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Water Resources Supply-Consumption (Demand) Balance Analyses in the Yellow River Basin in 2009

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Abstract

For this paper, according to the statistics of water resources amounts and utilization needs, we carried out a water resources security preliminary evaluation from the following points of view: water consumption balance analysis, available water resources analysis, supply-demand water resources balance analysis, and overall water resources security analysis for the Yellow River Basin in 2009.

The results of the research show that the consumption rate in 2009 was 75.5% for the Yellow River Basin. The total amount of local water in the Yellow River Basin was 58.210 billion m^3, but both the supply water and the amount of available water are very low. Meanwhile, from the point of view of net water consumption, the deficit water resource amounts to16.763 billion m^3, and in view of the size of the water supply, the deficit water resources amounts to 16.12 billion m^3. The current deficit has been created by over-exploiting groundwater, squeezing ecological water consumption, re-using wastewater, and utilizing brackish water, sea water. Therefore, the water supply in the Yellow River Basin is not sustainable, and so it is not secure. As there exist issues in terms of the water resource and in terms of socioeconomic security and ecological security in the Yellow River Basin, we can conclude that the present Yellow River water resource is not reliable, which means that this water resource may not be able to meet future normal demands for living, production, and ecology maintenance.

Keywords:Water resources; Consumption balance; Supply-demand balance; Yellow River Basin;

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1 Introduction

With the rapid development of science and technology and an expanding economic scale, human demand for water is increasing. The use of water resources today is unprecedented. Humans build large-scale database storage facilities, dig canals, and transfer inter-basin water and so on by using advanced scientific knowledge and engineering technology. With the increasing demand for water resources, pressure is increasing on the water supply. Therefore, the water crisis is the "bottleneck" in the flow of a sustained, healthy and coordinated development of the nation's economy, and water security problems have become increasingly prominent.

Water resources security has not been clearly defined, and there is not an accepted concept so far, but the connotation and the extension are more prevalent. Water resources security involves social, economic and ecological security, among others. The essence of the issue is whether the water supply can meet reasonable water resource needs. So, water resources security evaluation's primary focus is to carry on supply-demand (consumption) balance analyses. Water shortages caused by the destruction of the supply-demand balance, the use of ecology water and a contradiction between industrial and agricultural water consumption and urban development water consumption means that the water resources supply-demand balance issue is not only about new scientific questions faced by society and the economic development demand for water , but it also becomes an important subject for research in the field of resources and environmental science, a harbinger question in the field of international water science.

The Yellow River Basin is a political, economic and cultural center of China. It occupies a pivotal position in China's economic and social development layout, and it is one of China's strategic development areas that must be secure. However, most of the Yellow River Basin is in arid, semi -arid, and semi-humid climate zones, and it is one of the regions in China with the least water. Affected by environmental change, the Yellow River water resource has decreased significantly in recent years, water security problems - especially the disparity between supply and demand of water -- being particularly prominent and seriously affecting economic and social development. Meanwhile, future climate change may further exacerbate regional droughts and floods, affecting the river basin water supply, which makes the Yellow River as a future water source an even more prominent issue.

However, most of recent research has focused on the changing trends in some hydrological elements like rainfall, runoff in the Yellow River Basin, and some meteorological factors like temperature and the effects of other elements [1,2,3]. Meanwhile, many scholars have calculated the size of the available water resources, supply water resources, and so forth, to analyze water utilization, so as to provide support for water resources security in the Yellow River Basin [4, 5]. However, a few researchers have analyzed the relationship between the size of the water resource and the amount of water consumption, the relationship between the amount of water and the amount of available water, the relationship between the sizes of the water resource and the supply of water resources, and so forth, which means few of their papers are dealing with water consumption balance analysis, available water resources analysis, and supply-demand water resources balance analysis. Because water resources security evaluation's main point is to do water resources supply-demand (consumption) balance analysis, it is very important to calculate the amount of utilization of the various water resources, to do a preliminary security evaluation of the water resources in the Yellow River Basin.

In this paper, according to the statistics of amount of water resources and the usage situation, we carried out a preliminary water resources security evaluation, which will help people to scientifically understand the status of local water resources, and it will also provide scientific theory and guidance for the effective use and scientific management of water resources in the Yellow River Basin.

