IMPACTS OF AND SOLUTIONS TO URBANIZATION ON AGRICULTURAL WATER RESOURCES

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ABSTRACT

Cross-boundary issues in water resources development and management are very popular throughout the world. One of the most notable cross-boundary issues facing irrigation is water resources allocation between urban and rural areas, and typically industrial and agricultural uses. In many areas in the world, agricultural water resources (typically irrigation) is severely impacted by urbanization, which has been one of the crucial restricting factors to sustainable agriculture of the world, especially that of developing countries. This paper presents the impact of urbanization on agricultural water resources. The general impact in China is briefly described. Some special solutions to the impact are recommended which include raising the design standards of irrigation projects, bestowing priority on farmland irrigation, and stipulating an upper limit to the water available per capita. More attention should be paid to the comprehensive solutions: to set up a water-saving society, to strengthen water pollution prevention and water resources protection, and to speed up capacity building. A strategic framework for sustainable water resources development and management for the new millennium is proposed for central Shaanxi, one of China's typical regions suffering from severe water shortage. Based on the analysis of basic demand for sustainable development and probable water resources available, an amount of 500 cubic meters of water per capita per year on average might be an upper limit to this region. A rough allocation of the water to agricultural, industrial, residential and environmental for the year 2020 is suggested based on the objective of self-sufficient food supply, continuous development of industry, persistent improvement of life quality, and safe environment. These solutions may also be appropriate for most developing countries and other countries with similar issues.

INTRODUCTION

Urbanization is an essential trend of the developing world, which is accompanied by rapid industrialization and population growth in persistently expanding urban areas. One of the most important characteristics of urbanization is rapid increase in water demand for residential and industrial uses in urban areas. The residential

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water use includes domestic and municipal uses. The increase in water demand in urban areas often causes chronic urban water shortages because the deficit between water supply and demand may result in severe conflicts between different water users. Water scarcity has become one of the crucial restrictions to further development of the urbanized and urbanizing areas.

There are two commonly acceptable approaches to meet the increasing water demand in the growing urban areas. The first approach is to exploit new water sources to heighten water supply capacity of urban water supply systems. The second one is to develop highly efficient water-saving techniques to reduce net water consumption in urban water utilization systems. However, this is difficult to accomplish due to natural scarcity, deficient availability and uneven geographical distribution of freshwater, as well as lack of advanced technology, sufficient investment and powerful management. It may be possible to plan and implement projects and programs to solve the conflicts and meet the needs in some regions or countries with relatively abundant water resources. However, it is difficult for most developing countries because of their relatively lower levels in development in water supply projects and water-saving techniques. In addition there may be a lack of sufficient technical and financial supports to further the development of new water sources, especially, those in arid and semiarid areas.

In some developing countries or regions, a commonly adopted approach in making up for the deficit between water supply and demand in urban areas is to share the water which was originally intended for farmland irrigation, domestic and livestock uses in rural areas (so-called agricultural water resources). This has become one of the most notable cross-boundary issues impacting sustainable development of agriculture, the socio-economy and the environment.

A direct consequence of urbanization to agricultural water resources is the severe impact on the security of water quantity for agricultural uses. Urbanization also induces severe impact on the security of water quality of agricultural water resources frequently caused by a large amount of urban wastewater and pollutants returned into water sources directly used for farmland irrigation, as well as air pollution-induced acid rain. Therefore, the impact of urbanization on agricultural water resources consists of two aspects: quantity and quality of the water resources. These factors could cause crucial socio-economic issues and become tremendous restrictions to food security, economic growth, social progress and environmental safety.

To investigate both aspects of the impact of urbanization on agricultural water resources and to seek appropriate approaches to solve the issues are of major concern and should be well dealt with in depth. The purpose of this paper is to present the current status on the impact of urbanization on agricultural water resources in China and offer strategic solutions to reduce the impact. The paper also provides a brief case study on central Shaanxi, one of China's typical regions suffering from severe water shortages, under the consideration of basic water demands for a sustainable agriculture and a safe environment.

IMPACTS OF URBANIZATION ON AGRICULTURAL WATER RESOURCES

Every event has its cause and effect, so has the impact of urbanization on agricultural water resources. To understand the cause and effect of the impact is a basic requirement for seeking rational solutions to the problems.

Driving Forces

Several forces drive the impact of urbanization on agricultural water resources. They are rapid population growth and concentration, high-speed industrialization and increasing number of cities and expanding urban areas.

Rapid population growth and concentration: The development of socio-economy in a given region or country often results in rapid growth and high concentration of population in its urban areas. A high ratio of urban residents to total population is one of the most notable characteristics of developed countries compared to that of most developing countries. In 1990, for instance, the percentage of urban population was 75.2% in the United States and only 26.4% in China (the State Statistical Bureau, 1997). The rapid growth of population in urban areas leads to high concentration of the population. The density of the population in urban areas is much higher than in the countryside.

