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Status and Treatment Model of Water Resources Pollution in the Yellow River Basin of China

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ABSTRACT

The Yellow River basin water resources have established the material foundation for the livelihood of the local residents and the sustainable development of local economy and society. However, the water resources pollution in the Yellow River basin has been exacerbated due to rapid economic development, unrestrained discharge of industrial wastewater, and long-term shortage of average water resources. To analyse the water pollution status of the Yellow River basin in China and to develop an effective water pollution treatment model, this paper summarizes the research on water resources pollution status of river basins in developed countries of Europe and America and the experience of their treatment models, analyses the present situation of water resources pollution in the Yellow River basin, and proposes feasible treatment strategies. Research results suggest that the river basin water resources treatment experience of developed countries, notably the United States, Australia and Germany, can provide positive implications for the treatment of Yellow River basin. Water pollution in the Yellow River is mainly characterized by four aspects, namely, severity of point pollution sources and increase of sand content; water aggravation, soil loss, and ecological environment vulnerability; uniqueness of the low-reach morphology and frequent occurrence of floods; and serious discharge of industrial wastewater and aggravation of water pollution. In accordance with the Yellow River basin water pollution characteristics, a treatment model integrating the improvement of water resources management legal system, establishment and enhancement of water right transfer system, strengthening of hydraulic engineering projects, unification of water inflow management, and building of an ecological compensation mechanism is proposed. The research findings of this paper can provide references for future analysis of the overall water resources pollution status and trend of the Yellow River basin, as well as for upgrading of its water resources pollution treatment model.

INTRODUCTION

All forms of life, especially humans, on Earth cannot live without water. Water is an element paramount for survival. The fundamentality, irreplaceability, and strategic nature of water reflect its economic and political values. For a country, water is an organic factor underpinning its national comprehensive strength. Along with rapid globalization, water resources are playing an increasingly important role in all social sectors. Countries worldwide, have considered water as a resource with increasing strategic importance.

The Yellow River plays a strategic position in the social and national economic development of China. However, industrialization has caused the Yellow River to be one of the major rivers that pose substantial challenges for treatment efforts. The majority of the Yellow River basin lies in arid and semi-arid areas, where water shortage and drying up occur frequently. In the middle section of the Yellow River is the Loess Plateau, the largest of its kind in the world. In this area, water and soil loss caused by a bundle of complex factors have spread and worsened, thereby leaving sediments at the lower reach in the Yellow River and creating a complicated problem for flood control. As urbanization and industrialization accelerate, water pollution in the Yellow River has increased to an alarming level, spreading from point to surface sources. Industrial waste is discharged irresponsibly, which is coexisting with domestic waste. Moreover, the discharge amount and pollution degree showed no signs of alleviation, especially in recent years when a growing economy has been shaped in the Yellow River area. As to the Yellow River itself, the dry season continues to lengthen, thereby making drying up a common phenomenon. The functions of the water body are impaired and scarcity of water resources became an increasingly prominent problem due to the worsening water environment. No water source is available, especially during drying up conditions. If any water source is available, heavily polluted water cannot be used safely. Deterioration of the Yellow River water ecological environment has made it imperative to promote treatment legalization of the Yellow

River basin. This paper studies the water pollution status of the Yellow River basin, investigates the causes of its existing problems, and evaluates water pollution treatment model suitable for the Yellow River basin. Meanwhile, feasible countermeasures are established to realize the sustainable development of Yellow River water resources.