2 Analysis methods

In this paper, according to the statistics of the amount of water resources and the usage situation, we carried out a preliminary water resources security evaluation from the following points of view: water consumption balance analysis, available water resources analysis, supply-demand water resources balance analysis, and overall water resources security analysis for the Yellow River Basin in 2009. The data was adopted from Yellow River Water Resources Bullet (2009).

3 Statistics of water resources amount and utilization situation

3.1 Total amount of local water resources

The total amount of local water here includes both surface water (natural runoff) and ground water [6].

So, the total water resource at Huayuankou station was 56.339 billion m^3 in 2009 (of which the natural river runoff was 47.994 billion m^3 and the non-repeated groundwater amount was 8.345 billion m^3). This is 16.5% more than the year before, 1.7% more than the annual average amount between 1987 and 2000, and 9.3% less than the annual average between 1956 and 2000.

The total water resource amount at Lijin station was 58.210 billion m^3 in 2009 (of which natural river runoff was 48.366 billion m^3, and non-repeated groundwater was 9.844 billion m^3). This is 16.9% more than the previous year, 1.9% more than the annual average amount between 1987 and 2000, and 8.8% less than the annual average amount between 1956 and 2000.

3.2Water supply to outside the basin

The total water supply of the Yellow River Basin to areas outside the basin was 10.213 billion m^3 in 2009, accounting for 27.2% of total surface water, which was 37.573 billion m^3 and 33.3% of the consumption amount of total surface water, which was 30.644 billion m^3[6]. The amount of water supplied from the Yellow River Basin to areas outside the basin is shown in Table 1.

Table 1 Water supply from the Yellow River to areas outside the basin in 2009

Unit：$\times 10^{-1}$ billion m^3

	Gansu	Inner Mongolia	Henan	Shandong	Hebei, Tianjin	Total
Water supply amount	0.98	0.46	26.01	66.02	8.66	102.13

3.3 The overall status of water resources utilization in the Yellow River Basin

In 2009, the total water taken from the Yellow River was 50.284 billion m^3 (including inter-basin transfer surface water), of which the amount of surface water was 37.573 billion m^3 or 74.7%, and the amount of groundwater was 12.711 billion m^3, accounting for 25.3%. The total water consumption of the Yellow River was 39.257 billion m^3, of which surface water was 30.655 billion m^3, or 78.1%, and groundwater was 8.602 billion m^3, or 21.9% [6].

4 Calculation results and analysis

4.1 Water consumption balance analysis for the Yellow River Basin in 2009

Based on the statistics of the water resources and water consumption for the Yellow River Basin in 2009, an analysis of the overall water consumption balance can be done, which is shown in Table 2.

Table 2 Water consumption balance analysis for the Yellow River Basin in 2009

Unit: $\times 10^{-1}$ billion m^3

Total amount of local water resources	Transfer amount (in)	Transfer amount (out)	Water consumption in industry	Ecological environment water consumption	Water amount flowing into the sea	Over-exploitation amount of groundwater	Total water consumption	Consumption rate (%)
582.10	0	102.13	377	15.57	127.7	40.3	392.57	75.5

In which the transfer amount (in) is sum of the transfer amount to Gansu, Inner Mongolia, Henan, Shandong, Hebei, Tianjin, *et al.,* which was 10.213 billion m^3.

The water consumed by industry is the sum of surface water and groundwater consumption for irrigation, forestry, animal husbandry, livestock and fisheries, industry, urban public facilities, and urban and rural residential life, the details of which are listed in the Yellow River Water Resources Bulletin (2009). The water consumed by industry was 29.289 billion m^3 of surface water and 8.411 billion m^3 of groundwater, so the total water consumption amount for industry was 37.7 billion m^3.

The ecological environment water consumption is the sum of the surface water and groundwater consumption for ecology, listed in the Yellow River Water Resources Bulletin (2009). It mainly includes water consumption amount in wetlands. The amount of water consumed for ecology was 1.366 billion m^3 of surface water and 0.191 billion m^3 of groundwater, making the amount of water consumed for ecology to be 1.557 billion m^3.

Therefore, according to the principle of water balance, the amount of groundwater over-exploited in 2009 was about 4.03 billion m^3. The over-exploited amount of groundwater = Water consumption amount in industry + Ecological environment water consumption amount + Water amount flowing into the sea + Transfer(out) amount - Local water resources amount - Transfer(in) amount =4.03 billion m^3 .

The total water consumption is the sum of water consumed by industry (37.7 billion m^3) and ecological environment water consumption (1.557 billion m^3), so total water consumption in 2009 was 39.257 billion m^3.

