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PRESSURE OF WATER SHORTAGE ON AGRICULTURE IN ARID REGION OF CHINA

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ABSTRACT: The arid areas in China are mainly located in North China and Northwest China. The North China is the main region for food production. There is 31.19% of the total farmland and 26.01% of the total population, but only 6.14% of the available water resources of China. Groundwater is over pumped ($6.53\times10^9m^3$ every year) in the regions of Beijing, Tianjin, and Hebei Province, so water supply could not meet the water demand there. The distribution of water in Northwest China is uneven, some inland rivers and lakes are dried up, and desertification has expanded since river water in the upper and middle reaches is diverted for irrigation. Up to 2050, population will be up to 1.6×10^9 in China, and industry will be developed fast, therefore 50% of the water supply will be used by industry and resident, and water for agriculture will be decreased year by year. In the coming 50 years, water demand for agriculture will be increased by $5.6\times10^9m^3$ in the Huanghe (Yellow) River valley, and by $1.7\times10^9m^3$ in the Northwest China. It will be impossible for the Huanghe River to meet the water demand, because it always dried up in the cold half year since 1984. To avoid water shortage of agriculture in the arid regions, it is necessary to divert water from the Changjiang (Yangtze) River in the south of China, and to use water efficiently. It is the best way to use drip irrigation in agriculture, recycle water in industry and resident use, and control water pollution. Otherwise water shortage in the arid regions will restrict the development of agriculture in China.

KEY WORDS: water shortage; water demand; agriculture; arid region of China

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1 INTRODUCTION

With the development of the world, water demand is increasing, especially with the growth of population in the last 50 years, water demand for irrigation has greatly increased for food production. In the arid and semi-arid areas, water shortage becomes a heavier problem to restrict food production, local economy and environmental protection. China, with 22% of the total population in the world, has only 8% of fresh water in the globe; water shortage has affected agriculture and resident's life in the northern China. Some scientists indicated that China's water shortage could shake world food security (BROWN and HALWEIL, 1998).

China's per capita water resources ($2200m^3$) is less than 1/4 of world average; in the northern China, it is only $998m^3$ per capita; extremely in North China, one of the water-shortage regions in the world, per capita water resources is only $150-300m^3$. In Northwest China, annual runoff depth is less than 150mm because of little precipitation, and the diversion of the most river water for irrigation has caused water shortage out of oasis, so desertified area has expanded, and agriculture, even the existence of oasis is imperiled (QIAN, 1991).

Water for irrigation has been increased 4 times, for industry 22 times, and for urban resident 8.5 times, but population has been up only 1.8 times during the last 50 years. Up to 2050, China's population will reach 1.6×10^9 from 1.28×10^9 in 2000; irrigated area will grow from 54.35×10^6ha in 2000 to 64.50×10^6ha in 2050. Water demand for irrigation will be increased by 10% – 20% in the next 50 years, and total water demand for irrigation will be $450\times10^9m^3-500\times10^9m^3$ in 2050.

China depends on irrigation to produce 70 percent of the grain for its huge population, but it is drawing more and more water to supply the needs of its fast-growing

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cities and industries. As rivers run dry and aquifers are depleted, the emerging water shortage becomes heavier and heavier in the arid regions in the northern China.

2 BASIC SITUATIONS AND UTILIZATION OF WATER RESOURCES IN CHINA

2.1 Distribution of Water Resources

In China, 45% of precipitation transforms to surface water or groundwater, and river water is about 5.8% of the world's river water. Annual runoff depth is 284mm, being 90% of the average in the world. But per capita water resources is $2200m^3$, which is less than 1/4 of the average of the world. Most water resources (80.9%) of China are distributed in the southern China (the area to the south of the Changjiang River), the land area here, however, is only 36.5% of the total area of China. The population in the northern China (the area to the north of the Changjiang River) is 2/5 of the total population of China, but water resources there is less than 1/5 of the total of China. Per capita water resources in 8 provinces (mainly in the northern China) are less than $1000m^3$, among which Beijing and Tianjin are less than $380m^3$ (Table 1). Farmland in the southern China is about 3/5 of the total in China; in North China, though only 16.2% of the land is cultivated, 70% of water resources is used by irrigation (LIU and HE, 1998).

2.2 Some Problems on Water Use in Agriculture

In 1996, effective irrigated area had reached 49.925×10^6ha in China. There was 14.881×10^6ha in North China, which was 12.266×10^6ha more than that in 1950; and there was 5.561×10^6ha in Northwest China, which was 3.502×10^6ha more than that in 1950. Water for irrigation amounted to $416 \times 10^9m^3$ in the whole China in 1996 (LIU and HE, 1998).