People living in urban areas require more water for domestic and municipal uses to heighten their living standards. Therefore, rapid population growth in urban areas is a direct determinant to increasing water demand for domestic and municipal uses. For example, as the largest developing country of the world, China has made remarkable achievements in its economic development and modernization and received international acclaim since 1978 with the onset of reform (Elizabeth Economy, 1997). Correspondingly, the population in urban areas increased from 172 million by the end of 1978 to 370 million by the end of 1997 (the State Statistical Bureau, 1998). The population has doubled in the past two decades and the percentage of urban population increased from 17.9% to 29.9% during the period of the two given years. Figure 1 shows the accumulative population growth rate (ratio of annual to 1978's population) in urban areas where the growth rate in 1978 is assumed to be 100% and the ratio of urban to total population in China.

High-speed industrialization: Industrialization and urbanization are twin sisters. Industrialization causes urbanization, and urbanization accelerates industrialization. The reality of the world shows that the more the industrialization, the more the urbanization, and vice versa.

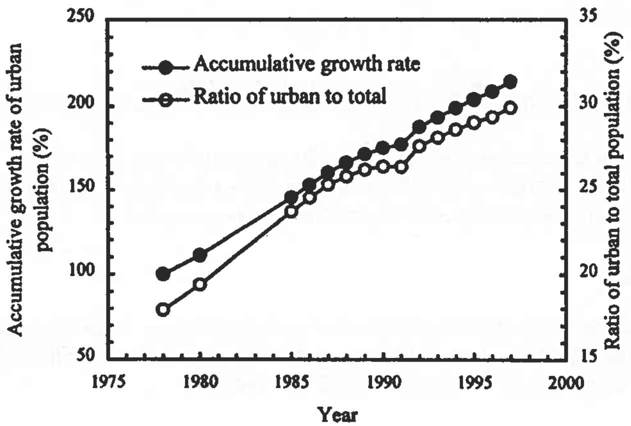

Fig. 1. Population growth in urban areas in China (data source: the State Statistical Bureau, 1998)

Regardless of the level of industrialization of a region or country, the key driving force to water resources is the speed of the industrialization. The higher the speed, the stronger the force. In particular, this could cause crucial industrial water shortages. China is also a typical example of severe water scarcity in industrial uses along with its high-speed economic industrialization. According to the State Statistical Bureau (1998), China's GDP (Gross Domestic Products) of industry increased 19.8 times during the period of 1978 to 1997. The average annual growth rate of industrial products was up to 10.5%, the highest in the world. Figure 2 illustrates the accumulative growth rate of industrial GDP (ratio of annual to 1978's GDP) where the growth rate is assumed to be 100% in 1978.

<u>Increasing number of cities and expanding urban areas;</u> On one hand, new cities continuously appear and grow. On the other hand, old cities are always under reconstruction and expansion. Within the past several decades, the number of cities in China dramatically increased to 668 in 1997, while it was only 191 in 1978 and 79 in 1949 (the State Statistical Bureau, 1998; Water Resources Bureau of the Ministry of Water Resources, 1995).

The most typical new city in China may be Shenzhen (see Figure 4), now called the window of reform and opening of China. It has become a worldwide famous modern metropolis. According to the Shenzhen Statistical Bureau (1998), the population of the city was 3.80 million by the end of 1997, which was 12 times the 0.31 million in 1979 when it was still an unknown small "fishing village". Its industrial products increased 233 times during the same period, which was approximately 12 times the national average.

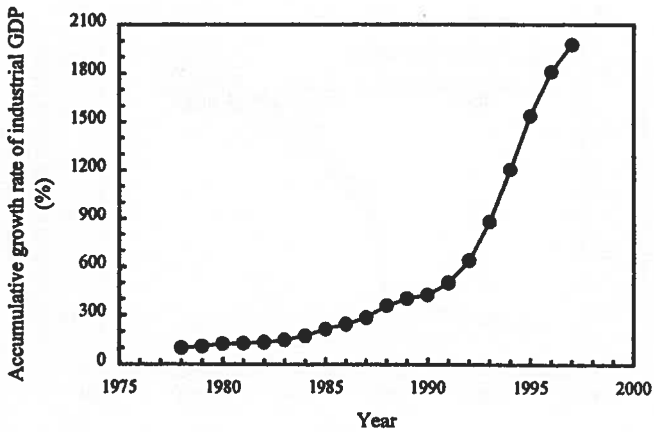

Fig. 2. Accumulative growth rate of industrial GDP (ratio of annual to 1978's GDP) in China (data source: the State Statistical Bureau, 1998)

At the same time, the constructed area of the cities in China was increased to 20,214 km^2 by the end of 1996. It was doubled in last ten years (the State Statistical Bureau, 1988, 1997).