The consumption rate (%) = Total water consumption / (Local water resources amount + Over-exploited amount of groundwater + Transfer (in) amount – Transfer (out) amount *100% = 39.257/ (58.21 + 4.03 + 0-10.213) *100% = 75.5%.

4.2 Available water resources analysis for the Yellow River Basin

4.2.1 Water demand for ecological environment

4.2.1.1Amount of water flowing into the sea and rivers

Maintaining a minimum amount of water flowing into the sea so as to preserve the ecological environment of the estuary is the lower boundary constraint used to determine the ecological water demand for the whole basin. A technical way to determine the water demand is the history reduction method, which means one chooses a historical turning point at which the environment of the estuary turned bad, and the amount of water flowing into the sea for this period can be considered in the calculation of the ecological water demand for water flowing into the sea and rivers.

After 1986, the amount of water flowing into the sea was significantly reduced from the Yellow River and showed a decreasing trend. It was 40.1 billion m^3 between 1956 and 1985 but decreased to 14.38 billion m^3 between 1986 and 2000, and the amount of reduction was 25.72 billion m^3, 64% less than prior [7].

Due to natural factors like a reduction in precipitation and human factors like water resources development and the construction of ecological environments, the amount of water flowing into the sea from the Yellow River continues to decrease. It is generally believed that the 1970s was a turning point in its water environment history, before which things were good, and then apparently turned bad. So we can use the 1970s, to determine the amount of water flowing into the sea, as a benchmark.

The amount of water flowing into the sea from the Yellow River in the 1970s was about 35.63 billion m^3. Besides this, the average amount of water flowing into the sea in non-flood seasons was about 15 billion m^3. Based on the historical data, the least amount of water a year needed to maintain ecological balance should be about 35.63 billion m^3 minus the amount of non-ecology-related flood water flowing into the sea during the same period. The estimated amount of non-essential flood water during the same period was about 15 billion m^3, so the minimum amount of water needed to flow into the sea should have been about 20.63 billion m^3.

In order to maintain a certain amount of water amount flowing into the sea, a river must have a certain amount of water to start with, part of which will be consumed by surface evaporation. The total amount of water flowing into the sea and rivers is estimated to be about 21.63 billion m^3.

4.2.1.2 Wetlands water demand

There are nine typical wetlands in the Yellow River Basin, and these can be divided into three types: the river wetlands type, the riverside wetlands type, and the estuary type.

According to the results of research done by Zhao *et al.,* the minimum wetlands water demand amount in the Yellow River Basin is about 2.03 billion m^3 [8].

4.2.1.3 Replenishment amount of groundwater

The exploitation of groundwater in the Yellow River Basin has increased rapidly since 1980, especially in some big cities along the Yellow River where there is serious over-exploitation of groundwater. Today there are 65 groundwater funnels in the Yellow River Basin, which are near 6,000 square kilometers. The over-exploitation of groundwater in the main plain of the watershed basin has amounted to about 420 million m^3 during the past five years. Therefore, we can estimate that the exploitation of groundwater

involves about 30 billion m^3 to 40 billion m^3 of surface water, about 10% of the amount of the surface water supply.

Currently, the over-exploitation of groundwater in the Yellow River Basin amounts to about 4.03 billion m^3. According to the principle that we should gradually reduce over-exploitation, stop over-exploitation, and properly replenish groundwater, the average amount of groundwater needed to be replenished will be about 400 million m^3 in the future, until a reasonable planning replenishment goal is reached.

4.2.1.4 Total ecological water demand

The total ecological water demand amount for the Yellow River Basin is about 24.06 billion m^3 of which the water amount flowing into the sea and river is about 21.63 billion m^3. Wetlands water demand is around 2.03 billion m^3, and the amount of groundwater needed to be replenished is about 400 million m^3.

4.2.2 Amount of water difficult to utilize

The amount of surface water that is difficult to utilize can be ignored, and this refers mainly to non-exploited shallow groundwater. We consider this amount to have been about 30 billion m^3 in the Yellow River in 2009. According to the results of national integrated water resources planning during 2002 to 2004-"Yellow River water resources survey and evaluation", Pan carried the evaluation on extraction amount of shallow groundwater in the Yellow River. The total recharge amount of shallow groundwater is 16.19 billion m^3, and extraction volume is 119.3 m^3, so the amount that is difficult to utilize is about 40 m^3 [9]. Here, we estimate the amount to be about 30 billion m^3 in 2009.