In the 1990s, the utilization ratio of surface water was 66%, and the utilization ratio of groundwater was over 90% in North China. Groundwater in the northern China had been over pumped; $6.53 \times 10^6m^3$ of groundwater was over pumped every year, of which $4.11 \times 10^6m^3$ was deep groundwater; from 1985 to 1998, $64.9 \times 10^9m^3$ of groundwater had been over pumped, of which $38.8 \times 10^9m^3$ was deep groundwater(CHEN, 2000). It was so difficult for deep groundwater to be replenished, that around Tianjin, a funnel of groundwater with an area of 21 400km^2 appeared in the deep ground; and around Beijing, a funnel of groundwater with an area of 14 000km^2 appeared in the deep ground. Because of the continuous drop of water table, there have been some environmental problems in the northern China, such as the drying of watercourses and lakes, subsidence of ground, infall of sea water, and so on. On the other hand, with the development of industry and urbanization, waste water has increased to pollute rivers and lakes, and even groundwater somewhere (SUN, 1993; WEN and XUE, 1991).

Table 1 Distribution of water resources, population and farmland in North China and Northwest China (LIU, 1998)

Area	Province	Water resources ($\times 10^9m^3$)	Population ($\times 10^6$)	Per capita water (m^3)	Farmland ($\times 10^6$ha)	Per unit area water (m^3/ha)
North China	Beijing	4.08	10.86	357.7	0.413	9885.0
	Tianjin	1.46	8.84	165.2	0.431	3384.0
	Hebei	23.69	61.59	384.6	6.556	3613.5
	Inner Mongolia	50.67	21.63	2342.6	4.966	10204.5
	Shanxi	14.35	28.99	495.0	3.693	3886.5
	Shandong	33.50	84.93	394.4	6.853	4884.0
	Henan	40.77	86.49	471.4	6.933	5880.0
	Subtotal(average)	168.52	303.33	555.6	29.845	5646.0
	Percent of China(%)	6.14	26.01		31.19	
Norhtwest China	Shaanxi	44.19	33.16	1332.6	3.533	12508.5
	Gansu	27.43	22.55	1216.4	3.476	7890.0
	Ningxia	0.99	4.70	210.6	0.796	1243.5
	Xinjiang	88.28	15.29	5773.7	3.087	28600.5
	Qinghai	62.62	4.48	13977.7	0.578	108414.0
	Subtotal(average)	223.51	80.18	2787.6	11.470	19486.5
	Percent of China(%)	8.14	7.03		11.99	

In Northwest China, the driest region of China, annual precipitation in the steppe area is less than 100mm but 100 – 200mm in front of mountains in Xinjiang Autonomous Region and Gansu Province. Irrigation water depends on the river water and groundwater that comes from rainfall, glacier and snowmelt in mountain areas. Nearly 60% of the surface water was used for agriculture, industry and resident; in the Hexi region of Gansu, 80% of the surface water was diverted for irrigation; and in Xinjiang, 55% of it was diverted. Not too much of groundwater was used over there, but in some inland basins, groundwater has been over pumped. For instance, water table around Urumqi in Xinjiang was 17m lower than that 20 years ago; water table in the lower reaches of the Shiyang River in Gansu Province was 30m lower than that 30 years ago (TANG *et al.*, 1992).

Xinjiang was the region with most irrigated area in Northwest China (Table 1), annual water demand for irrigation was $45.35 \times 10^9 m^3$, of which $42.39 \times 10^9 m^3$ was surface water and $2.96 \times 10^9 m^3$ was groundwater. Irrigated area has increased for 1.8 times during the last 50 years, over 50% of the river water was diverted for irrigation, of which more than 70% was inland rivers (LI *et al.*, 2000; MA and LI, 2001).

Some environmental problems were the results of water migrating to oasis in the inland river basins, many rivers and lakes were dried up at the lower reaches, desertification was expanded. Desertified lands in the lower reaches of the Tarim River in Xinjiang and the southeastern Qaidam Basin in Qinghai expanded 4% or more every year. There were 150 lakes in Xinjiang in the 1950s, with an area of $9000 km^2$. Tens of lakes in Xinjiang were dried up during the last 50 years, and the surface area of lakes reduced $4395 km^2$.

