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Water Quality Management in China: The Case of the Huai River Basin

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ABSTRACT *This paper addresses the importance of water quality management and the impacts of water pollution control and water development projects. The case study of the Huai River Basin is an example of the major challenges on water quality management that China is facing, and why water quality management will play a key role on its sustainable use and management. Three urgent issues for the Huai River Basin are identified: water and ecosystem interactions on the river system due to the impacts of increasing pollution and water development projects; comprehensive assessment on impact of dams and sluices on changes of river flow regimes, water quality and ecosystems; and improvement of water quality, and the restoration of river ecosystems through state-of-the-art environmental monitoring and integrated water management practices.*

Water Quality Management in China

Water quality management is a key issue throughout the world. China is a developing country with a variety of climates and increasing stress from its population and economic development (Xia & Chen, 2001; Xia *et al.*, 2007, Xia & Zhang, 2008; Shen & Yang, 2001), which in addition is affected by floods, droughts and water environment-related issues. In terms of water shortage, it was estimated by the Ministry of Water Resources (MWR) (2010) that 59% of the total area of China faces water stress, that it has an impact on 60% of the population at the national level, in 67% of the cities and on 72% of the gross domestic product produced from these impacted areas. The annual water shortage reaches 100–110 BCM with annual economic losses almost US$30 billion.

In terms of floods, the major disasters occurred in the Yangtze Rivers in 1998. Just this sole event caused at least US$22 billion-worth of damage. The Huai River, analysed in this paper, is also one of the most vulnerable zones in China. In 2007, floods seriously affected the basin: a maximum rainfall for 7 days reached 304 mm, and maximum rainfall for a single day reached 138 mm, resulting in serious natural disasters in the basin.

In terms of water resources per capita, the Hai River Basin has only 305 m^3, that is, only one-seventh of the national average and 1/24th of the world average. Water crises have occurred in, for example, 1972, 1999 and 2000 in Beijing and other big cities in Northern China due to severe droughts. Water shortages have also resulted in ecosystem

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degradation, such as some rivers drying up, wetland degradation, over-extraction of the groundwater and decreasing outflow from the Hai River Basin to the Bohai Sea (Xia *et al.*, 2007; Xia & Zhang, 2008).

Another major problem in China is that of water-related environmental issues. It is clear that China is facing huge challenges to do with water quality due to rapid social–economic developments. Poor natural water quality in some areas reaches 25% of surface water and 35% of groundwater. In some rivers the total pollution load is beyond the carrying capacity of the water resources, since it has accounted for 40–50% of runoff. Unsafe drinking water-related problems in rural areas are also urgent issues since they affect almost 0.3 billion people. Thus, water quality management has become a priority issue for water security (Xia *et al.*, 2009; MWR, 2010; Cao & Wang, 1999; World Bank, 2006).

To tackle water quality-related constraints at the national level, the MWR, the Ministry of Environment Protection (MEP), and other water-related institutions have carried out extensive work on environmental monitoring, assessment and control of water pollution since the nation entered the reform path in 1979, particularly since industrial growth began in the mid-1980s. China has established a water quality classification system based on the use of water and setting targets for protection, following Environmental Quality Standard GB 3838-2002 (China State Environmental Protection Administration, 2002). This water quality standard has five grades:

- Grade I, mainly applicable to the source of water bodies and national nature reserves.
- Grade II, mainly applicable to a class A water source-protection area for centralized drinking water supply, sanctuaries for rare species of fish and spawning grounds for fish and shrimps.
- Grade III, mainly applicable to a class B water source-protection area for centralized drinking water supply, sanctuaries for common species of fish and swimming zones.
- Grade IV, mainly applicable to water bodies for general industrial water supply and recreational waters in which there is no direct human contact with the water.
- Grade V, mainly applicable to water bodies for agricultural water supply and for general landscape requirements.
- Grade V+, essentially without any use.

Based upon this classification, water quality is being monitored on a major systematic basis in China.

For instance, the MWR, in collaboration with the MEP and other government sectors, established task forces for land and water quality assessment in 2000, taking into consideration the related river systems, lakes and reservoirs, and head water areas for drinking water (Zhou & Wang, 2005). For this comprehensive job, a huge amount of representative monitoring information and a data set on water quality in China were collected, which included the water chemical characteristics from over 2,442 monitoring stations and river water quality from 5,952 monitoring stations covering the major rivers; water quality from 237 lakes and 813 reservoirs; drinking water quality from 1,073 head water areas, etc. The changing trend of water quality in the last 30 or more years was also analysed based on 846 representative monitoring stations. Assessment and analysis showed that most water mineralization is of a standard sufficient to satisfy domestic, industrial and agricultural demands; however, both point and nonpoint pollution have