4.2.3 Amount of available and supply water resources

4.2.3.1 Amount of available water resources

The amount of available water resources = Local water resources amount - Water demand for ecological environment - Amount of water that is difficult to utilize - Amount of transfer (out) water.

So the amount of available water is about 20.937 billion m^3, which is approximately equal to the amount estimated by Jing [4] 。

The amount of surface water in the Yellow River for 2009 was 48.36 billion m^3, and the groundwater resource amount was 38.02 billion m^3, of which the overlapping amount with the natural river surface water resource was 28.181 billion m^3. So the groundwater amount became 38.025 - 28.181 = 9.844 billion m^3. As the overlapping part of surface water and groundwater resources can be exploited in the form of groundwater (about 3 billion m^3), the amount of groundwater that can be exploited and utilized exceeded 9.844 billion m^3, while the amount of river runoff decreased. However, the amount of the total water resources remained unchanged, namely, the amount of groundwater reached 12.844 billion m^3 , and the amount of surface water was reduced to 45.366 billion m^3.

When the amount of transfer water is not considered:

The amount of available surface water resources was about 24.936 billion m^3 in 2009 (Amount of available surface water = Surface water amount - Water demand for ecological environment = 45.66 - 24.06 =21.306 billion m^3.)

The amount of available groundwater is the recoverable amount of shallow groundwater, which was about 9.844 billion m^3. (Amount of available groundwater resources = Groundwater resources amount - Amount of water that is hard to utilize = 12.844 -3 = 9.844 billion m^3.)

4.2.3.2 Size of the water supply

Supply water refers to water removed from natural bodies (surface and groundwater) for human use. The difference here from the available water resource is that the available amount is the amount that can be consumed, while supply water includes the re-use factor of withdrawn water. The size of the water supply equals the amount of available water multiplied by the re-use factor. As the water from natural bodies of water is not completely consumed and some returns to its source (like the return water in irrigation, among others) to be reused, the amount of supply water from natural bodies of water can be larger than the amount of water consumed. The size of the supply water resource can be calculated by using the following method [5]:

$$W=r_1Y_1+r_2Y_2-Y_3 \quad (1)$$

Where W represents amount of supply water resources, Y_1 represents the amount of available surface water (net consumption amount) in the basin, r_1 is the re-use factor of surface water, Y_2 represents the amount of available groundwater (net consumption amount) in the basin, r_2 is the re-use factor for groundwater, and Y_3 represents amount of transfer(out) water.

Therefore, W = 1.43×21.306 billion m^3 + 1.25 × 9.84 billion m^3 -10.213 billion m^3 =32.55billion m^3.

The amounts of available water in the Yellow River Basin in 2009 are shown in Table 3.

It can be seen from the table that the total amount of local water in the Yellow River Basin in 2009 was 58.210 billion m^3, but the actual available water was only 20.937 billion m^3 when the transfer (out) water, the water needed for ecology, and the amount of water difficult to utilize are excluded. Meanwhile, the amount of supply water can also reach only 32.55 billion m^3.

4.3 Supply-demand water resources balance analysis for the Yellow River Basin

From the point of view of net water consumption, the available water in the Yellow River Basin in 2009 was only 20.937billion m^3, but the actual net water consumption for production and human life was 37.7 billion m^3, 16.763 billion m^3 , or 80.1% more than the available amount of water.

From the point of view of supply water, the amount of supply water in the Yellow River Basin in 2009 was 32.55 billion m^3, but the actual water supply was 48.67 billion m^3, 16.12 billion m^3 or 49.5% more than the amount of supply water.

The current deficit is made up by over-exploiting groundwater, squeezing ecological water consumption, re-using wastewater, and utilizing brackish water, sea water. Therefore, we can see that the water supply of the Yellow River Basin is not sustainable, and thus there is no water security. Supply-demand water resources balance analysis for the Yellow River in 2009 is shown in Table 4.