3 PRESSURE OF WATER SHORTAGE IN THE 21ST CENTURY

3.1 Water Demands from Urban Residents

Population in China was nearly 1.3×10^9 in 2000, and the annual increasing rate was 1.29% in the 1990s. According to the calculation of Chinese government, China's population will be 1.5×10^9 in 2020 with the annual increasing rate of 0.721% during 2000–2020, and population will reach 1.6×10^9 with the annual increasing rate of 0.22% up to 2050 ①. In 2000, the urban residents were 280×10^6, and annual water demand for resident was $18.9 \times 10^9 m^3$ (LIU and HE, 1998); in 2050, urban residents will be 800×10^6, and annual water demand will be 3.86 times as much as that in 2000, being about $73 \times 10^9 m^3$ (Table 2).

Table 2 Prediction of China's annual water demand on urban resident in the first half of the 21st century

Year	Residents ($\times 10^6$)	Per capita water demand (L/d)	Annual water demand ($\times 10^9 m^3$)
2000	280	185	18.9
2010	350	210	26.8
2030	500	250	45.6
2050	800	250	73.0

3.2 Shortage of Water Demand from Industry and Ecology

China's production value of industry will increase 6% every year from 2000 to 2020, and will increase 5% every year from 2020 to 2050 according to the prediction (LIU and HE, 1998); water demand on industry in 2000 was $66.5 \times 10^9 m^3$, and it will reach to $343.6 \times 10^9 m^3$ in 2050 (Table 3), which will be 5.17 times of that in 2000.

Table 3 Prediction of China's annual water demand for industry in the first half of the 21st century

Year	Production value of industry ($\times 10^9$ yuan)	Water demand ($\times 10^9 m^3$)	Water demand for 1000yuan of industry product (m^3/1000yuan)
2000	2122.1	66.5	21.3
2010	5918.1	92.9	15.7
2030	18085.8	189.9	10.5
2050	49077.8	343.6	7.0

The increment of water demand for industry and resident (from 15% of China's total water demand in 2000 to 50% in 2050) will share the water resources for agriculture. In the Huanghe (Yellow) River valley, the Huaihe River valley and the Haihe River valley in the North China Plain, there is about 1/3 of the total population and 40% of the total agricultural production in China. Water shortage for agriculture is inevitable in the future, which will probably shake the food security and economic of China.

Northwest China will be the important region of China's economic and agricultural development in the 21st century, and population there will increase faster than other regions in China. Irrigated area will expand and water demand for agriculture will be 80% or more of the total water demand in 2030. Now, more than 50% of the surface water is diverted for irrigation and the ecological environment is deteriorated because of the lack of water, even some farmlands are suffered from deser-

① The white book of population and development of China in the 21st century, People Daily, 2002-12-19 tification. Water demand for ecology will be the all-important in Northwest China. Xinjiang has most area with deteriorated ecological environment, but with a maximum increase of irrigation area in Northwest China. Up to 2030, water demand for ecology will be $8.01\times10^9m^3$, water demand for industry and resident will be $4.95\times10^9m^3$, and for agriculture will be $56.16\times10^9m^3$, the total demand will be increased by 40% as much as that in 2000. Agriculture will face the pressure of water shortage then ①.

3.3 Water Demand from Regional Water Deficit

Since last mid-century, the population of China has grown by 700×10^6. Twenty-five years ago, with more and more river water pumped out for national multiple uses, the Huanghe River began to falter. In 1972, the water level fell so low that it dried up for 15 days before reaching the sea at the first time in China. It dried up each year with a progressively longer period. In 1996, it was dry for 133 days. From 1997 to 1998, due to drought exacerbation, the river water failed for 330 days, with 704km of the dry river course, and did not reach Shandong Province. Agricultural irrigation in the Huanghe River valley was suffered from water shortage pressure because the half of irrigation water depends on the Huanghe River.

The drying-up of the lower reaches of the Huanghe River is one of many such signs. The Huaihe River, a small river situated between the Huanghe River and the Changjiang River, was also dry for 90 days in 1997. Satellite images show hundreds of lakes disappearing and local streams going dry recent years, so groundwater tables fall and spring cease to flow.

In the northern China $6.53\times10^9m^3$ of groundwater was over pumped every year, and $64.9\times10^9m^3$ of groundwater had been over pumped from 1985 to 1998. Aquifer would be exhausted after 9–10 years if the pumping does not stop, and it would need 150–200 years for aquifer restitution.

