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CONSTRAINING FACTORS TO SUSTAINABLE UTILIZATION OF WATER RESOURCES AND THEIR COUNTERMEASURES IN CHINA

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ABSTRACT: This paper discusses the constraining factors to sustainable utilization of water resources in China, and the countermeasures to realize sustainable water utilization. The result of comprehensive analysis shows that constraining factors to sustainable utilization of water resources in China are complicated, including physical geographical factors and socio-economic factors, such as uneven distribution of water resources at temporal and spatial scales, inappropriate institutional arrangement and non-water-saving and non-water-conservation production and life mode. The countermeasures against constraining factors to water resources sustainable development are put forward as follows: 1) using wetlands and forests, and through spatial conversion to realize temporally sustainable supply of water resources; 2) transferring water between basins and areas and developing various water resources in water shortage area; 3) establishing water-saving society; 4) strengthening water pollution control and water resources protection; and 5) establishing unified water resources management mechanism.
KEY WORDS: water resources; sustainable utilization; China

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Water resources are essential and indispensable for sustaining biologic lives and supporting social and economic development, and sustainable utilization of water resources is vital to human existence and socio-economic sustainable development. Although water resources are relatively plentiful in China, with a total amout of $2.8124\times10^{12}m^3$, the per capita average water resources are only $2500m^3$, which accounts for 1/4 of the world average level (DENG *et al*., 2002). With the rapid population growth and socio-economic development in China, the demand for water is increasing and water resources are under mounting pressure, and the exploitation and utilization of water resources is becoming unsustainable. Constraining factors to sustainable utilization of water resources in China are complicated, including physical and geographic factors and socio-economic factors. To comprehensively analyze these constraining factors and give their countermeasures can provide a scientific base for the reasonable utilization of water resources and is beneficial for the socio-economic sustainable development.

1 CONSTRAINING FACTORS TO WATER RESOURCES UTILIZATION IN CHINA

1.1 Uneven Distribution of Water Resources at Temporal Scale

Physical geographic conditions of China result in quite uneven distribution of water resources over the country at temporal scale. The country lies in the east of the Eurasia Continent, and it covers a vast territory with varied topographic and diverse physical features, including complex climates. The southeastern part of the country is affected by the southeastern monsoon of the Pacific Ocean and its southwestern part is influenced by the southwestern monsoon of the Indian O-

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cean. Influenced by monsoon and continental climates, precipitation in the northern China tremendously varies with a change rate of 15%–30%. Precipitation in summer (June, July and August) accounts for 60% of total annual precipitation and from May to October the precipitation constitutes about 80% of total annual precipitation, thus floods tend to be in summer and droughts are likely to occur in other seasons. Continuous dry-years phenomenon appeared in all main river basins in China such as the Songhua River Basin in Northeast China, where once dry period lasted for 7 years continually with extremely less precipitation. The temporally uneven distribution of water resources due to physical geographic restrictions makes it very difficult to sustainably exploit and utilize water resources.