Water resources are mobile and basin-wide, and thus, classifying water resources is necessary on a basin basis. In other words, a natural basin is regarded as a unit for unified management. The management model has currently gained increasing recognition from different countries and regions. The river basin treatment resources in developed countries, such as the United States, Australia, and Germany, are highly representative. As to water pollution and its hazards, the following scholars have accomplished positive research attempts. Zhu analysed the polycyclic aromatic hydrocarbon (PAH) pollution on the surface water of Hangzhou, China and evaluated the hazards of PAH pollution (Zhu et al. 2003). Volk examined the water pollution in the Ems basin caused by agricultural, animal husbandry, and fishery production (Volk et al. 2008). Aiping proposed targeted treatment countermeasures after analysing the water pollution in China's rural areas (Aiping 2009). With the participation of the Chinese public in studying the water pollution treatment, Hu (2014) developed some innovative treatment models (Hu et al. 2014). Zhang recognized and evaluated the pollution grade of heavy metal pollution incurred by sediments in China's Daye Lake (Zhang et al. 2014). Groll assumed that oil refinement and plastic production can contribute to water pollution based on the water quality status analysis of the Zarafshan River (Groll et al. 2015). Oh investigated the water resource management status and policies of California, United States (Oh et al. 2015). Scholars worldwide have also achieved productive research findings on water pollution countermeasures. Watkins introduced the framework for a sustainable water resource planning model and constructed representative water resource joint scheduling model for water pollution treatment (Watkins et al. 1995). Dai designed a network model that can reflect the overall water flow and quality of the river basin to realize water pollution treatment (Dai et al. 2001). Ioslovich assumed that effective distribution of various water resources should be realized through market mechanism and that price mechanism should be at the core of market mechanism (Ioslovich et al. 2001). Khare explained the evaluation of water resource allocation plan (Khare et al. 2007). Pagiola indicated the necessity of analysing the internal logic of water resource ecological compensation in the river basin area before building a water resource ecological compensation (Pagiola 2008). Young examined the evaluation functions and value of the water resource ecological compensation in the river basin area and investigated the methods for the optimal allocation and protection of water resources (Young et al. 2009). Tang concluded that the charge of water and water environment pollution behaviours in the river basin provided positive ecological effects, although not fully for ecological purpose (Tang et al. 2012). Read expounded on how to realize optimization and stability of water resources in the water basin area (Read et al. 2014). From the above mentioned literature, water pollution occurred with economic and social development and concentrated in some regions. To effectively treat the pollution of water resources, legislation, administrative orders, and economic measures should be integrated. In this paper, water pollution in the Yellow River basin is adopted as the research object. Hazards caused by its water pollution are examined, based on which specific treatment measures are established. Meanwhile, this paper provides suggestions on building a water pollution treatment framework and policy system in the Yellow River basin.

WATER RESOURCES POLLUTION STATUS IN THE YELLOW RIVER BASIN

Severity of point pollution sources and increase of soil content in water quality: Point pollution sources, mainly refer to wastewater discharged by industrial, mining enterprises, and urban domestic sewage. Major sections of the Yellow River basin, including the Fen River, the Wei River and other trunk streams, frequently accumulated a large amount of wastewater discharged annually. These sections are adjacent to either medium-and large-sized cities or highly industrialized areas. From the industry perspective, industries involved in chemical engineering, paper making, electric power, and coal, are the major sources of wastewater. To local governments, these industries are the main contributors of tax revenues. As a result, some government agencies have connived at their flagrant damage of water resources and environment. These water contaminators paid an amount much lower than the operating cost of pollution treatment facilities. With extensive increase in human population and living space influenced by precipitation of relevant areas, water inflow, sand inflow, sand outflow, and water percentage inflow of upper and middle reach in the Yellow River basin have changed. Fig. 1 presents the Yellow River basin water quality in December 2016.

Serious water and soil loss and ecological environment vulnerability: From Table 1, we can see the discharge of wastewater and main pollutants in the Yellow River River Basin. Loess Plateau, a plateau with a large area of water and soil loss, that suffered most from water and soil erosion in the world, is the main source of sand in the Yellow River. Many unique animals and plants live in different sections