Some inland rivers were dry up because river water was diverted for irrigation, and water table beside of rivers had fallen down. For example, annual runoff of Minqin Oasis, located in the lower reaches of the Shiyang River, had decreased from $500\times10^6m^3$ to less than $200\times10^6m^3$ in the last 40 years, $200\times10^6m^3$ of groundwater was over pumped each year, and $4\times10^9m^3$ had been over pumped to the 1990s. Groundwater table over there had dropped 10–30m, three funnels of water table with an area of $3000km^2$ were formed inside of Minqin Oasis. Desertification land was expanded after 49.3ha of tree was dead and 26.7ha of farmland was abandoned (QU and MA, 1998). Much water is required to balance groundwater for combating desertification.

3.4 Shortage of Water from Water Pollution

Tens billion tons of wastewater is discharged every year in China, and 80% of them directly flows into rivers or lakes without decontamination. Groundwater around cities is also polluted to varying degree due to the infiltration of wastewater of industry and domestic sewage (Table 4).

Table 4 Prediction of China's wastewater discharge in the 21st century ($\times10^9t$)

Year	From industry	From resident	Total
2000	26.0	19.0	45.0
2010	29.5	20.5	50.0
2030	31.0	21.0	52.0
2050	31.5	21.5	53.0

Much chemical fertilizer and pesticide flows into the rivers and lakes from farmland, even pollutes groundwater. Salt is also transported to the lower reaches of rivers or lakes by leaching water in inland watersheds. For example, in the upper reaches of the Tarim River, the longest inland river in China, 3.7×10^6t of salt migrates to the river every year. The river water is getting salty and fresh water is lack at the lower reaches (Table 5)(FAN, 1998).

3.5 Prediction of Water Demand from Irrigation

According to the calculation, irrigation area in China will increase from 54.35×10^6ha in 2000 to 64.50×10^6ha in 2050, but water demand for irrigation will decrease from $485.1\times10^9m^3$ to $415.7\times10^9m^3$ due to the decreasing of water demand for per unit area. Anyway, water demand for agriculture will be 49.9% of the total demand then, now water demand for agriculture is 85% of the total (LIU and HE, 1998). However, water demand in the Huanghe River valley and Northwest China will be more than now, water demand for industry and resident will increase, too (Table 6); but supply water is limited, it is difficult to avoid water shortage on agriculture in the future.

① Xinjiang Institute of Water Conservancy and Electricity, 1998. The exploiation and program of mothball water resources in Xinjiang.

Table 5 Monthly change of mineralization of river water in Alar Hydrological Station at the upper reaches of the Tarim River(g/L) (FAN, 1998)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1976	—	—	—	—	—	—	—	—	—	—	—	0.895
1977	0.751	0.540	2.560	4.862	5.462	0.440	0.640	0.530	1.440	—	—	—
1984	—	—	—	—	—	—	—	—	—	1.972	4.130	0.054
1985	0.976	0.848	1.216	4.016	5.152	5.964	1.276	0.664	1.520	5.028	1.760	1.266
1986	0.932	1.340	3.412	4.823	4.694	6.036	0.463	0.469	3.804	1.824	2.924	1.580
1987	0.976	0.863	3.208	4.560	6.640	4.480	—	—	—	—	—	—
1991	1.210	1.730	2.240	5.760	4.570	1.850	3.400	1.120	5.990	1.980	5.640	2.870
1997	—	—	—	—	—	4.256	0.864	0.820	1.672	0.548	4.128	3.460
1998	3.164	1.564	6.088	8.424	10.89	—	—	—	—	—	—	—

Table 6 Prediction of water demand for irrigation in 2000 and 2050 in North China and Northwest China

Region	2000			2050		
	Irrigation area ($\times 10^6$ha)	Irrigation water (m^3/ha)	Water demand ($\times 10^9 m^3$)	Irrigation area ($\times 10^6$ha)	Irrigation water (m^3/ha)	Water demand ($\times 10^9 m^3$)
Haihe River valley	6.75	5250	35.4	9.00	3750	33.8
Huaihe River valley and Shandong	8.87	7050	62.5	11.50	5250	60.4
Huanghe River valley	4.33	7200	31.2	7.00	5250	36.8
Norhwest China	2.20	9975	21.9	3.50	6750	23.6
Whole China	54.35	8925	485.1	64.50	6445	415.7

Water demand for industry and resident will increase quickly in the first half of 21 century in China, especially water demand for industry will be up 5 times and total demand will be increased by 41.3% in 2050 (Table 7). It will share much water from water demand for agriculture, irrigated area could not increase 2 million ha per year if water demand could not be meet in the future 50 years.