increased in China. Based on statistics, good water quality (i.e., water quality within Grades I–III of water quality standards) reaches 66% in all the assessed rivers; bad-quality water (i.e., water quality within Grades IV and V) reaches 18%. The lowest-quality water (i.e., water quality over Grade V) is about 16%. Polluted water in river systems can be characterized by a combination of organic concentrations (biological oxygen demand and chemical oxygen demand (COD)) and nutrients (ammonium nitrate concentrations), particularly in the tributaries of river systems in North China such as the Hai and Huai rivers, etc. However, high organic concentrations, particularly high COD loads, are a critical factor in poor water quality. Lake eutrophication in China is also a very serious problem. It significantly threatens water supply security and fisher products and reduces its recreational uses.

The qualifying rate at the head water levels for drinking water in China is 75.3%. The population without access to safe drinking water is 0.323 billion people, representing a major limiting factor for regional sustainable development. The trend analysis shows that even though specific pollutants can be controlled for, total surface water quality is still declining. It also appears that increased agricultural activities and higher urbanization are resulting in significantly higher ammonia nitrate concentrations.

The efficient control of the trends in water pollution in China is still a huge challenge, which makes it a priority to achieve water quality management in the country. Over the last 30 years or more China has established an extensive water pollution-control system with a large set of institutions, a variety of legislation and policy instruments, and comprehensive investment plans that were largely shaped within the traditional five-year plan preparation process. In the earlier phases water pollution control was characterized mostly by command-and-control instruments (industrial permit systems, simultaneous control programmes) and partly by economic instruments (such as pollution levy fees and discharge permits). In recent years there has been a gradual increase in voluntary approaches (such as environmental management systems like ISO 14000 and cleaner production) and public disclosure (World Bank, 2006).

Along with China's social and economic development, water policy has changed significantly. The government has recognized the need for more effective management of its water resources. Water resource management issues have been given a high priority in the 2006–2010 and 2011–2015 five-year plans. Among the many Water Resources Ministry (WRM) issues that the government must address, priorities include (1) ensuring water availability in water-scarce areas; (2) providing a clean supply of water in order to reduce the heavy burden of water-related diseases; (3) treating wastewater, with a focus on the impact on receiving water bodies; (4) rehabilitating the heavily polluted water bodies that are critical for local communities; and (5) protecting drinking water sources (World Bank, 2006).

Water policy in China is shifting from water quantity management to water quality management. Major actions highlight the need for an overall strategic plan for water quality management that establishes a long-term vision and realistic targets for five-year plans over the next 20–30 years. The Ministry of the Environment has also implemented new modifications in the Comprehensive Water Resources Programme in the river basins since 2005. The Ministry of Environment Protection and the Ministry of Science and Technology (MOST) have carried out the Key Water Environmental Project (KWEP) since 2008 which considers all issues related to China's water pollution based on scientific and new technology studies and institution innovation on water quality management.

New policy instruments include effluent standards, environment impact assessment (EIA) requirements, discharge permits, fee and levy systems, ISO 14000, and total load control. The 2002 Water Law (re-draft) in China addressed river basin management directly, specifying that "the state shall adopt a 'combined division responsibility' (CDR) system of river basin management in conjunction with jurisdictional management". It indicated that river basin management should be set up by the water administration department under the State Council, and it set out the following river basin management functions: (1) planning; (2) protection of water resources, water areas and projects (including pollutant discharge loading and sewage facilities); (3) water resources allocation; and (4) water dispute resolution. China is thus facing the dilemma of reducing water pollution problems and, at the same time, continuing with its social and economic development on which water quality management plays a fundamental role, in addition to big challenges such as floods and droughts.

Water quality management is thus related to integrated water quality and quantity management and also to water projects operation. The Huai River Basin (HRB) is a very complex case in terms of water quality management. It is presented here as an example of the major challenges in water quality management in China and why water quality management will play a key role in water sustainable use and management. This paper also addresses how water quality management is impacted by wastewater control and the operation of water projects.

Background of the Huai River Basin

The HRB (30°55′–36°36′N, 111°55′–121°25′E) is one of the top seven river basins in China. It is located between the Yangtze River Basin and the Yellow River Basin (Figure 1). It flows through the five provinces of Hubei, Henan, Anhui, Shandong and Jiangsu. It is the most densely inhabited river basin and the main grain-producing area of China. In 2005, the total population and grain yield accounted 13.1% and 16.1%, respectively, of the national total. Its average population density is approximately five times of the national average.