Conflicts Between Urban Water Demand and Supply

Rapidly increasing water demand: In the process of urbanization, water demand for residential uses will inevitably increase with rapid population growth. On one hand, the people living in cities require persistent improvement of their living quality. In relation to water demand, popularization of piped water provides chances for wide uses of house showers and washing machines in cities. They are highly water-consumed compared to traditional living surroundings. On the other hand, with the improvement of living quality, the people living in cities desire more public water-related recreational facilities. It usually leads to rapid construction of municipal infrastructures, such as swimming pools, water amusement parks, water landscapes, green land irrigation and municipal sanitation.

Similarly, at the developing stage of urbanization in a region or country, rapid increase in industrial water demand is also inevitable. According to an urban water resources plan, 270 cities of China were water-short in 1990, which was 57.8% of the total cities (Water Resources Bureau of the Ministry of Water Resources, 1995). Residential and industrial water demand in 1990 was 23.03 Gm^3 (billion cubic meters) while predicted demands are 48.19 Gm^3 by 2000 and 71.37 Gm^3 by 2010, respectively. The number of cities is increasing, including the

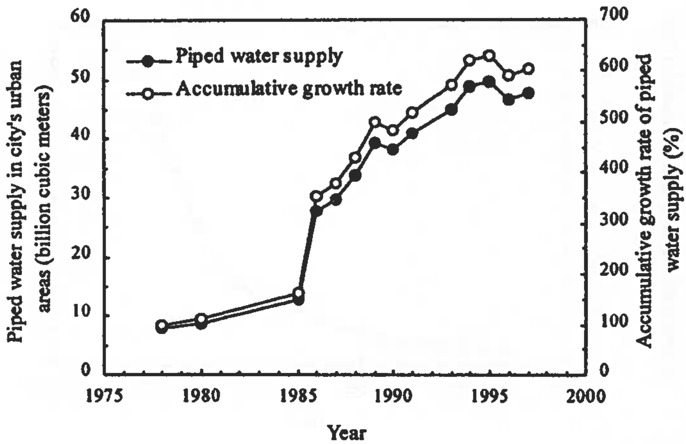

Fig. 3. Increase in piped water supply in recorded city's urban areas in China (data source: the State Statistical Bureau, 1981-1998)

water-short cities. An estimated countrywide water demand for residential and industrial uses in urban areas by 2000 is 152.12 Gm^3 (Institute of Water Resources and Hydropower Planning and Design of the Ministry of Water Resources, 1989).

Figure 3 presents the increase in piped water supply and accumulative growth rate of the water supply (ratio of annual to 1978's water supply) in city's urban areas in China, where the growth rate in 1978 is assumed to be 100%. In the city's urban areas with recorded piped water the pipes supplied 6.1 times water in 1997 and 6.3 times (the highest) in 1995 compared to the water supplied in 1978.

<u>Slowly growing water supply capacity:</u> Increased water demand needs correspondingly heightened water supply capacity. The Chinese government made the decision to promote the building of urban water supply systems. Some projects have been well planned and designed, some have been built and put into operation, and some are under construction. All cities of China have solutions to their water shortages. However, the speed of building urban water supply capacity has not yet kept pace with the increasing water demand due to relatively long construction periods of water projects, inadequate investments allocated to the projects, and some societal, economic, political and legislative reasons.

<u>Deficit between water supply and demand:</u> The unbalance between the water demand and supply will lead to water deficit in urban water resources systems. In the urban water resources systems of the aforementioned 270 water-short cities,

the total water deficit of residential and industrial uses are estimated to be up to 12.12 Gm^3 by 2000 and 35.30 Gm^3 by 2010 if no new projects were put into service and only the currently available water supply projects of the year 1990 were used. Moreover, if all the planned new and reconstructed water supply projects for urban areas in the planning period were completed and put into full services, the deficit could not be completely filled and would still be in the range of 6.87 Gm^3 by 2000 and 10.25 Gm^3 by 2010 (Water Resources Bureau of the Ministry of Water Resources, 1995). In fact, the number of water-short cities may currently be counted at over 300 and up to 400. The countrywide urban water deficits in fact are much higher than the above figures.

Impacts on Quantity of Agricultural Water Resources

Although it is difficult for China to meet the increasing water demand for residential and industrial uses in urban areas, a surprising fact is that actual water supplied to urban areas has been steadily increasing. The total water supplied to all China's cities and towns in 1997 was reported to be 115.48 Gm^3, in which 24.68 Gm^3 for residential uses and 90.80 Gm^3 for industrial uses, respectively (the Ministry of Water Resources, 1998). This is very close to the predicted total urban water demand of 113.30 Gm^3 estimated from the total demands in 1980 and 2000 (Institute of Water Resources and Hydropower Planning and Design of the Ministry of Water Resources, 1989), using an average annual increment rate during the period. This implies that the estimated water deficit at the planning level has been filled though there were many reports about regional and seasonal water shortages in urban areas. The reported water scarcity indicates that the predicted water demand might be less than the real demand. In fact, a large part of the increased urban water supply has been the shared agricultural water resources including both surface water and groundwater.