Unreasonable exploitation of floodplains especially deforestation and encroachment of wetlands intensified the uneven distribution of water resources temporally. More than 90% of cities are located in and about 600×10^6 people live in floodplain areas in China. The latest census statistics show that in floodplain areas there are 300 –500 persons/km^2 with the highest as 1000 persons/km^2 and population in floodplain areas are rising (Nanjing Institute of Hydrology and Water Resources, Office of State Flood Control and Drought Relief Headquarters, 1997). Due to over lumbering and less afforestation stimulated by economic profits, forest coverage in the upper reaches of main rivers and floodplains in China dwindled severely, and taking the Changjiang (Yangtze) River as an example, forest coverage in the upper reaches diminished from 50% before the 13th century to 22% in the 1950s and to about 10% at present. Excessive exploitation and ceaseless encroachment of the naturally flood occupied the areas under the pressure of population growth and agriculture and industry development, especially blind reclamations from riverside wetlands resulted in loss or shrinkage of the floodplain wetlands, reduction of the cross section of river course and the flow increasing of flood stage in rivers, thus water storage capacity of basins was lessened. In the middle and lower reaches of the Changjiang River, more than 800 000ha of floodplains have been reclaimed and changed into farmlands and industrial areas in the past half century, and 82% of the seasonal inundation floodplains completely lost (CHEN and CHANG, 1995). The capacity of water interception and storage by forests and wetlands was severely decreased and rainfall was not sufficiently regulated by forests and wetlands before and after the flood period. In order to protect life and economy from damage caused by flood, preventing and controlling flood through building levees and dams is the major theme of river management in China. In the country, cognition about flood is almost entirely biased on its socio-economic calamitous effects, and flood is generally viewed as disaster, calamity and even evil. However, flood is intrinsically a kind of water resources and flooding is a form of water resources reallocation and it plays a significant role in balancing and modifying the distribution of water resources especially at time scale (ZHAI *et al*., 2000). Natural flood is extremely constrained within river channels because the flood management strategy stresses more drainage than storage and the general guideline of flood management is anti-flooding, thus plenty of flood water resources are not intercepted by floodplain wetlands and forests, on the contrary, they are drained and wasted in the rain season and after the rain season there is severe water shortage.

1.2 Uneven Spatial Distribution of Water Resources and Water Shortage Especially in the northern China

Due to physical geographic conditions, the eastern and southwestern parts of China are moist and have relatively plenty of precipitation, while the northwestern part of the country extends into the deep inland of the Eurasian Continent and is quite arid with little precipitation. To the north part of the Changjiang River, with an area accounting for 64% of China, water resources takes only 20% of the whole country (FENG, 2000). Only 10% of China's groundwater lie under one-quarter of the country's cultivated land, which is located in Beijing and Tianjin municipalities, and Hebei, Shandong and Henan Provinces. Water resources per capita in China only accounts for one fourth of the world's average level, and in the Huanghe (Yellow) River basin, the Huaihe River basin and the Haihe River basin in the northern China water resources per capita is only one fifth of the country's mean level and water shortage has constricted socio-economic development in those areas severely. At present, annual water shortage is 21.8×10^9m^3 in China and 18.1×10^9m^3 in the northern China. Annual economic losses due to water shortages in the northern China amount to more than 120×10^9 yuan (RMB) (about US$14.5 billion) each year. About 27×10^6ha of farmland are hit by drought each year countrywide and there are 30×10^9m^3 of water shortfall for irrigation annually. More than 400 of China's 699 cities are confronting water shortage and 110 cities are seriously threatened by water shortage and in urban areas the annual water

shortage is $6\times10^9m^3$ in the country. In drought years such as in 2000, water rationing was adopted for dwellers in cities such as Tianjin, and in cities of Harbin, Changchun, Tianjin and so on public baths, car washing were limited even closed for saving water. In rural areas, it is very difficult for 65×10^6 persons and 60×10^6 domestic animals to get drinking water. Water shortage has been "the neck of bottle" for sustainable social and economic development in China.

1.3 Tremendous Water Resources Waste

In China, there is a phenomenon of the coexistence of serious water shortage and severe water waste. Irrigation consumes over 70% of total water supply in China but the irrigation efficiency is very low in the country. Of China's existing 130×10^6ha of cultivated land, 40% are irrigated, but of which only 5% have adopted modern water-saving irrigation techniques such as spray and drip irrigation. In most of the irrigation areas, the irrigation method is to let the water flow freely all over the piece of land until it is covered with a certain depth of water. Because of poor ditches and antiquated and outdated irrigation facilities, irrigation water is seriously lost through evaporation, leakage and deep drainage and the result is that only about 40% of the country's irrigation water is used effectively. Taking the Huanghe River basin as an example, about 90% of the water resources there are used for irrigation but the irrigation efficiency is very low, and only about 30% of the irrigated water is used effectively. Besides agriculture, expanding industrial sector needs a larger amount of water resources and the water use efficiency in industries is 75%, being lower than that of developed countries. Water leaking in the municipal water supply system is very serious, and more than 20% of the water is leaked out in most of the cities. Welfare water resources allocation system formed under the planned economy makes agricultural and industrial and other water users have little incentive to invest in water recycle and wastewater treatment because they receive little benefits for doing so, and at current low price levels, people tend to care little about wasting water and concern little about the government's advocacy of water conservation and water saving.