Although annual mean precipitation and water resources of the basin are 888 mm and 83.5 billion m^3, respectively, water resources per capita and unit area are less than one-fifth of the national average. Moreover, because 50–80% of annual precipitation is concentrated during the rainy season (June–September), the basin faces both flood and drought problems. Before the establishment of the People's Republic of China in 1949, the average flood and drought disasters occurred 94 and 59 times more per century, respectively. The basin was thus named the "disastrous river basin" in China.

Due to demands on flood control and water supply in the HRB, more than 5,700 reservoirs and 5,000 sluices have been constructed in most of the main streams and tributaries. This is a positive development since dams and sluices in the HRB provide a useful engineering solution for flood control, irrigation, water supply, etc. On the other hand, the water project's impact on water quality and the ecosystem are also considered as a new and urgent issue for the sustainable development of the HRB. One warning was the river pollution event in 1994 during a period of flooding in Huai main stream. Due to heavy rainstorms upstream, the water level in the reservoirs was alarmingly high and gates had to be opened to discharge the excess water. This event allowed 0.2 billion m^3 of polluted water accumulated in sluices during the non-flood period to flow downstream of

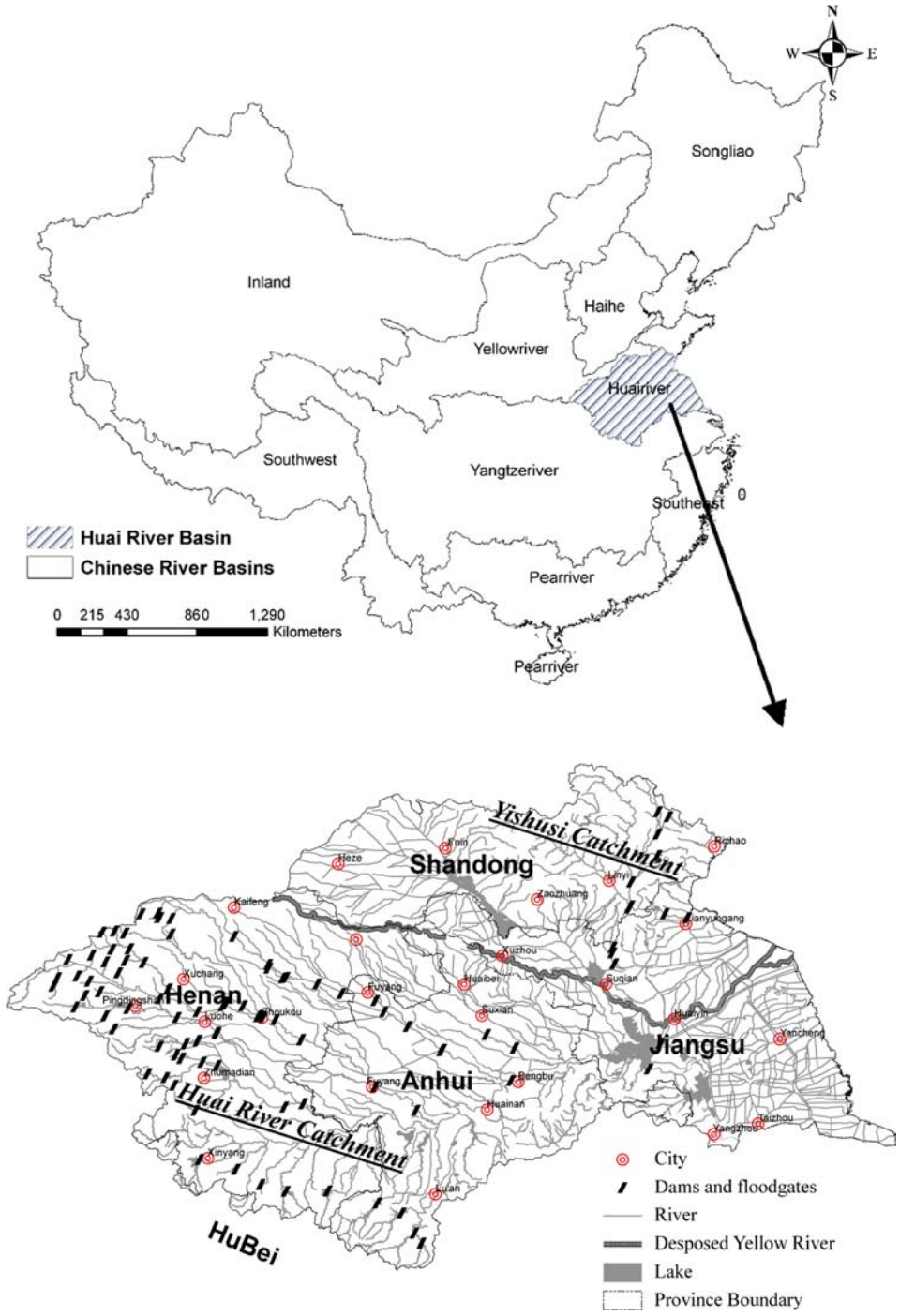

Figure 1. Location of the Huai River Basin.

the HRB. Polluted water reached 90 km. Waterworks in the main channel of the HRB had to stop supplying water for 54 days and this resulted in 1.5 million people facing drinking water problems. It also caused at least RMB2 billion of damage. The excessive number of water projects and unreasonable regulation resulted in the discontinuous flow, slowing flow velocities and reducing the water environment-carrying capacity, and so triggered the accidental pollution events, all of which further contributed to the deterioration of the water environment.

