Constraint of Water Resources and Countermeasures for Local Sustainable Development of Xi´an

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Abstract
With tremendous pressure of population on natural resources and environment, sustainable utilization of water resources is one of the key problems that is to be solved urgently with the development of Xi´an, which is one of important cities in west China. Based on sufficient data such as hydrometrical data and yearbook statistical data, an analysis of current situation of water resources in Xi´an city has been done. Furthermore, the paper examines various factors that contribute to the shortage of water resources in Xi´an city, those are: lack of water resources, excessively rapid urban development, aggravated situation of waste water and pollution. Finally, countermeasures of the sustainable utilization of its water resources are put forwards.

Key words: Xi´an, water resources, sustainable utilization,
Introduction

Xi’an lies between 107°40′-109°49′ of east longitude and 33°39′-34°44′ of north latitude, locating in Guanzhong Plain, in the Northwest of China. It has nine districts and four counties, with the area of 9,983 km². The agricultural population is 4.037 million while the non-agricultural population is 3.129 million, and the urbanization level is 41.5%. With the superior geographical position, abundant human resources and far-reaching historical origin, Xi’an becomes the important base of scientific research, higher education, new high-tech industry, travel and trade of our country and the key city of Long-Hai-LanXin area. With the development of global economic integration and regional grouping, the economy of Xi’an is developing toward internationalization day by day, and it becomes strategic emphasis of the economic development of China, and an important fulcrum, which narrows the disparity between the east and west. In the 9th Five-Year Plan, Xi’an was regarded as a special topic to support water resources system optimization to allocate and study. The relevant experts and scholars have carried out researches to it. Based on the study, through the annual analysis of equilibrium of supply and demand in 2050 of Xi’an, considering the situation about locality water-saving and water diversion, it is predicted that until 2020, Xi’an area will be lack of water 1,600,000,00 km³ (Wang, 2001), with the further development of the industry and agriculture, especially because the increase of the water for industrial use, in 2020-2030, the unbalance between supply and demand of water resources will appear again, and will become more serious. Because the water resources carrying capacity of Xi’an is limited, at this stage, the problem of water resource will become the main factor of restraining social sustainable development of Xi’an.

Water resources state

In the surrounding of Xi’an flow Wei River, Jing River, Chan River, Feng River, Ba River, Luo River, Hei River, etc. Relevant statistics show that the annual average flows of surface water in Xi’an is 2,178,000,000 m³, groundwater resources amount are 1,727,000,000 m³, deducting the repetition amount between the two of 1,239,000,000 m³ the general amount of water resources of the whole city is 2,666,000,000 m³ (Yu, 2000). For many years, the development and utilization degree of groundwater has been high, and now it doesn’t have great potentiality being excavated more, and the degree of surface water is low, and therefore the developing amount is limited. The supplying water amount in Xi’an was 1.83 km³ in 2000, of which the surface water was 0.53 km³, accounting for 29% of the total, and the groundwater was 1.3 km³, accounting for 71%. Water consumption of industry in the whole city was 0.36 km³, accounting for 19.7% of total amount, the water consumption of township industry 0.171 km³, accounting for 9.3%, the water
consumption of agricultural irrigation 0.954 km$^3$, accounting for 52.7%, the urban domestic water 0.257 km$^3$, accounting for 14% and that of the rural domestic water 0.078 km$^3$, accounting for 4.3% (Ge, 2004).

**The water resources problems**

**Lack of water resources amount**

Xi’an belongs to the continental monsoon climate of semi-arid and warm temperate zone, and the four seasons are very clear. The annual average temperature is about 13.0-13.4$^{\circ}$C, and annual average precipitation is 580.2 mm. It can be found out from Fig. 1 and Fig. 2. (data from the statistical yearbook of Xi’an) that precipitation changes within the year and inter-annual differences are very great. The precipitation in spring, summer, autumn, and winter accounts for 32-39%, 31-36%, 24-29%, 3-5% of the total precipitation. We can find out from the precipitation statistics in 1992-2001 that the inter-annual precipitation distribution is extremely uneven, the most precipitation is 115-133% of the long-time annual average, and the least has only 56.7-77.4% of it. Besides, since 1996 (Fig. 2) the precipitation has been reduced year by year, and has demonstrated the aridity trend.

![Fig.1. Monthly precipitation of Xi’an (1992-2001)](image-url)
According to the analysis, during the most years, if the precipitation increases by 10% each time, its radial flow will increase by 18-30%, on the contrary, if the average precipitation reduces by 10% each time, the radial flow will reduce by 16-27%, the groundwater will reduce correspondingly by 10-20%. The precipitation is little and it changes largely, this becomes the main reason of the less water resources amount in Xi’an.