1.4 Water Shortage Aggravated by Water Pollution and Destructive Use of Water Resources

Industrial waste water and urban sewage treatment rate is low, with only 1 sewage treatment plant per 1.5×10^6 persons in China, compared with 1 sewage treatment plant per 5×10^3 persons in developed countries. About $41.6\times10^9m^3$ of waste water and sewage are discharged by municipalities and industry each year, among them 95.5% of the municipal sewage and 83% of the industrial wastewater are discharged into rivers and nearby water bodies or used as irrigation water without any treatment. According to the Bulletin of Chinese Environment Status Quo in 2000 by the State Environmental Protection Administration of China, seven major rivers are all polluted to various degrees and organic contamination is serious in rivers. Lakes are losing and the remaining parts are eutrophic. Over extraction of groundwater in a plunderous way in the northern China has produced depression cones in aquifers. Depression cones in the deep aquifers in Heibei Province, the north of Henan Province and the northwest of Shandong Province have linked together and formed an area of over $40\times10^3km^2$ with depression cones in the northern China, including Beijing, the capital of China, and Tianjin, one of the municipalities directly under the jurisdiction of the central government (The State Environmental Protection Administration of China, 2001). Within the extremely over-extracting areas, land subsidence and seawater intrusion and other environmental problems has been induced. For instance, the central area of Tianjin has subsided by 2.6m since the 1960s. From inland rivers, lakes and reservoirs to marine water areas, the overall water eco-environment has been widely polluted and destructed.

Widespread contamination of surface waters by industrial wastewater and inappropriate application of pesticides and chemical fertilizers in farmland resulted in regional disease such as gastric illness and cancers, and the yearly discharge of 30×10^9t of sewage, of which only 2.7% were treated, resulted in 1.5×10^6 cases of acute schistosome infections every year. The loss of yield of fresh water fish due to water ecosystem destruction amounted to 80×10^3t yearly. The available water resources reserve for development and utilization via engineering measures has been obviously polluted, reduced and heavily damaged. The quantity, quality and availability of clean water resources have been severely changed. Water pollution and destructive exploitation of groundwater have worsened the eco-environment quality, aggravated the contradiction between water demand and supply thus intensified the already strained water shortage crisis in China.

1.5 Lack of Unified and Integrated Water Resources Management Mechanism

In Chinese folklore, dragon in the heaven was responsible for water resources management. Now, in the country, there are too many agencies and governments giving approval to water management and this phenomenon is called "multi-dragons manage water" in China. Ministries of the P. R. China, including Ministry of Water Resources, Ministry of Construction, Ministry of Agriculture, Ministry of Transportation, Ministry of Land and Resources, National Development and Reform Commission, and the State Environmental Protection Administration *et al*., all have some responsibilities for water resources management. There are corresponding affiliated departments and bureaus to each of the above management sectors in governments at all levels such as provincial, prefectural and county. All of the ministries and administrations have some management authorities, for instances, approval to water source engineering rests with the Ministry of Water Resources and its affiliated departments and bureaus, and water supplying rests with the Ministry of Construction and its affiliated departments and bureaus, and water pollution control rests with the State Environmental Protection Administration and its affiliated bureaus. Exploitation of surface water and groundwater is separately managed by different agencies. There are short of efficient and sufficient co-operations between different agencies in water resources management as the management sectors strengthen their own benefits as they take part in the management affairs. There are river basin commissions affiliated to the Ministry of Water Resources in main river basins in China, but their responsibilities and accountabilities are not definite and their roles in basin and water resources integrated management are constrained.