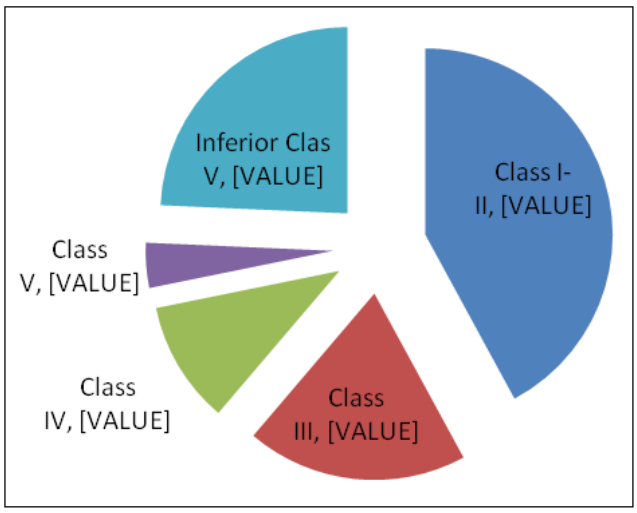

Fig. 1: Percentage of different water quality classes on December 2016. (Data source: Provincial Boundary Water Resources Quality Report by the Yellow River Basin Water Resources Protection Bureau).

of the Yellow River area. As a bridge, the Yellow River connected different wetland ecological basins, including the river source, the upper reach area, the middle reach area, the lower reach area, and the estuary. These environmental units provided favourable habitats for various aquatic organisms and fish migration to multiply in number. However, the Yellow River basin became one of the ecologically vulnerable areas in China due to its ecological and geographical location. Several forms of ecological vulnerabilities are found in the Yellow River.

Uniqueness of the lower reach morphology and frequent occurrence of floods: The ecological environment of the Yellow River basin is extremely unbalanced. The water surface of the lower reach continued to rise due to the small amount of water, but large amount of sediments. As a result, the topologies on two banks of the river channel are significantly higher than in the North China plain. The river bed in the lower reach of the Yellow River is about 4m to 7m higher than the surface. The lower reach of the Yellow River is wide at the surface, but narrow at the bottom. Substantial changes occurred that posed a significant threat to the flood control projects on two banks due to water erosion.

Serious discharge of industrial wastewater and water pollution aggravation: Point pollution sources, including wastewater discharged by plants on the two banks and mine fields, and domestic sewage of urban residents, should take the main responsibility in the water pollution of the Yellow River. In addition, surface pollution sources, including hazardous materials, industrial waste fishing nets, pesticides, chemical fertilizers, and other solid wastes, flowed in the Yellow River along with the surface runoff. Water and soil loss also carried parts of pollutant, such as sediments, pesticides, fertilizers, and solid waste, in the Yellow River. Among them, sediments mainly came from the Loess Plateau. Increasing flow of sediments in the Yellow River increased the turbidity and chromaticity of the river water and influenced the sensory properties of the river water. Moreover, pollutants, especially fertilizers and pesticides, impaired the deoxygenating conditions in the Yellow River. From the sediments in the Yellow River, heavy metals, such as Ar, Hg, Pb and Zn, are found, in which Ar accounted for the highest percentage. The triggered piles of solid waste on the two banks in the Yellow River caused the secondary pollution in the river. Thus, they are also a potential danger to the water body. From Table 2, we can see the pollution exceeding standard in the the Yellow River River basin.

WATER RESOURCES POLLUTION TREATMENT MODEL OF THE YELLOW RIVER BASIN

Improvement of the water resource management legal system: The Yellow River has its own characteristics. Water supply shortage, water and soil content imbalance, serious water pollution, and weak flood control - all these problems of the Yellow River are fundamentally difficult to address. The Yellow River failed to obtain immediate legal protection because of backward legislation. Thus, considering water supply shortage, water and soil content imbalance, and serious water pollution, the accelerated issuance of relevant laws is necessary to comprehensively cope with these problems. With the increasing severity of flood control, laws should be introduced to push efforts in addressing special problems with floods and droughts in the Yellow River. Institutionally, the flood control capacity of departments at different levels shall be strengthened. Systematically, problems involving flood control construction and management should be addressed. All these above mentioned solutions can increase the level of management modernization.