As early as the beginning of the 1990s, the water supplied to urban areas by the projects controlled by the Ministry of Water Resources and its sub-agencies has been as high as 55.5 Gm^3 (Ren and Huang, 1992). Most of the water was supplied by former rural water supply projects.

Impact on surface water: In addition to the original and newly built urban water supply projects, the contributors to the urban water supply are projects originally built for rural water supply. In order to solve the current water scarcity in urban areas, a large number of surface water supply projects for rural uses are now required to be shared and transferred in part or whole to urban uses. This is partly based on the priority to domestic uses stipulated in the Water Law of the People's Republic of China (the State People's Congress of the PRC, 1988) and partly due to high output of industries.

Typical examples of sharing or transferring agricultural water resources for urban utilization are numerous. The notable example is Beijing, the capital of China.

Beijing has been facing severe water shortages for a long time and has become one of the most water-short cities in China. Because it is the capital, much more attention has been focused on its water supply security. A large-scale construction of water supply projects started in the early 1950s made considerable contribution to the city's safe water supply. The well-known two reservoirs, Miyun on the Yongding River and Guanting on the Bai River, the tributary of the Yongding River, once were major surface water sources of Beijing for both urban and rural uses, as well as for the uses of its neighbor city, Tianjin. The locations of the two cities are shown in Figure 4.

By 1980, annual total water used in Beijing was 4.92 Gm^3, in which 1.75 Gm^3 (35.5% of the total) for urban residential and industrial uses and other 3.17 Gm^3 (64.5%) for rural uses, mainly farmland irrigation. An estimated total water demand for 2000 is 52.7 Gm^3 and the portions for urban and rural uses are 23.6 Gm^3 (44.8%) and 29.1 Gm^3 (55.2%), respectively (Institute of Water Resources and Hydropower Planning and Design of the Ministry of Water Resources, 1989). Although the city operated under water shortages both the urban and rural had been steadily developing without acute conflicts in water challenges at that time.

Unfortunately, since 1980, with unprecedented development of the city and relevant regions, increased withdrawals on the upper reaches of the Yongding River and persistent droughts together induced significant reduction of the two reservoirs' inflows. This severely threatened the security of the city's water supply. Facing this crucial situation, the State Council of China made a decision to ensure the security of the water supply in the capital area through reducing its rural water supply and stopping the water supply to Tianjin (Institute of Water Resources and Hydropower Planning and Design of the Ministry of Water Resources, 1989). Since then, the conflicts in water allocations for urban and rural uses in Beijing have been acute. The problem could not be solved until the planned South-North Water Diversion Project (to be the largest interbasin water diversion project in China) is completed, and this is in spite of over-depletion of local groundwater for current uses.

Another typical case is the urban water supply systems in Liaoning province in northeastern China. A planned amount of surface water for industrial and residential use was 0.35 Gm^3 supplied by eight reservoirs on the Liao River, the Hun River, and the Taizi River in the province. The actual amount of the water supplied into the urban water supply systems was increased to 1.23 Gm^3 by the early 1980s. The increased water in urban areas was mainly obtained from rural uses (Institute of Water Resources and Hydropower Planning and Design of the Ministry of Water Resources, 1989). The situation has been getting worse. For instance, the annual average water for industrial and residential uses supplied by Dahuofang Reservoir on the Hun River, one of the eight reservoirs, was 0.26 Gm^3 in 1981 and increased to 0.45 Gm^3 by 1995. Meanwhile, the water for farmland irrigation was reduced from 0.88 Gm^3 to 0.48 Gm^3 (the Management Bureau of

Dahuofang Reservoir, 1986 and 1996).

Fig. 4. Map of China with locations of the cities, provinces and major rivers mentioned in the context

Impact on groundwater: Aforementioned are typical cities depending on use of agricultural water resources. They directly impact the surface water quantity of agricultural water resources. In addition, an impact of urbanization on agricultural water resources is over-abstraction of groundwater in both urban and near suburb areas for urban uses. It is seemingly an indirect impact but the consequence could be dangerous.

Similar to most of the world, in China, surface water is significantly affected by changing climate and human activities and has high variability in space and time. Moreover, groundwater has traditionally been major urban water resource and plays an important role in water supply in most cities. In some cities groundwater is the only water source. For example, Xi'an, the capital city of Shaanxi province, surface water was never diverted into the city to improve its water supply in spite of the severe geo-environmental hazards induced partly by over-pumping of groundwater until the severe water crisis during the early 1990s (Feng et al., 1999).

