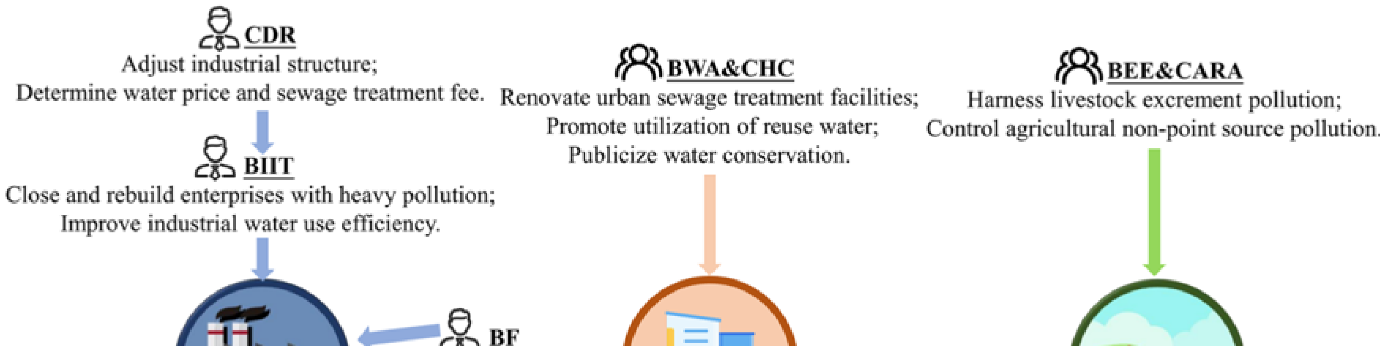

Figure 3

Multi-department collaboration of water pollution management in Tianjin

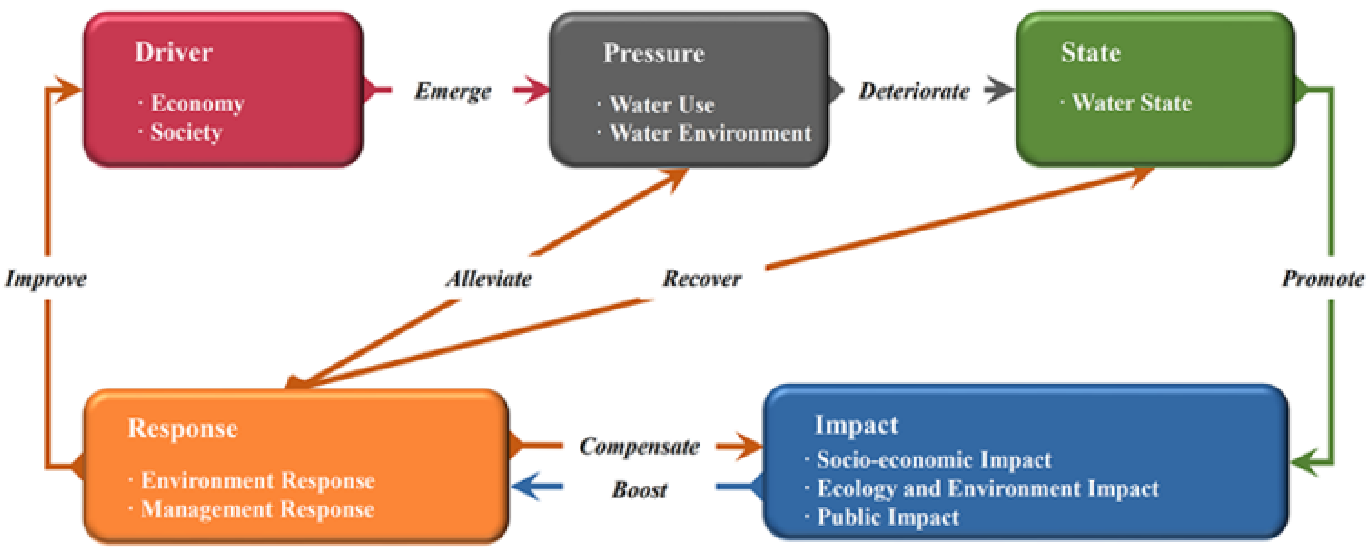

Figure 4

Influence mechanism of various components in DPSIR framework

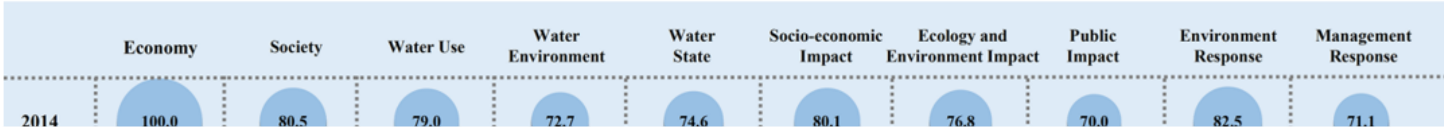

Figure 5

Performance of Factor Layer from 2014 to 2018