Table 3 Available water in the Yellow River Basin in 2009

Unit：$\times 10^{-1}$ billion m^3

Total amount of local water resources	Transfer water amount (out)	Total water resources amount	Basin ecological water demand amount	Amount of water difficult to utilize	Available water resourcesamount	Supply water resources amount
582.10	102.13	479.97	240.6	30	209.37	325.5

Table 4 Supply-demand water resources balance in the Yellow River in 2009

Unit：$\times 10^{-1}$ billion m^3

	Water resources amount	Actual water utilization amount	Deficit water resources amount	Ways to meet the deficit amount		
				over-exploitation of groundwater	ecological water deficit amount	others（wastewater reuse, brackish water, and sea water）
Balance of supply water resources amount	325.5	486.7	161.2	33.5	95	32.7
Balance of water resources consumption amount	209.37	377	167.63	40.3	97.33	30

5 Overall water resources security analysis for the Yellow River Basin

5.1Water deficit- type analysis for the Yellow River Basin

The Yellow River Basin has 113 million people, 244 million mu of (1/15 ha) arable land, accounting for 8.8% of the population and 12.5% of China's arable lands, respectively. But the Yellow River supplies 8.8% of China's people and 12.5% of the land. The water demand per capita and per mu for the Yellow River is 243 cubic meters for the people and 113 cubic meters for the land, again accounting for serving 11% of the people and 8% of the land, respectively. We can see that for the whole country a shortage in the Yellow River Basin would be serious. In addition, it is assumed that there is a responsibility to transfer water to other parts of the country. Therefore, the Yellow River water supply for the land and the water supply for the population exceed the capacity of the Yellow River, and this will lead inevitably to an imbalance between supply and demand. Frequent drying up in the downstream areas of the Yellow River indicates that there is already an imbalance between water supply and demand.

5.2Water resources security analysis for the Yellow River Basin

The amount of water required by residents of the Yellow River area is about 2.421 billion m^3. This accounts for 55.1% of the standard water demand, which is 112.5 * 365/1000 * 1.07 = 4.393 billion m^3. The amount of water needed by residents living in the area of the Yellow River does not reach the standard required.

Water pricing policy is unreasonable in the Yellow River area, and the water price is too low, which causes farmers to not care about the water supply and not be willing to spend money on water-saving

irrigation equipment. Therefore, irrigation management methods cannot make ends meet but only encourage farmers to use more water, which in turn makes water maintenance and the renovation of irrigation projects hard, and so water-saving benefits decline. Water in the Yellow River Basin is affordable now.

5.3Water resources economic security analysis for the Yellow River Basin

Enterprise' average time without water in Yellow River Basin can be ignored, and the proportion of water costs to total production costs is within an acceptable range. However, the irrigated area without water has a large proportion of irrigation water land, which results in insecurity factors.

5.4 Water resources ecological security analysis for the Yellow River Basin

We can see that ecological water demand is about 24.06 billion m^3， but actual ecological water consumption is about 14.327billion m^3， which cannot ensure the ecological safety of the water resource.

Meanwhile, according to incomplete statistics, in 2009 there were four deep-confined descending water funnels here, five shallow groundwater descending funnels, and three serious over-exploitation zones of shallow groundwater due to the over-exploitation of underground water for a long time in the valley of the Plain (basin) area of the Yellow River. In 2009 the over-exploitation reached 4.03 billion m^3.

It is clear that the ecological security of the Yellow River water resource is not guaranteed.

As there are insecurity factors regarding the water resource, socioeconomic security, and ecological security in the Yellow River Basin, we can basically conclude that the Yellow River as a water resource is not secure at present, which means that its water cannot meet projected life and production needs, and ecology's normal demand.

6 Conclusions

We can see that the consumption rate is 75.5% in the Yellow River Basin in 2009. The total amount of local water in the Yellow River Basin in 2009 was 58.210 billion m^3， but the actual available water was only 20.937 billion m^3 when the transfer (out) water, ecological water demand amount, and the amount of water difficult to utilize are excluded. Meanwhile, the amount of supply water can only reach 32.55 billion m^3, which means that the amounts of both the supply water and available water are very low. Meanwhile, from the point of view of net water consumption, the deficit is 16.763 billion m^3, and from the point of view of supply water, the deficit is 16.12 billion m^3. The current deficit is made up by over-exploiting groundwater, squeezing ecological water consumption, re-using wastewater, and utilizing brackish water, sea water. Therefore, we can see that the water supply in the Yellow River Basin is not sustainable, and thus its future as a water resource is not guaranteed.

As there exists insecurity factors regarding the water resource, socioeconomic security, and ecological security in the Yellow River Basin, we can conclude that the present Yellow River water resource is not dependable, which means that this water resource cannot meet the life, production, and ecology's normal demands at present.

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