The over-withdrawal of groundwater caused chronic declines in groundwater tables, caused many large and deep cones of groundwater depression, and led to hazardous land subsidence and fissures, as well as saltwater intrusion. It was reported that in 1990 there were 56 regional huge cones of groundwater depressions in China. Most of the cones were centered near large water-short cites. Total area of these cones on the ground was up to 87,000 km^2 and was continually getting larger and deeper. In some cities groundwater tables had declined over a hundred meters with a continuing annual decline of 2 m to 4 m (Water Resources Bureau of the Ministry of Water Resources, 1995; the Ministry of Water Resources, 1998). Though they occurred in urban areas and/or water source zones of the cities, they seriously affected the quantity of agricultural water resources indirectly.

The heavy decline in groundwater tables implies that the aquifer is getting unwatered from cones' centers to the outer margins with steep hydraulic slopes. This can lead the groundwater to flow from rural areas outside the cones with higher water tables towards the cone center under the urban cities. As a result, the groundwater in the rural areas flows into urban areas, accompanied by a decline in the water tables in rural areas, which makes pumping more difficult and sometimes impossible for rural uses. Meanwhile, it may cause changes in soil water status on farmlands and further affects land productivity.

Impacts on Quality of Agricultural Water Resources

The impact of urbanization on quality of agricultural water resources mainly covers the following aspects.

Urbanization-induced water pollution and its impact: Urbanization contributes to consumption of a large amount of natural resources but also products a large amount of wastes. A large quantity of residential and industrial sewage is frequently directly discharged into surface water bodies without proper treatment. Most of the wastewater comes from urban areas and becomes main pollution sources in developing countries (Morcoux, 1994). It pollutes not only the urban environment but also the entire environment, as well as agricultural water resources.

In China, though the urban sewage effluents have been properly controlled and the amount of the sewage discharged into water bodies in some well-controlled typical regions was reported to be gradually reduced or properly treated, the total amount of the wastewater within the country is still large and enough to severely pollute the water involved. In some regions, water quality is getting worse. The water in rivers, lakes and reservoirs has been universally polluted, except for some remote inland rivers and individual branches of water resources systems. In 1997, the total amount of discharged wastewater was 41.6 billion tons, of which 22.7 billion tons was industrial liquid waste and 18.9 billion tons was residential sewage. With industrial wastewater, the county-level and above industries produced 18.8 billion tons and the Township and Villages Industrial Enterprises produced the other 3.9 billion tons. Because the large amount of the wastewater was discharged into water bodies, in a total length of 65,405 km of monitored river sections, the length of water quality was in Grades 1 and 2 of the national Quality Standards for Surface Water Resources (SL 63-94) (the Ministry of Water Resources of the PRC, 1994) was only 32.8% of the total length, 23.6% in Grade 3, 27.7% in Grades 4 and 5, and 15.6% above Grade 5. Particularly, in 138 monitored river sections flowing through urban areas, water was polluted above Grade 5 in 53 sections, Grades 4 and 5 in another 53 sections, Grades 2 and 3 in the other 32 sections, and no Grade 1 existed. Meanwhile, up to 50% of groundwater in urban areas was also polluted (the Ministry of Water Resources, 1998; the State Environmental Protection Administration, 1997 and 1998).

Economic losses of urbanization-induced water pollution include those resulting from the impact of water pollution on farm yields, livestock and fisheries, as well as human health. According to Xia (1998) total economic loss resulting from the impact of water pollution within the country was 21.86 billion RMB yuan (2.63 billion US dollars) excluding industrial loss. This loss includes 0.70 billion RMB yuan of wastewater irrigation caused farm yields reduction, 1.16 billion RMB yuan of water pollution damaged livestock and fisheries, and 20.00 billion RMB yuan of polluted drinking water and food caused human diseases (including urban residents' health loss).

<u>Urbanization-induced acid rain pollution and its impact:</u> Urbanization-induced acid rain pollution has an important and widespread impact on agricultural water resources as well as eco-environment. In China, the area receiving acid rain is now about one third of its territory. It is mainly distributed to the south of the Yangtze River and to the east of the Qinghai-Tibet Plateau. According to the data from 84 cities in the State-Controlled-Network, in 1997, annual average pH value of acid rain in 44 cities, i.e., 52.3% of the total monitored cities was less than 5.6 and varied among 3.74 and 7.79 in the entire acid rain covered region. In some cities the pH value was less than 4.5. The occurrence frequency of the acid rain was equal to or greater than 60% in 24 cities and greater than 90% in 5 cities in the State-Controlled-Network (the State Environmental Protection Administration, 1997 and 1998; Wang, 1999).