2 COUNTERMEASURES AGAINST CONSTRAINING FACTORS TO WATER RESOURCES SUSTAINABLE DEVELOPMENT

2.1 Using Wetlands and Forests or Other Methods, and Through Spatial Conversion to Realize Temporally Sustainable Supply of Water Resources

Wetlands and forests serve as natural regulators of floods in river basins as they intercept rainfall or give places for runoff from precipitation to be stored and also supply water for rivers. Forest can regulate river runoff through water interception by canopies, trunks and branches and infiltration into forest soils during flooding period and give them back into rivers after flooding. Water storage of forest can reach 50×10^3 m^3/km^2 to $200\times10^6 m^3/km^2$, and flood runoff can be reduced 70%−95% in forest stands. In China, rainfall water resources caught by forest crown can reach 134−626mm and the average precipitation interception rate by forest crown is 21.6% (LI, 1999). During the periods of flooding over banks, wetlands act as sponges soaking, absorbing and holding water, and after the flooding period, wetlands gradually release the water they stored into river again. So, in flooding period wetlands and forests can reduce flood peak runoff and reduce the flood discharge, thus suspend the coming of flooding peak and store water resources, and in low-water season, they can significantly enhance the runoff in rivers by recharging water stored in flooding period, thus low-water period of rivers is shortened and water resources are relatively evenly distributed in rivers at temporal scale (DENG *et al*., 2000). Unreasonable deforestation and excessive encroachment of wetlands in China especially in environmentally vulnerable areas have brought about increased soil erosion and hydrological regime negative changes of rivers as demonstrated in the 1998 flooding in the Changjiang River basin, the Songhua River basin and the Nenjiang River basin. Effective measures such as establishing more wetland and forest natural reserves must be taken to protect forests and wetlands from being further damaged, and related projects such as the project of Natural Forest Protection and the project of Turning Farmland into Forests and Wetlands should be promoted. In the upper reaches of the Changjiang River and in the upper and middle reaches of the Huanghe River, remaining natural forests should be strictly prohibited from lumbering. Frequently inundated wetlands by floods should be prevented from being reclaimed. We recommend that all the hillsides above 25° in slope degree with forests and all the wetlands within 10-year inundation frequency floodplains should be prohibited from being further reclaimed and developed, and in environmentally fragile areas they should be closed and used as natural regulators for runoff and water resources even distribution at time scale.

Besides using wetlands and forests to store rainwater and through spatial conversion to regulate river runoff, rainwater should be fully used according to local topography and physiognomy and the measures should be adopted according to local conditions. In

some areas the northwestern China, people dig kariz, water cellars and vaults, water pools and ponds in their courtyard or on their fields on the slope spontaneously to store the rainwater. They use the stored rainwater both for drinking and for irrigation after the precipitation period. Through these approaches the rainwater is distributed evenly the year round and used more efficiently. The 121 Rainwater Collection Projects in Gansu Province, the 112 Rainwater Collection and Water-saving Irrigation Projects in Inner Mongolia Autonomous Region, and Rainwater Collection by Vaults and Water-saving Irrigation Project in Hui Autonomous Region of Ningxia have gained efficient eco-environmental and socio-economic benefits. Through the spatial pattern exchange of water resources comparatively sustainable distribution can be available in the temporal pattern.