Pollution discharged into rivers has increased year on year. More than 83% of rivers in the HRB do not reach the national standard (GB 3838-2002; China State Environmental Protection Administration, 2002), having the worst water quality in the nation's top seven basins in 2005 (MWR, 2010). The water pollution has further aggravated water shortages and destroyed the river's ecosystem. Water pollution has become a major issue for management of the HRB.

Research Plans and Actions

The Chinese Academy of Sciences (CAS) is the national scientific research body. The water cycle and water security in China are priority issues regarding resources and environmental management fields. In the past decade several studies by the Key Laboratory of Water Cycle and Related Land Surface Process, CAS, and the Center for Water Resources Research, CAS, have focused on water-quality issues in the HRB. Thanks to cooperation with the Huai River Commission of MWR on water quality management, several research projects on Huai River water quality management, pollution control and the operation of water projects are supported by CAS and MOST. Major goals and research projects focus on three aspects: (1) identifying the major causes of water problems in the Huai River; (2) assessing the impact of dams and sluices on water quality and the ecosystem; and (3) developing comprehensive best management practices based on the operation of water projects and wastewater control to improve river health. Three-phase plans have been implemented in 2007–2011, i.e., environmental monitoring for the overall water cycle and related ecosystem changes due to water projects and reservoir operation in the river system; modelling systems to integrate the main interactions and impacts of dams on physico-chemistry, biology and other characteristics; water quality management and operational systems to evaluate the positive and negative benefits on economic, sociological and ecological aspects under different operational modalities; and development of the best operation schemes for river restoration. More than four years after having started these projects, the major challenges on water quality managements have been identified as follows.

Water Quality is the Priority Issue on Water Security in the HRB

Water pollution in the HRB began in the 1970s and it became increasingly serious after the 1980s (Xia *et al.*, 2009). The main pollutant sources were industrial and municipal point sources and agricultural nonpoint sources (Zhou & Wang, 2005). The Water Resources Protection Bureau of the Huai River Commission has implemented as routine a water quality monitoring system in the whole basin since the 1980s with the support of the local governments in Henan, Anhui, Jiangsu and Shandong provinces. Monitoring activities

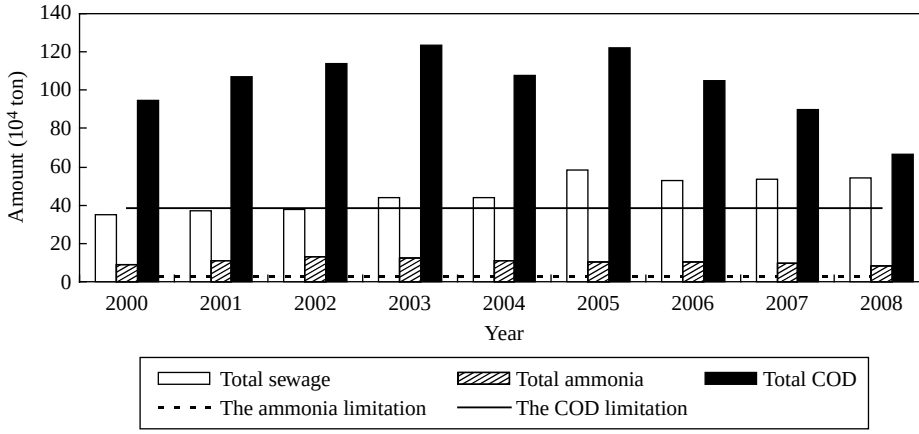

Figure 2. Pollutant discharge amount in the Huai River Basin from 2000 to 2008.

include monthly sampling of the polluting load in the sewage outlets into rivers, in rivers of 220 cities; and water quality in 153 areas of different water resources and 51 provincial boundary cross-sections. Water quality monitoring indexes included water temperature, turbidity, pH, dissolved oxygen, organic pollutants, nutrients, metal material, etc. (He & Wang, 2001; Xia *et al.*, 2009).