4 COUNTERMEASURES TO WATER SHORTAGE IN THE ARID REGION OF CHINA

4.1 Diverting Water from South to North

Per capita water resources in the Huanghe River valley, the Huaihe River valley and the Haihe River valley was 637m^3 in 1980, and 500m^3 in 1997, the available per capita water is also dropped from 468m^3 to 340m^3; but the total water demand increased from $39.6\times10^9 m^3$ in 1987 to $46.0\times10^9 m^3$ in 1997, anyway, $6.53\times10^9 m^3$ of groundwater was over pumped every year in the 1990s. Local water resources is too limited to meet the demand, diverting water from the south is the unavoidable way to meet the demand (YOU, 1994).

Table 7 Water demand in the first half of the 21st century

Year	For Agriculture			For Industry			For Resident			Total ($\times 10^9 m^3$)
	Water ($\times 10^9 m^3$)	Increase rate (%)	Percent (%)	Water ($\times 10^9 m^3$)	Increase rate (%)	Percent (%)	Water ($\times 10^9 m^3$)	Increase rate (%)	Percent (%)	
2000	4848	-0.41	85.0	665	3.34	11.7	189	3.56	3.3	5702
2010	4653	-0.13	79.5	929	3.64	15.9	268	2.69	4.6	5850
2030	4530	-0.43	65.8	1899	3.00	27.6	456	2.38	6.6	6885
2050	4157	—	49.9	3436	—	41.3	730	—	8.8	8323

Three proposals have been made for diverting water from South to North in China, the first, the so-called "western" route, calls for diverting water from the upper reach of the Changjiang River to the upper reach of the Huanghe River; the second, "middle" route, would be diverted water from the northernmost point of the Hanshui River, a tributary of the Changjiang River, directly to Beijing; the third, or "eastern" route, has being diverted water from the lower reaches of Changjiang River nearby Yangzhou South to Tianjin North.

Investment of the project to divert water from south to north is about 200×10^9yuan(RMB) based on the price in 2000, $8\times10^9-9\times10^9 m^3$ of water will be diverted, in which $5\times10^9-6\times10^9 m^3$ will be diverted to the north of the Huanghe River. The price of diverted water is high enough to ensure efficient industrial use that is many times higher than that for irrigation(CHEN and MA, 1998).

4.2 Using Water More Efficiently

Higher prices of water would encourage shifting to efficient irrigation practices for farmers. For example, drip irrigation, which is not economical for use on grain, but on high-value fruit and vegetable crops, can save irrigation water up to 70% (WANG, 2000).

Another promising possibility is to increase water use efficiency for residents and industry. As new cities rise throughout China and older cities expand or are rebuilt, urban planner would do well to keep the streams of industrial and residential wastewater separation — as opposed to the Western model that combines these flows. Industrial pollution water, residential wastewater can be recycled through decontamination, while nutrients in wastewater can be removed for use as fertilizer, etc.

The present rush of expansion, for environmentally damaging and difficult to manage, at least offers a unique window of opportunity for sound design, because poor designs adopted now will incur the economic costs of future retrofits and the social costs of water shortages. The potential for saving water in industry is perhaps even more promising. For example, the amount of water used to produce a ton of steel in China ranges from 23 to $56m^3$, whereas in the industrialized countries, such as the United States, Japan and Germany, the average is less than $6m^3$.

4.3 Controlling Water Pollution and Cleaning Wastewater

In China, 46.5% of rivers is polluted in varying degree, and 10.6% is heavy polluted that cannot use at all. Surface water and groundwater around most cities is also polluted. With the quick increasing of water use on resident and industry, discharged wastewater increases in large quantity. Water resources that agriculture can use would reduce if water pollution cannot be prevented. Especially in the Huaihe River, the Huanghe River and some inland rivers, polluted water is difficult to refine by themselves during the flow. If the waste water from industry and resident could not be refine and recycle as now, situation of water shortage in the northern China will be heavier and heavier, sustainable development of China's agriculture is impossible and it would also affect environment improvement and food security of China.

Water used for agriculture is over 80% of the total used water for national economy and social life in China. It is possible to use less water for agriculture in the future by systematically research and apply the technology of saving water. The processes include the use of rainwater, storage of precipitation, prevention of water pollution, avoidance of excessive consumption. Therefore, percentage of water use for agriculture to the total used water in whole China will decreased, and much more water could be supplied for the demand of natural ecology, industry and resident.

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