Establishment and enhancement of the water right transfer system: In building and standardizing the water right transfer system, the Chinese government should consider the national conditions in China.

In China, water right transfer is still at the beginning stage, and thus, it will encounter many hurdles during its development. The advanced concepts of the water right market abroad, can provide valuable references for China. Based on the advanced concepts, China can accelerate the building of a proper water right transfer market and system and introduce a set of laws and regulations to promote sound development of the water right transfer. Specifically, water right transfer pricing and profits should be legalized and standardized. Regarding different water resource statuses

Table 1: Wastewater of the upper and middle reach in the Yellow River basin and discharge of major pollutants.

Year	Wastewater (Unit: 1 billion ton)			Chemical oxygen demand (COD)/1 million ton				Ammonia/1 million ton			
	Industry	Life	Concentrated	Industry	Agriculture	Life	Concentrated	Industry	Agriculture	Life	Concentrated
2011	1.335	2.412	0.001	0.3865	0.8292	0.6315	0.0100	0.0334	0.0370	0.1067	0.0012
2012	1.324	2.661	0.001	0.3667	0.7400	0.6174	0.0101	0.0354	0.0358	0.1021	0.0012
2013	1.270	2.808	0.002	0.3509	70.196	0.6011	0.0087	0.0335	0.0341	0.1004	0.0009

Table 2: Excessive amounts of chemicals in the Yellow River basin in 2014.

Indexes	Statistical number of cross sections	Annual average cross-section excessive rate (%)	Annual average scope/(mg/L)
Ammonia nitrogen	62	29.0	0.19-17.4
Chemical oxygen demand (COD)	62	29.0	5.4-105.4
Biochemical oxygen demand after five days (BOD_5)	62	27.4	1.0-26.7
Total phosphorus (TP)	62	25.8	0.039-2.49
Petroleum	62	21.0	Undetected-0.492
Permanganate index	62	16.1	1.6-27.6
Volatile phenol	62	8.1	Undetected-0.088
Fluoride	62	8.1	0.21-1.35
Anionic surfactant	62	4.8	0.024-0.534

(Data source: Water Resources Report (2014) by the Yellow River Basin Water Resources Protection Bureau)

and water resource shortages in different sections, a floating range should exist for the water right transfer price. Water transfer subjects should be allowed to determine the price within the floating range based on local water use and demand. This suggestion will contribute to the rationality and legality of water right transfer. China is still in the experimental period of water right transfer. Thus, problems are inevitable. When water resources enter the market for redistribution, they become special commodities with a value. If the national government disregards the water right transfer pricing and profits, several water use right holders driven by the pursuit of interests might purposely increase water price to seek unwarranted profits. This condition will upset the sound and orderly development of the water market. If the national government can provide a price range guide, dealers will rationalize their pricing in accordance with the situations of the local water resources. In this manner, abuse of water use right transfer can be limited.

Strengthening of hydraulic engineering projects: Construction of hydraulic engineering projects in the Yellow River basin can achieve the scientific and rational configuration of water resources. Improved storage and regulation of water resources can fundamentally cope with problems, such as water shortage and disproportional distribution of water resources in time and space. Society should be encouraged to save water. With less water waste, internal water crisis in the Yellow River basin can be avoided. The establishment of a water-saving society is essential to hydraulic engineering techniques for the development, utilization, and protection of water resources. Advanced hydraulic engineering techniques should be introduced to dynamically support the sustainable development of China's economy and society and guide the circulation and storage structure of water resources for the production and living demands of humans. However, hydraulic engineering projects are frequently large in scale, and thus, their negative influence in the ecological system should not be ignored. Measures should be considered in advance to address their influence on the natural environment.