Groundwater resources amount, which can be exploited, is 1.548 km³ in the whole city, and because of the excessive exploitation, it has caused a series of ecological and environmental problems, and has no development and utilization potentiality any more. There are only Jing river, Wei river and Luo river, the three great rivers which are long rivers in the district, most of the others are short and small rivers, what is more, the slope is steep and the flow is rapid; With the change of the precipitation, the water amount changes within the year and inter-annual differences are very great, and the guaranted rate of water supply is low. The sand content in Wei river is great, and the flow is small in dry season, combined with the serious pollution today, the water resources for the city to utilize are quite limited; Jing river and Luo river are difficult to be used in the cities and towns to supply water, besides their water is used for field irrigation at present. So the surface water resources are limited.

**Unbalance between supply and demand**

Xi’an is in the semi-arid West, belonging to the area lacking of water as a resource. The annual amount of water resources per capita is only about 300 m³, equivalent to 1/6 of the whole country and 1/3 of Shaanxi Province. The amount is far lower than the internationally acknowledged 1000 m³ per capita critical value to maintain normal development of regional social economy. There were more than 7.17 million people in Xi’an at the end of 2003. We can draw a conclusion from the analysis of remote sensing image in 2000-
2003 that Xi’an has expanded a lot towards north and west. The urban area expanded to 351.21 km² in 2003 from 253.37 km² in 2000, growing nearly 100 km² (Fig. 3 and Fig. 4). According to the programme during the State's 10th Five-Year Plan Period, the urbanization level of Xi’an will be up to 55% in 2005. The urbanization rate of Xi’an should be increased by 2.5% every year. Based on population of 7.5 million in 2005, except the population from other places flowing in, population in Xi’an will increase by 373,300 people every year. The amount of water supply was 1.83 km³ in 2000. It is predicted that by 2010 water of productive use and domestic use of the whole city would continue increase, and the total water consumption will be up to 3.6 km³. The total amount of water resources is 2.666 km³ at present, and with the present state of annual amount of water supply, it will be unable to meet the need of the social and economical sustainable development of the city in the future.

![Fig. 3. Urban scope of Xi’an (2000)](image1) ![Fig. 4. Urban scope of Xi’an (2003)](image2)

### Water pollution

According to the monitoring of the environmental protection department, there is only Ba River, in which the total water quality is good of the main rivers of Xi’an; the others are all polluted in various degrees. It can be found out from Table 1 (data from the materials of Environmental Protection Agency, Xi’an) that the pollution with organic substances has been already very serious, tri-nitrogen pollution has already reached the serious pollution degree, and the heavy metals have slight pollution too. In a word surface water in Xi’an is polluted seriously already, and in most areas the water is unsuitable for use. The excessive exploitation of the groundwater causes pollution when surface water permeates to the groundwater in a direct or indirect way. This makes the groundwater receive the pollution in various degrees, among them the phreatic pollution is the most outstanding, and the pollution possesses the characteristics of zonation in the contaminated area. It has been formed a heavily contaminated area including urban areas near north suburb

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and centre. Pollution makes mineralization generally improve; it is the high-
est with the urban area and sewage irrigation area of north suburb, exceeding
1.5 g/L, and it is 3.1 g/L to be the maximum. With the increase of mineraliza-
tion, the phreatic chemical type is turned into chloride type water progres-
sively by the heavy carbonic acid type water. Water quality is worsening, and
it has been already unsuitable to drink. The pollution of nitrogen is aggra-
vated, according to observational materials; the average content of nitrogen is
189 mg/L in phreatic water in the urban area and suburb nearby. It exceeds
the background value greatly already and is increasing above 2 mg annually
at present. Pollution is aggravated year by year, and water quality is aggra-
vated too.

The amount of municipal sewage admitted of pipe network of sewage of
Xi'an was 800,000 m³/d in 2000, and it has been already built up two urban
sewage treatment plants in Xi’an. The total handling ability is 310,000 m³/d,
among them the Beishiqiao sewage treatment plant occupies 150,000 m³/d,
and the Deng’s village sewage treatment plant occupies 160,000 m³/d. The
sewage-handling rate is 38.7%; sewage handling capacity is obviously on the
low side.