According to the water resources bulletins from 2000 to 2008, the main pollutants in the HRB were NH_3-N and COD, and the total pollutant amount in the rivers has always been above the emission limitation (COD = 38.2 tons, NH_3-N = 2.66 tons). In 2008, the amounts were 0.74 and 2.05 times more than the limits, respectively (Figures 2 and 3). The industrial and municipal point sources are the main pollution sources. In addition, the nonpoint sources of pollution were also considered because HRB is the major grain-producing area. Its contribution was nearly 30% of the total amount of pollutants going into the river in 2000. The main sources are the excessive use of pesticides and chemical fertilizers, livestock and poultry farming, and straw decay, all of which are washed into the rivers and thus increase the load of COD, total nitrogen and total phosphorus.

The excessive pollution load has caused most rivers to become seriously polluted. The Huai River Commission has insisted on assessing water quality status in the whole basin every year based on the national standard (GB 3838-1983, 2002, etc.; China State Environmental Protection Administration, 1983, 2002). It has also published a water resources bulletin since the 1990s. The rivers that were in or below Class V (unsafe water) were always nearly 50% of the total samples assessed, and the rivers in Classes I–III (suitable for drinking water) were less than 40%. Furthermore, the percentage of non-safe water was greater than 60%, and the water suitable for drinking use was only nearly 20% between 1994 and 1998. (Wang *et al.*, 2005) (Figure 4).

The monitoring of provincial boundary cross-sections has shown that the water quality status of these cross-sections was even worse than in other areas from 1994 to 2005. Thus, although great efforts have been made to improve the environmental quality of the river basin, the goal of "Huai River water is clean" has not been achieved so far. The situation of water pollution is extremely critical.