Promotion of the unified water resource management process: Globally, water resource management models in basins vary significantly; however, unifying the management of water resources regarding the basin as a unit became a common selection of countries worldwide. Strengthening the unified management of water resources is a critical attempt to alleviate the water crisis in the Yellow River. Demands of urban life, industry, agriculture and ecological environment about water volume and quality should be comprehensively considered to enhance water demand management and gradually realize optimal allocation of water resources. The unified water resource management model should be adopted as a response to the natural properties of the Yellow River water resources and to reduce contradiction between supply and demand. During the unified allo-

cation and scheduling process, practical management and utilization situations in the Yellow River basin should be considered. By expounding the management responsibilities of institutions and administrative regions in the basin area, a basin management mechanism featuring clear labour distribution, participation of all parties, democratic negotiation, and joint decision-making are shaped. However, the Yellow River basin covering a large scale should be indicated. Natural conditions vary significantly in the basin. Basin-based unified management cannot fully replace regional management due to the unsynchronized degree of water resource development and the utilization and degree of economic and social development. Thus, powers, responsibilities, and procedures should be first explained before unified management and planning. The local water administration department should play a positive role during the process. In other words, the unified management of the Yellow River water resources is essential to be consistent with the administrative organization water resource management.

Building of an ecological compensation mechanism: In the middle reach of the Yellow River basin, water and soil loss became a serious problem. Loess Plateau is a main contributor of sediments to the middle reach. Regardless of the years of treatment, the problem of sediments showed no signs of improvement due to natural factors and human activities. The lower reach of the Yellow River is recessive in economic development and vulnerable in ecological environment. Long-term ineffective supervision increased the contradiction between economic construction and environmental protection. The worsening of the vulnerable ecological environment calls for the intensification of water and soil loss treatment. The ecological compensation system can provide capital, technological, and policy support for water and soil loss treatment. Design synchronization, construction, and stipulated operation in regulations on water and soil conservation, should be implemented strictly to guarantee the continuity of ecological protection and promote the sustainable development of economy and society. The Yellow River basin spans nine provinces and regions. The Yellow River Hydraulic Engineering Committee established the water quality monitoring cross-sections to improve the water quality on provincial boundaries for periodical monitoring of the cross-provincial water quality. The relationship between the upper and lower reach of the Yellow River basin is reflected as the water volume and quality on the regional boundaries. As the water quality and volume of the upper reach cannot meet the requirements, they will delay the social and economic development of the lower reach. However, if the upper reach adopts a series of effective measures but obtains no compensation after providing quality water resources for the lower reach, the interest of the upper reach area to guarantee water quality and volume for the lower reach will be reduced. Therefore, cross-provincial (regional) ecological compensation is necessary to maintain a harmonious demand and supply relationship between the lower and upper reaches.

CONCLUSIONS

With little water and voluminous sands, the Yellow River in China experienced serious water and soil content imbalance. The treatment of the Yellow River is a long-term and complex process. Progress on the river water pollution treatment depends on the evaluation of the water pollution status, water environment status, and development trends. Targeted treatment measures should be established with social, economic, and natural environment conditions in the basin area fully considered. This study summarized the statuses and experiences of developed countries in treating water pollution and investigated the status of the Yellow River basin water pollution. Results showed that the river basin water pollution treatment experiences of developed countries in Europe and North America provided implications for their Chinese counterpart. The Yellow River basin water pollution is mainly reflected as the aggravation of point pollution sources, increase of soil content in the water quality, severity of water and soil loss, ecological environment vulnerability, uniqueness of the lower reach, frequency of floods, serious discharge of industrial waste, and deterioration of water pollution. Regarding these problems, a treatment model is established in combination with the improvement of the water resource management legal system, building and enhancement of the water right transfer system, strengthening of the hydraulic engineering construction in the Yellow River basin, unified management of water resources in the basin, and establishment of an ecological compensation mechanism. Based on the limitations of this research, the author suggests that future research efforts should be made in the following aspects: The Yellow River basin network treatment model, the water pollution countermeasures adopted by different provinces in the basin area, the overall status and provincial distribution of water pollution, the establishment of a total pollutant control system and cross-provincial cross-section regulation, the combination of the basin and regional management, and the integration of hydraulic engineering with environmental protection.

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