Most of the acid rain in China was caused by air pollution from industrial and residential waste gasses in urban areas. Inversely, acid rain heavily polluted the environment. In particular, the acid rain severely damaged crops and polluted the soils on farmlands as well as local water bodies in the acid rain covered region. According to a research carried out by an expert group organized by the State Environmental Protection Administration in 1994, annual total economic loss resulting from acid rain pollution in 1992 was approximately 14 billion RMB yuan (1.69 billion US dollars). The estimated loss was confirmed by the State Environmental Protection Administration and others (Xia, 1998). Most of the loss was due to acid rain-induced decline in agricultural products including crop yields, livestock and fisheries, as well as human health-related losses.

Urbanization-induced saltwater intrusion and its impact: This kind of urbanization impact occurred in coastal cities with over-withdrawals of groundwater. According to the Ministry of Water Resources (1998) the area which was intruded by saltwater was up to 1,433 km^2 along the coastal cities in only three northern provinces (Liaoning, Hebei and Shandong provinces, see Figure 4). It affected the security of drinking water of 90 million people and 24 million animals and resulted in the loss of 1.26 million tons of grain.

SOLUTIONS

China's water issues have been of long standing. Its water scarcity, in particular, and water-short-related problems concerning sustainable development have attracted worldwide attention and have been recognized as one of the most severe restricting factors to China's sustainable development in the forthcoming new millennium (the State Council of the PRC, 1994; the Sate Planning Commission and the State Scientific and Technological Commission, the PRC, 1994; Elizabeth Economy, 1994; Brown and Halweil, 1998).

Facing the severe restriction to the nation's sustainable development, China has made considerable efforts in solving water scarcity and achieved universally acknowledged successes (Institute of Water Resources and Hydropower Planning and Design of the Ministry of Water Resources, 1989; Qian, 1991; the Compilation Committee of Almanac of China Water Resources, 1988-1997). It was the successes in China's water issues' solutions that ensured China's high-speed economic development and food security in the past several decades.

In recent years, China conducted a series of researches on water resources and attempted to solve its water scarcity. Many strategies, approaches and measures have been proposed on current and long-term developing levels as part of socio-economic development plans and the agenda 21 (the State Council of the PRC, 1994; the State Planning Commission and the State Scientific and Technological Commission, the PRC, 1994). Water-saving agriculture, especially water-saving irrigation is now being popularized in water-short areas. Countrywide, water-saving cities are being establishment. The research results on China's water and water-related issues are thoughtful in both concept and reality. However, in relation to water scarcity, the current research seems to favor retaining many of the traditional models. For instance, in the current water resources plans, water demands and solutions are still based on the traditional "determine the supply according to the demand". Although the concept of "determining demand according to supply" has been introduced for a period of time it is still on the level of suggestion. This could lead to over reliance on the "inflow" or "passing through flow", and interbasin water diversion instead of making efficient utilization of local water resources under a target upper limit to the water available per capita. Meanwhile, the impact of urbanization on agricultural water resources seems to not be fair for rural water users in the currently available plans.

To reduce the impact of urbanization on agricultural water resources, China needs to (1) raise design standards of irrigation projects, (2) bestow priority on farmland irrigation, (3) stipulate an upper limit to the water available per capita in each given urban area, (4) set up and promote a water-saving society, (5) strengthen water pollution prevention and water resources protection, and (6) speed up capacity building. The first three solutions are directly concerned with agricultural water resources and the others are universal solutions. The three direct solutions are now described as follows.

To Raise Design Standards of Irrigation Projects

In China, farmlands have been irrigated for thousands of years. In the past several thousand years, the farmlands were irrigated without design standards for the concerned water supply projects in spite of advanced designs such as the famous 2255-year-old irrigation project, Dujiangyan in Sichuan province (Zhu, 1991). Since the concept of water supply reliability was introduced, China's irrigation projects were designed and built with given probabilities of water supply reliability. Since the 1950s, China has promulgated a series of regulations for water resources planning and water project design. The regulations include the probability of water supply reliability of water projects including irrigation, which should be guaranteed by design and pertinent techniques. Although the regulations have been revised several times and many techniques have been updated, the probability of meeting a full water supply is reduced instead of increased.

According to the regulations, each irrigation project should be designed and built using a given probability of water supply reliability, which is determined by scarcity or abundance of the water as well as the capacity of water resources development. However, in a recently revised regulation for water basin planning, the probability is reduced to 50% to 70% for dry-land crops, of which the lower limit is for water scarce regions and the upper limit is for water abundant regions or vegetable irrigation in suburbs. For paddy crops, the lower limit is 75% and the upper limit becomes 90% (the Ministry of Water Resources of the PRC, 1997). Some irrigation projects even have the probability less than 50% in design and some in operation. This is much lower than the probability of 95% to 97% for industrial water supply (the Ministry of Water Resources of the PRC, 1997).