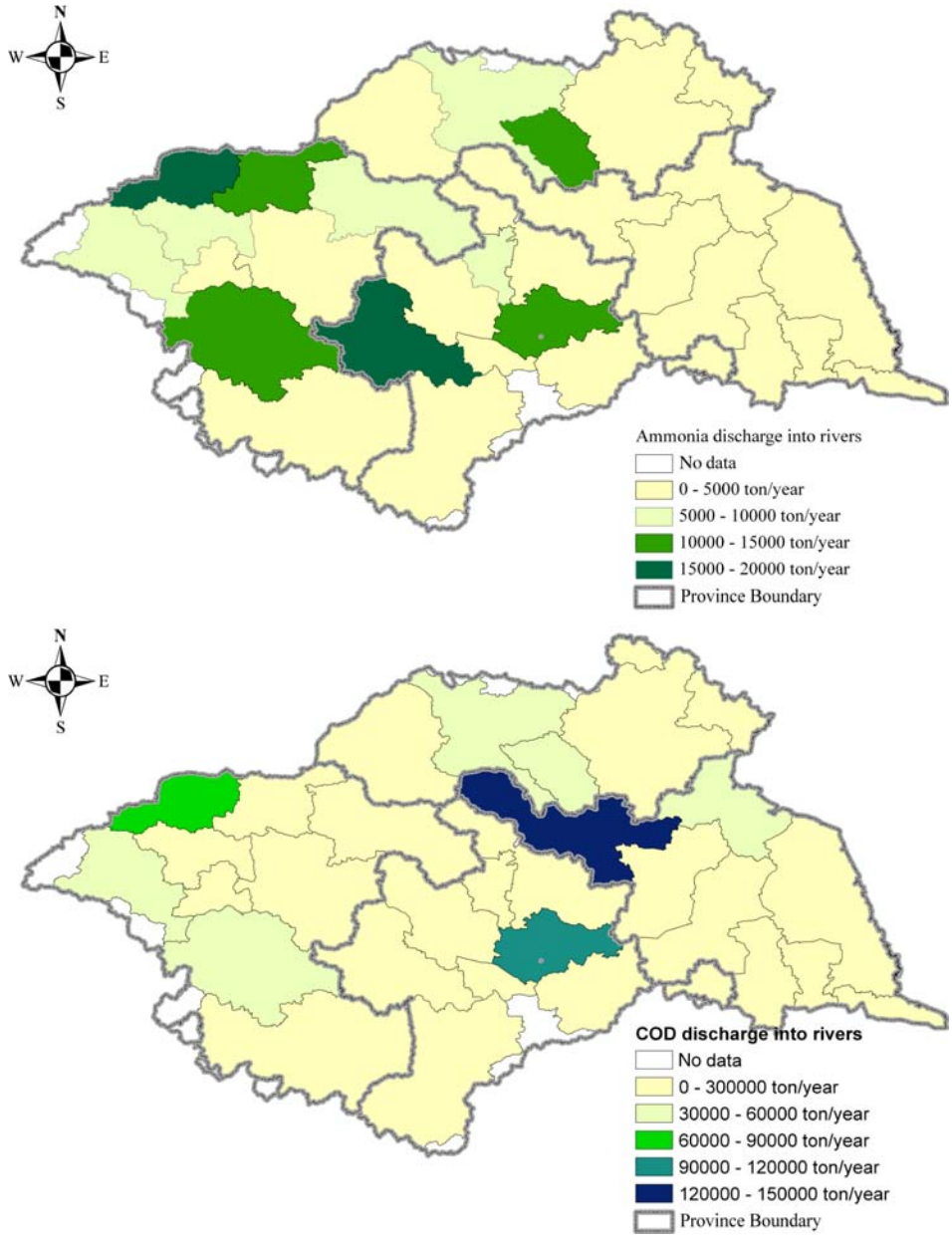

Figure 3. NH_3-N and COD sources distribution in the Huai River Basin in 2000.

Control of wastewater pollution sources is thus essential for water quality management in the HRB. Total maximal daily load (TMDL) and its load content in the basin was suggested to have been identified by the National Key Water Project (2009–2019) where water quality is the priority issue from a water security viewpoint in the HRB.

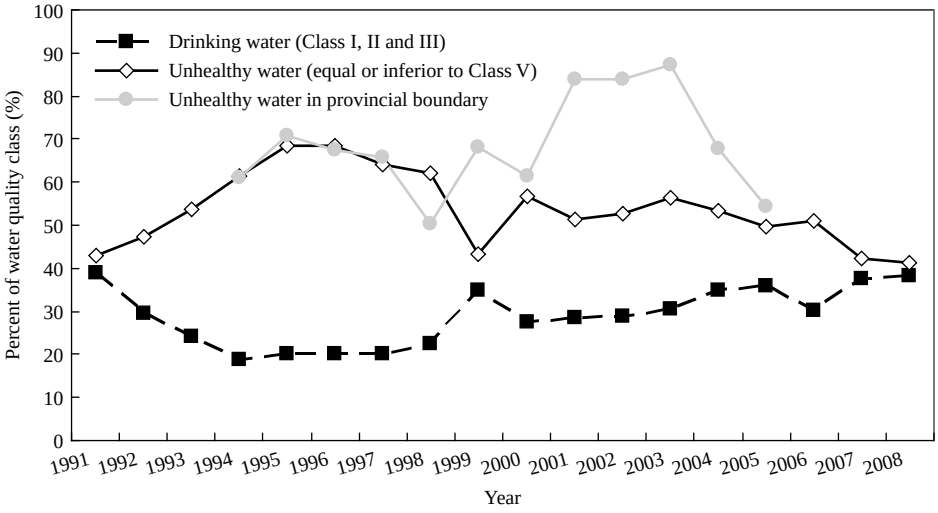

Figure 4. Percentage of river water quality classes from 1991 to 2008 in the Huai River Basin.

New Challenges on Integrated Water Quality and Quantity Management

The Huai River is a strongly regulated river due to a large number of water projects for flood control and water supply. The traditional regulation of water projects has focused mainly on its use (e.g., flood control, electricity generation, water supply, irrigation and aquaculture), but it has not taken into consideration environmental issues. However, so many water pollution sources have posed a huge risk of pollution for the river. Thus, new challenges will focus on how to integrate water quality and quantity management as well as the operation of projects in the HRB.

Some research on the impact of water projects on the river flow regime, the environment and ecology in this basin was carried out by CAS (Xia *et al.*, 2008). The research focused on the 87 main dams and sluices, and the typical year was 1999 ($p = 95\%$, an extremely dry year) when the impacts of dams and sluices were significant (Figure 5). The results showed that compared with the pre-dams' scenario, the annual runoff at the outlet of the river basin in the post-dams' scenario decreased by 13%, the downstream carrying capacity of the water environment decreased by 16%, the contribution of a single dam on water quality in 1999 was less than 30%, and the average contribution was nearly 10%. Furthermore, the contribution of the dam groups in the upper and middle stream of the HRB was less than 38% (Xia *et al.*, 2008; Wang & Xia, 2010; Zhang *et al.*, 2010). The impact of water projects on water quality cannot be disregarded.

Water projects in river systems have thus the potential to increase water pollution, but only when there is no appropriate control of polluting sources. Thus, it is a very important issue that China integrates water quality and water quantity management, and the operation of water projects. This issue should be emphasized in the overall operation of river systems.