2.2 Transferring Water between Basins and Areas and Developing Various Water Resources in Water Shortage Areas

Water resources shortfall would continue to increase even to unbearable levels with the further social and economic development in North China since water resources in this area have been tapped rather sufficiently and there is less potential to further increase locally available water supply. According to the Ministry of Science and Technology, 80% of water resources in North China have already been exploited and the remaining parts are all too expensive to be developed. Water saving and water tapping measures can not thoroughly resolve the water resources shortage problem and change the situation of the deteriorating of water eco-environment in North China. The South-North Water Transfer Project, which transfers water resources of the Changjiang River Basin to the Huanghe River Basin, the Huaihe River Basin and the Haihe River Basin, is necessary to be carried out. The South-North Water Transfer Project, which would be the largest water transfer project ever, has drawn broad discussions in academia of different backgrounds such as economy, ecology, geography and so on. Although there still has disputation even controversy about the project, now a consensus is emerging in China that the Central and Eastern Routes of the project should be built as quickly as possible and this has been backed up by Chinese government as the project has been listed as one of the four most important projects during the "the 10th Five-year Plan", which is the basic social and economic development plan of the country. There are some other water transfer projects carried out or being implemented such as the project of Transferring the Songhua River′s water to Changchun City, the project of Transferring the Yingna River′s water to Dalian City and so on. These projects play significant roles in supplying water for municipal and industrial demand and relieving the constraint of water shortage to social and economic activities in the water receiving cities and areas.

Besides receiving transferred water resources, in water shortage areas especially in coastal areas, seawater should be developed. China has $4.73\times10^{6}km^{2}$ of sea area on the middle part of the West Pacific coast and a long coastal line in its east and southeast. Utilization of seawater including directly using seawater and seawater desalination is an important pass to mitigate fresh water shortage in coastal cities and areas. In China now, seawater is mainly used for cooling electric and chemical industries and the use of freshened seawater is far more behind because of lagging of related technology development. Advanced technology and methods should be studied, developed and applied to seawater desalination or seawater direct utilization. Besides developing and utilizing seawater, technology research and application of light saline water in irrigation or municipality using should also be promoted to reduce the pressure upon freshwater resources.

2.3 Establishing Water-saving Society

Regional socio-economic development plan should be in accordance with the loading capacity of water resources and should include water resources development plan as one part of it. Agricultural, industrial, municipal and domestic water consumption should all be on the basis of water saving. It is very significant to develop water-saving irrigation and water-saving agriculture management since agriculture is the largest consumer of water resources in China. According to the basic economic and technologic conditions of agriculture in China, the technology of plugging channel leaks or using low-pressure pipes instead of channels to reduce water leakage, evaporation and infiltration must be promoted and developed, and to adopt spray or drip irrigation technology in the areas with the appropriate economic and technological conditions. Besides water-saving irrigation, effective technological measures should be taken to develop water-saving agriculture management, including selection of drought-resistance species, preservation of soil moisture, plastic film or crop straws covering, reasonable

utilization of chemical agent for moisture preservation and so on. To industrial water using, efforts should be made to raise the efficiency of the industrial water consumption and lessen water consumption by adjusting and optimizing the industrial structures, adopting the water-saving technology, limiting the highly water consuming productions, raising up the ratio of the new technological industries which has less water demand. To domestic and municipal water supply and consumption, water supply plan should be scientifically made and management should be strengthened, and efforts should be made to improve efficiency of water delivery by reducing the seepage loss in the running water conveyance pipes network. Public education and professional training programs should be widely initiated and strengthened to raise public awareness and increase productive efficiency in water-saving. The establishment of water-saving society must be realized via multimeasures including administrative, economic, technical, legal and moral measures.