The probability is an integrated indicator reflecting the importance of the water users and the capacity of water resources development. As the largest developing country with 22% of world population being fed by only 7% of the world arable land (EIU, 1998), China has to ensure its food security. It needs not only to enlarge the area of irrigated farmlands but also to raise the probability of water supply for farmland irrigation. Irrigation water supply should have the probability close to or equal to that of industrial water supply.

To raise the design standard or probability of water supply reliability of irrigation projects, the most important is to let those who are authorized to revise the regulations legislatively acknowledge the importance of agricultural water supply in the nation's food security, socio-economic development and the relationship between agricultural and industrial water uses. Only by revising the regulations legally can the probability be raised.

To Bestow Priority on Farmland Irrigation

Agriculture is the mainstay of China's rural economy (the State Planning Commission and the State Scientific and Technological Commission, the PRC, 1994) and the fundament of China's economy. It has been widely recognized that China has to produce enough food to meet its needs. To do so, the fundamental position of agriculture in the nation's economy could not be altered. China has to bestow priority on its farmland irrigation. This should not only be stipulated through legislation but also put into practice through the support of legislation, administration, science and technology.

According to China's Water Law (the State People's Congress of the PRC, 1988), in developing and utilizing water resources, water demands of agriculture, industry and navigation should be considered overall. It means that irrigation and industrial water uses have equal priorities. However, once the available water cannot simultaneously satisfy both agricultural and industrial uses, agricultural water supply may be reduced and even stopped. This is mainly due to increasing demands of industrial products and high output of industry compared to that of agriculture. At the initiatory stage of a country's industrialization, this may be unavoidable. But with the rapid development of industry which is capable of supplying sufficient products to meet the basic needs, and food production becomes pressing, the priority of water supply should be fairly balanced and might need to be transferred to irrigation.

To Stipulate an Upper Limit to the Water Available Per Capita

Water resources are limited. Total demand in a given area should not exceed a probable maximum. The maximum consists of local water resources obtained through appropriate water projects regulating the inflow or passing through flow and diverting water from other basins, i.e., interbasin water diversion. This should be specified as a target upper limit to the water available per capita in given areas.

The upper limit should be determined on either natural or administrative space-scales, such as watersheds and provinces. For practical purposes, on watershed scales, the limit should be specified at least on the first and second tributaries of large rivers and major river sections. On administrative scales, the limit should be specified at least on county-level administrative districts. The currently used divisions in the Water Resources Assessment of China (Hydrological Bureau of the Ministry of Water Resources, 1987) and those in the Water Resources Utilization of China (Water Resources Bureau of the Ministry of Water Resources, 1989) may be adopted as the basic districts for the limit stipulation on watershed scales. The current administrative districts should be adopted as the basic districts for the limit stipulation on administrative scales.

CASE STUDY

As a case study on the solutions to the urbanization impact on agricultural water resources, this section presents a brief description to the problems in Central Shaanxi, the core part of Shaanxi province of China.

Background

Central Shaanxi is located in the center of Shaanxi province and comprised of five prefectures. This region is not only the geographical but also political, economic and cultural centers of the province. Figure 5 shows the locations of this region in Shaanxi Province and geographical relationship of the province to the Yellow River.

The total area of Central Shaanxi is 55,384 km^2, which is 26.9% of the provincial territory. The population in this region was 20.48 million in 1995, which was 59.7% of the provincial population. The gross industrial and agricultural products were 74.5% and 67.1% of the provincial totals, respectively (Shaanxi Statistical Bureau, 1996). Also, 51.8% of arable lands and 86.6% of irrigation lands of the province are distributed in this region. However, the total amount of local water resources is only 8.96 Gm^3 (long-term annual average). It is 62 m^3 less than the "absolute scarcity threshold" of 500 m^3 per capita (OIEAU, 1998). In some areas the local water resources available per capita is even below the "extreme scarcity threshold" of 100 m^3 (OIEAU, 1998). With population growth, the water available per capita will gradually decrease. According to an acceptable estimate, the local water available for each resident in the region will decrease to 335 m^3 by 2020 and 248 m^3 by 2050 (Feng, 1999). It is obvious that there is tremendous contrast between the highly concentrated population, industry and agriculture, and the poor water resources in the region.