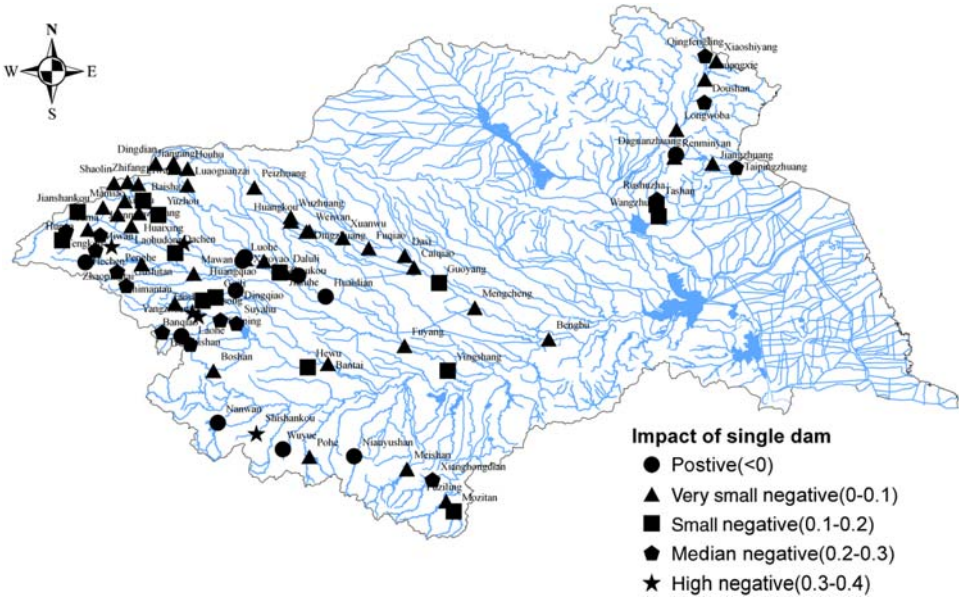

Figure 5. Contribution of 87 single dams and sluices on water quality in 1999 ($p = 95\%$, extreme dry year) in the Huai River Basin.

Challenge on Institutional Innovation on River Management Mechanisms

The State Water Resources Ministry, Environmental Protection Ministry and the local provincial governments are the management authorities in terms of river basins in China. Therefore, all these organizations have collaborated in the environmental management of the HRB directly, including the Water Conservancy Bureaus of Anhui, Henan, Jiangsu and Shandong provinces, the Environmental Protection Bureaus of the four provinces and the Huai River Commission.

The Huai River Commission was considered the main administrative department in the Water Law of P. R. China. However, it could not be a true leader in terms of environmental management because of the limitations it faced in terms of law enforcement. Every department that participated in this study worked on its own, within different jurisdictions. In addition, contradictions and a lack of effective communication and cooperation occurred among different departments, especially between the environmental protection and the water resources departments.

There were also some blind spots regarding law enforcement, such as in the provincial boundaries. At the same time, law enforcement existed in the different sectors, such as the water conservancy departments and environmental protection departments for a considerable time. Both the Water Resources Ministry (WRM) and the Environmental Protection Ministry (EPM) had their own monitoring system and there was a great gap between these two data sources. For example, the COD load discharged into the rivers, as published by the WRM, was 94.7×10^4 tons in 2000 and the load was 123.2×10^4 tons in 2003, which means an increase of 30%. However, the data published by the EPM were 81.2×10^4 tons and 71.2×10^4 tons in 2000 and 2003, respectively. This means that the

load in 2003 decreased by 12.3%. The management departments were confused and could not make reasonable decisions because of this discrepancy in the information.

Furthermore, economic development and environmental protection have been traditionally regarded as opposite issues. Gross domestic product growth was a key indicator for evaluating the achievements of government officials in their positions, while the indicator related to environmental quality was not considered at all. The implementation of Environmental Protection Law was obstructed by local protectionism. The harmonious development of the socio-economy and environmental protection in different regions was always emphasized, but was difficult to realize.

Conclusions and Recommendations

Water quality management in China is facing enormous challenges due to pressures from its population and economic growth. Along with China's social and economic development, water policy has gone through significant changes. The government has recognized the need for more effective management of its water resources. In fact, water resource management issues are given a high priority in the 2006–2010 and 2011–2015 five-year plans.

In the case of the HRB, water pollution has resulted from both the impacts of wastewater load increase and the development of water projects. It is a very good case study of how to handle effectively environmental impact assessments and water quality management-related issues.

The control of pollution sources in the HRB will be the most essential issue for water quality management. TMDL and its load allocation in the basin area could be used to identify major polluted areas as well as sources by the National Key Water Project (2009–2019).

Water projects in river systems also contribute to the increased risk of water pollution when there is no appropriate control of polluting sources. Therefore, integrated water quality and water quantity management, as well as the operation of projects, have become very important issues in China.

Several suggestions regarding integrated water quality and water quantity management as well as for operation of projects are suggested below.