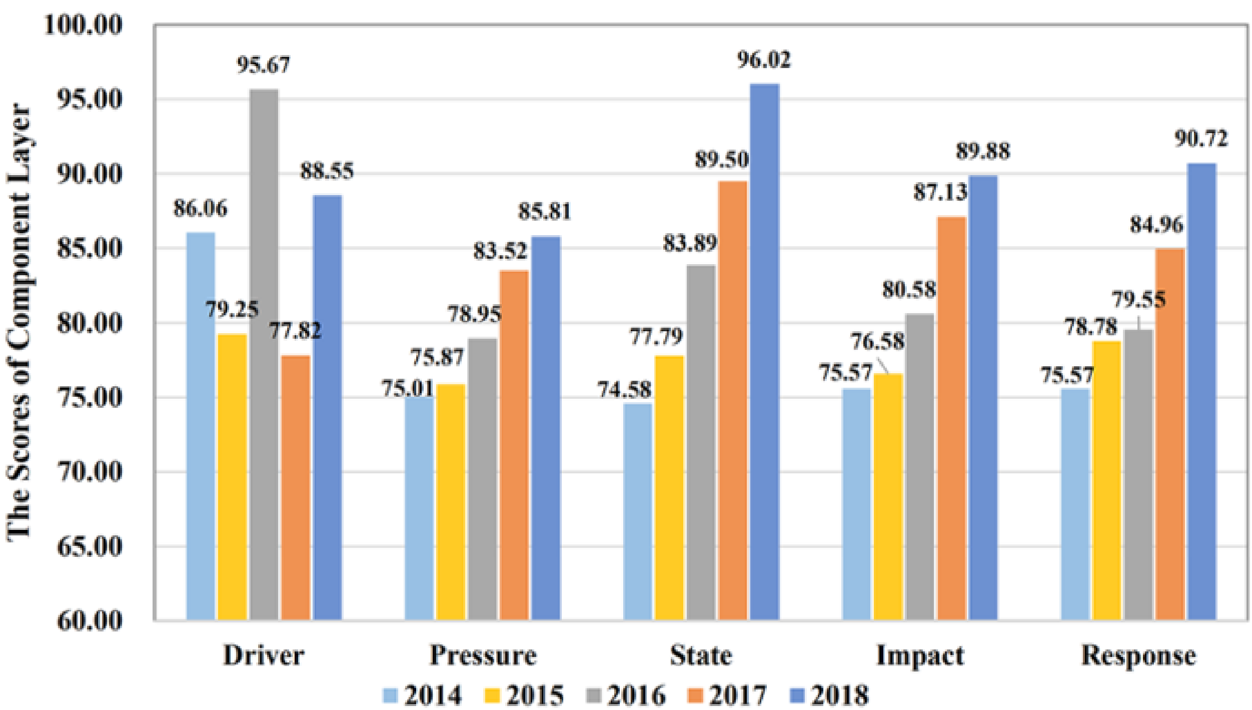

Figure 6

Performance of Component Layer from 2014 to 2018

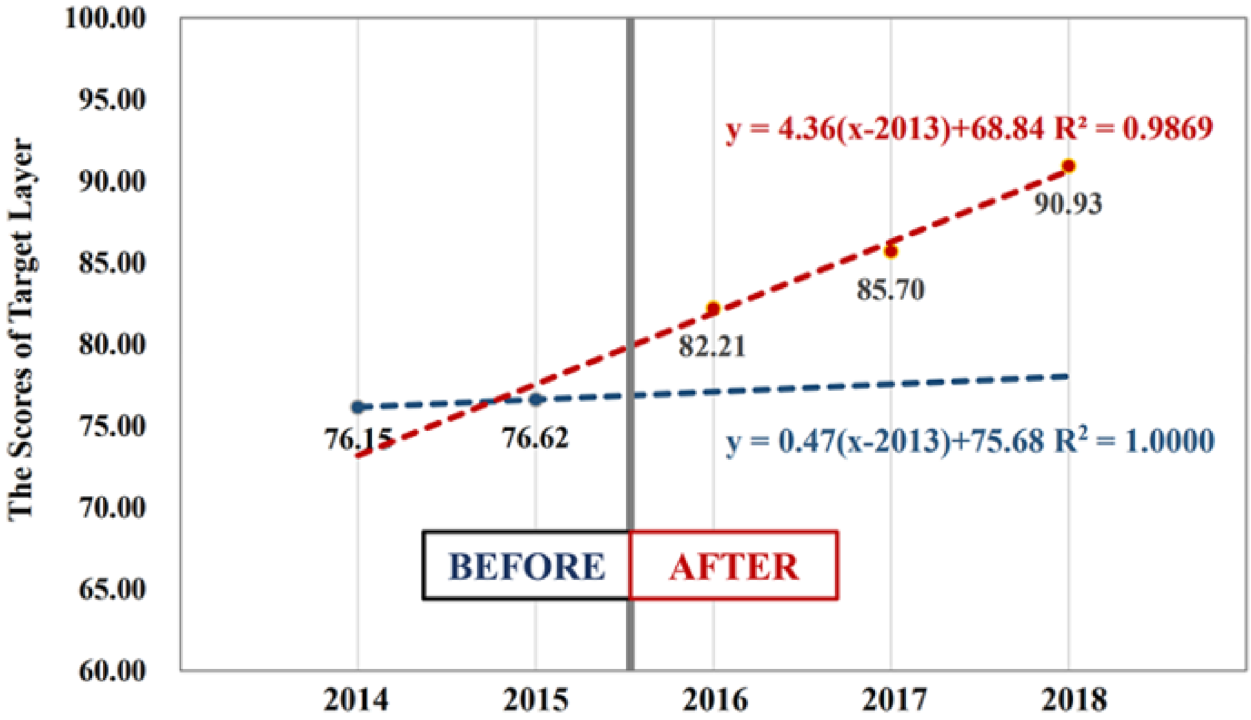

Figure 7

Final annual scores of comprehensive assessments / Target Layer

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix.docx
- 12.2Graphicalabstract.tif