Water scarcity has become the "bottle neck" of the region's socio-economic development. Particularly, the scarcity in urban areas has resulted in severe economic losses, geo-environmental disasters, and some social problems. Having faced the water-short-induced problems, the provincial government and its water

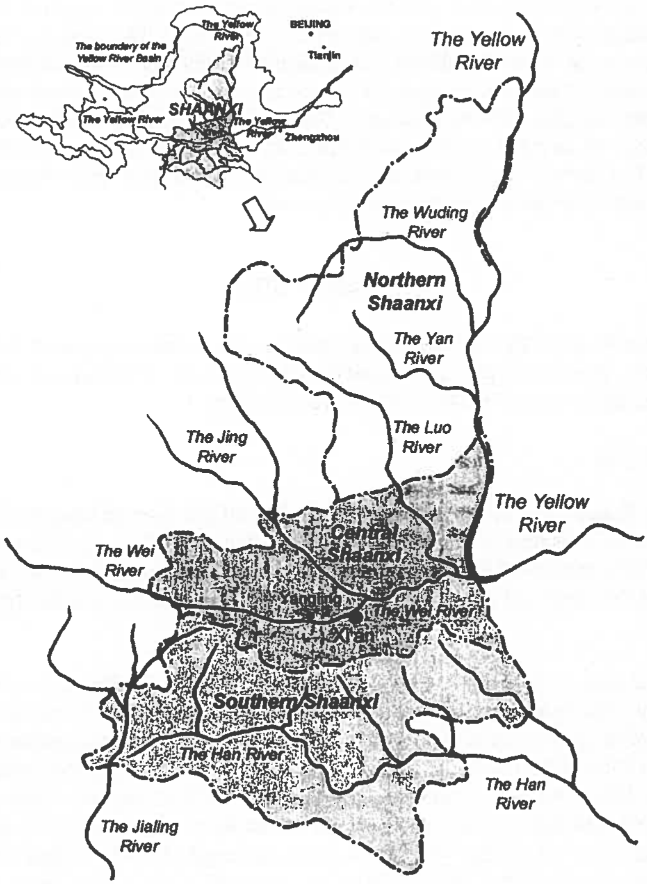

Fig. 5. Map of Shaanxi Province with locations of the main regions and places and distribution of major rivers and their relationship to the Yellow River

authorities as well as local governments have focused more attention on the solutions of the problems. For instance, in order to supply water for basic demand in urban areas, several water supply projects have been and are being built for the provincial capital and other cities. These are major water supply projects sharing water with agriculture for urban uses in this region. This significantly reduces agricultural water supply and severely impacts crop yields in spite of severe over-withdrawal of groundwater in irrigation districts.

The Solutions

To reduce the impact of urbanization on agricultural water resources for central Shaanxi, the basic solutions are similar to those mentioned earlier but noted here with more details. The following are some quantitative proposals to the problems for the region.

Based on the point of view of safe food supply and healthy environment, as well as overall sustainable development of the region, the author recognizes that in central Shaanxi, the target upper limit to per capita available water resources should be 500 m^3. It is, on one hand, basic requirement for improvement of living quality, sufficient supply of food products, continuing development of well-organized industries, and effective protection and amelioration of natural and artificial environments. On the other hand, it is based on the water resources for the region's uses. They consist of available local water resources, probable inflows and the allocated water of the Yellow River by the Ministry of Water Resources. The new projects include the provincial South-North Water Diversion Project (diverting water from the Han River and the Jialing River in the south to the center of Shaanxi province), Guxian Reservoir on the main stream of the Yellow River and local water projects (Zhao and Wang, 1999).

The annual quotas of the water allocated to residential, agricultural, industrial and environmental uses are 51 m^3, 163 m^3, 106 m^3 and 180 m^3 per capita in 2020, respectively, in which the quota for environmental uses includes inexploitable local water resources.

The water allocated for agricultural use is based on a reasonable improvement of efficient utilization rate of irrigation water, reliable crop yields per hectare and sufficient vegetable and fruit production. The crop yield could provide 400 kg of crop grain per capita annually which is about 100 kg higher than the current crop grain per capita.

In addition, the priority of agricultural water uses would be particularly important for the region's sustainable development.

CONCLUSIONS

The impact of urbanization on agricultural water resources has become a notable cross boundary issue facing farmland irrigation and a key factor restricting sustainable agriculture. It is mainly caused by urbanization-induced occupation and pollution to agricultural water resources.

In reality, the solutions to the impact are associated with the overall integrated water resources systems and their management and should be comprehensive. However, the solutions should emphasize specific aspects.

In view of the status of urbanization and its impact on agricultural water resources in China, efficient solutions directly concerning with the impact should be to raise design standards of irrigation projects, to bestow priority on farmland irrigation, and to stipulate an upper limit to the water available per capita. They may be also appropriate for most developing countries and other countries with similar problems.

Agricultural water resources itself is a complicated problem. In addition to the impact of urbanization, there are many other factors affecting the security of agricultural water supply. They should be solved together with the impacts of urbanization.

This paper mainly focuses on the impact of urbanization on agricultural water resources and its solutions in China. These are very notable cross-boundary issues that need to be jointly addressed comprehensively in overall water resources development and management. However, the issues are also worldwide and should be dealt with through international cooperation on sharing of potential solutions.

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