Strengthen Integrated Monitoring and Unify Different Data Sources

The current monitoring processes of water quality are not continuous nor systematic because of a shortage of funding. The frequency of routine monitoring was only two or three times per month and real-time monitoring was very difficult also because of low investments (He & Wang, 2001). It was common that some small but highly polluting workshops or factories would close their outlets during the monitoring process to avoid being fined, only to open them again later. In addition, routine monitoring was of no use for tracking spatial and temporal variation of water quality along the rivers whenever there was an accident which involved pollutants. Therefore, the monitoring plan should be strengthened and new techniques included into routine monitoring plans such as real-time monitoring systems, auto-monitoring systems or remote sensing (RS) monitoring techniques. Moreover, the different data sources from WRM and EPM should be unified.

Strengthen Pollution Source Control and Adjust Industrial Structure

The control of wastewater load is still a significant issue for Huai River Basin. The COD and NH_3-N amounts discharged into rivers were 0.74 and 2.05 times more than the limits set in 2008 (Wang *et al.*, 2005). Thus, pollutant emission is still the major cause of water pollution in the HRB. The construction of sewage treatment facilities (pipe networks, treatment plants, etc.) should be further speeded up and the improvement of industries should be strengthened. Strict control and discharge permit management for the total pollutant amount should be carried out. Some highly polluting enterprises (paper-making, tanning, brewing, chemical industry, etc.) should construct sewage treatment facilities as soon as possible, or control the pollutant load by modifying their infrastructure, including closing, combining or transforming some facilities. In addition, agricultural nonpoint source pollution control should also be strengthened.

Strengthen Integrated Water Quality Management and Research at the Basin Scale

Water pollution is the biggest water problem in the HRB. Although improvements have been carried out for nearly two decades, the achievements have not been remarkable. One of the main reasons is that all the previous works were confined to a particular region or one water problem, but they ignored the influence of different regions or other water problems. Following the advanced experience of river basin management, the best practices should integrate all water related-managements issues (e.g. flood control, pollution control, water supply, ecological restoration, regulation of water projects, etc.) at a basin scale. The basin water cycle (hydrological and socio-economic) should be the foundation for the integrated management which should also explore the interactions of these water problems in the different regions. For integrated water quality management, some primary works should be completed in the HRB, for example:

- Identify the spatial and temporal distribution of pollutant sources.
- Identify the types of pollutant materials (organic pollutants, persistent organic pollutants (POPs)) and their contribution to water pollution.
- Develop integrated water quality warning and prediction systems based on the water cycle model by using RS and geographical information system (GIS) techniques, and quantify the risk probability of water pollutant events.

Water quantity and quality regulations of water projects should be made jointly. The regulation of water projects should give considerable attention to the environment and the ecology, and not just to flood control and water supply in the HRB. A joint water quality–quantity operation of water projects is an important approach to improve the environment (Chen *et al.*, 2005; Zhang *et al.*, 2010). In highly polluted rivers (Shaying, Guo, Hongru, etc.), operations should keep a small discharge rate in order to make sure that water storage is not affected by any form of upstream pollution during the non-flood season. In the flood season, operations should control floods and extend the discharge time of polluted water by using the storage capacity of the dam groups. Moreover, the dams in highly polluted streams should dispatch with the dams in lesser polluted streams to lighten the damage of polluted water, especially in the event of pollution accidents.

Strengthen Legal Management and Public Participation

In August 1995 the State Council enacted China's first basin-wide water pollution control laws and regulations: "Interim Regulations on the Prevention and Control of Water Pollution in the Huai River Basin".

The State Council also applied successive programmes for the prevention and control of water pollution and the 9th and 10th five-year plans of the HRB in 1996 and 2003, respectively (Zhou & Wang, 2005). Nearly 2,300 water management laws and regulations have been issued. The excessive management departments and laws made decentralization and the legal system imperfect.

Environmental protection management should insist on the principle of integrated legislation, integrated planing, integrated supervision, division of labour with individual responsibility and responsibility of the government. The implementation of all planning and activities should follow the laws and regulations. The Huai River Commission should become the implementing agency for integrated water quality management in the HRB; and the environmental protection responsibilities of the authorities at the local level, the environmental protection departments and water resources departments at all levels should be clearly defined by law, especially in the Interim Regulations. The accomplishment of the water pollutant protection objectives should be an indicator to evaluate the performance of local governments and officials. All local governments should be required to sign a responsibility pledge committing to fulfil the protection, reducing the target set up in the 11th five-year plan.

Finally, multi-department cooperation and consultation systems and public participation processes should be developed. Environmental protection and improvement is not just the mission of management departments. All residents should also play active roles in this long, complicated and difficult task.

Acknowledgements

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