2.4 Strengthening Water Pollution Control and Water Resources Protection

Efforts should be made to prevent the deterioration of the aquatic eco-environment and realize the benign cycle of water resources through strengthening water pollution control and water resources protection. It is necessary to set up an effective mechanism of supporting information for water pollution control and water resources protection decision making through establishing an integral monitoring network of surface water and groundwater. To control agricultural pollution to water resources, countermeasures should be taken, including improving farming techniques especially about reasonable fertilizer and pesticide using to reduce run-off of nitrogen and phosphorus, toxicants and harmful matters. To industrial pollution, total discharge amount of industrial wastewater contaminants must be limited within the self-purification capacity of rivers and other water bodies. Countermeasures should be taken, including promoting cleaner production and controling pollution throughout whole production processes and strengthening pollution sources treatment and reducing the generation and discharge quantity of pollutants. Investment in building treatment facilities and sewage plants for industrial wastewater and municipal sewage treatment should be increased. Enterprises that bring out heavy pollution to water environment should be imperatively ordered to close down, suspend operations, merge with other enterprises or change their products. To municipal sewage pollution, one of the significant countermeasures we recommend is that detergent with phosphorus should be prohibited throughout China by administration rules to relieve eutrophication of water bodies.

To areas where groundwater is destructive, groundwater protection areas should be defined and rainwater should be used efficiently to replenish natural aquifers and resume the groundwater ecosystem balance to gradually realize the benign cycle of water resources, and technological standards pertaining to the control of groundwater pollution should be set up. In water conservation and pollution control of surface water and groundwater, it is important to enhance examination of law enforcement and reinforce the legal supervision, and to promote public awareness and participation.

2.5 Establishing Unified Water Resources Management Mechanism

Lack of unified and integrated management mechanism has strictly constrained water resources sustainable utilization in China. Appropriate institutional arrangements with clear responsibilities and accountabilities are essential for water resources sustainable management, and it is urgent to establish such unified water resources management institution through reforming the existing management mechanism. At the basin scale, river basin commissions should be responsible for basin integrated management especially water allocation to the provinces, autonomous regions and municipalities, and in regions within river basin, once water allocation have been determined by the river basin commissions, the detailed water allocation in different sectors such as agriculture, industry and municipality should be integratedly planned within administrative districts. In China now, river basin commissions are affiliated to the Ministry of Water Resources, so, water resources management at both basin scale and region scale can be systematically responded by the same series of agencies after the unified management institution arrangement is completed. Unified and integrated management would be carried out to realize reasonable control of over exploitation, harnessing, conservation and utilization of surface water and groundwater in both urban and rural regions, which should rest with the Ministry of Water Resources and its provincial departments and prefectural and county bureaus.

Along with establishment of unified institutional

mechanism, market-based water pricing regime should be scientifically established and the key of it is to raise the unrealistically low prices of water to approximate its true economic value. Welfare water allocation in China under the planned economic mode hinders the foster of water-saving mechanism because water saving cannot bring income to the executants and water allocation is determined by the government. It is necessary to foster water entitlement market and institute a system of tradable water entitlements subject to state supervision. Price hikes are effective measures to prompt improvements in water distribution efficiency, and also can produce revenue devoted to pay for water-related investments and management. Laws and regulations should be developed and formed as a complete set to guarantee unified and integrated water resources management.

3 CONCLUSIONS

Constraining factors to sustainable water utilization in China are very complicated, which include physical geographic factors and socio-economic factors. Physical geographic factors such as the uneven distribution of water resources at temporal and spatial scales make it difficult to be sustainablely utilized. Socio-economic constraining factors such as inappropriate institutional arrangement and non-water-saving production and life mode result in water waste and pollution. It is imperative to accelerate the transition from water-waste and water-destruction society to water-saving and water conservation society in order to realize sustainable utilization of water resources. The way depends on scientific and technological progress to overcome the influence of physical constraining factors and tap water resources potential, on appropriate institutional arrangement reform to ensure efficient water resources management, and on market and administration and legal strength to guarantee establishment of water conservation and water-saving society. However, establishment process of water conservation and water-saving society and realization of sustainable water resources utilization is a very complicated and systematic work involving the factors of population, resources, environment, society, economy and so on. So, water resources utilization must be in accordance with the development of population, resources, environment, society and economy together and follow the road of sustainable coordinated development, and definitely this will be a gradual process, which needs long-term efforts.

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