Table 1. Pollution classification and pollution degree of Main River in Xi’an
(2000)

<table>
<thead>
<tr>
<th>Pollution classification</th>
<th>Pollution index</th>
<th>Pollution index sum</th>
<th>Average pollution index</th>
<th>Pollution classification average index</th>
<th>Pollution degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic substance</td>
<td>Permanganate index</td>
<td>23.78</td>
<td>3.96</td>
<td></td>
<td>7.46 Severe</td>
</tr>
<tr>
<td></td>
<td>BOD</td>
<td>19.36</td>
<td>3.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Volatile phenols</td>
<td>56.78</td>
<td>9.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Petroleum</td>
<td>97.14</td>
<td>16.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tri-nitrogen compound</td>
<td>Non-ionic ammonia</td>
<td>33.44</td>
<td>5.57</td>
<td></td>
<td>2.07 heavy</td>
</tr>
<tr>
<td></td>
<td>Nitrite nitrogen</td>
<td>3.64</td>
<td>0.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nitrate nitrogen</td>
<td>0.125</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy metal</td>
<td>Total As</td>
<td>0.37</td>
<td>0.06</td>
<td></td>
<td>0.28 slight</td>
</tr>
<tr>
<td></td>
<td>Total Hg</td>
<td>3.54</td>
<td>0.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sexivalent Cr</td>
<td>3.14</td>
<td>0.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Pb</td>
<td>0.9</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Cd</td>
<td>0.62</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>Total suspended substance</td>
<td>8.42</td>
<td>1.4</td>
<td></td>
<td>0.65 Medium</td>
</tr>
<tr>
<td></td>
<td>Total hardness</td>
<td>5.66</td>
<td>0.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyanide</td>
<td>0.08</td>
<td>0.0135</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
People waste water

Agricultural water usage is wasting enormously, because agricultural irrigation uses the traditional flood irrigation method. The water consumption of agricultural irrigation was 0.954 km\(^3\) in 2000 which took up 52.7% of the total amount, whereas use coefficient of irrigation is only 0.49. The reuse ratio of the water for industrial use is only 44.4%. Urban domestic water is wasted seriously, especially the “running away, dripping, and leaking” of the water of the communal facilities and using the drinking water to irrigate flowers and trees in yards and gardens aggravating the situation of water resources shortage (Xu Zhiqiang, 2003). The market’s spotting check of the second quarter of 1999, launched by the Bureau of Technical Supervision of Shaanxi Province, showed that the faucet qualification rate on the market of Xi’an was 72.58%; nearly 30% of water outlets it was difficult to shut water in. Water price is a little low, and the citizen has weak consciousness of saving water. The people use water wastefully and don’t cherish it. It was reported that, at the moment of lacking water in summer of 1995 in Xi’an, people who waited until the water finally washed; it was seen everywhere that public faucet and water closet pan were forgotten to shut or could not be shut off; on a lot of construction sites, the water from the pipes of the heavy-calibre gurgled from morning till night. There was no consciousness of saving water.

Conclusions

Countermeasures for sustainable utilization of water resources in Xi’an

The sustainable utilization of water resources in Xi’an should regard the thought of sustainable development as its guideline, namely it not only can meet the contemporary demand of economic development and human life, but also can meet different needs of the descendant. Thereby we can develop and utilize the water resource rationally on the premise of not damaging contemporary’s and descendant's interests of various fields. We need coordinate the relations between “water using for ecological purpose, domestic water and industrial water” (Yan, 2003; Yi, 2001); the domestic and international scholars have already proposed a lot of constructive suggestions and methods in this respect (Hui, 1998; Xin, 2001; Ma, 2003; Ge, 2004). Here, the authors propose some ideas too, for your guidance.

Water-saving and water diversion simultaneously

On one hand we must strengthen the treatment and recycling of the sewage and improve the reuse rate of the sewage, giving full play to the function of intermediate water, on the other hand a batch of project for sources of water will be put in practice, in this way the utilization ratio of surface water can be improved and the water table can get rising, thus the groundwater can main-
tain fine circulation. The first diversion works of Hei River alleviates the urban water shortage, but it has not totally solved the urban water problem in Xi'an. The channel of Hei River is just “transporting water”, but not “producing water”, so it has nothing to do with the total amount increasing of water resources in Xi'an. In order to guarantee the supply of water for sustainable development of Xi'an, several diversion projects should be put into practice. These would transport water from south to the north inside Shaanxi, such as “from Qian (the Qianyou River, which lies in southern foot of Qinling Mountains) to Shi (the Shibiawayu valley, which lie in northern foot of Qinling Mountains)”, “from Jin (the Jinjing River) to Ba (Ba River)”, etc., which will make the total amount of water resource to expand further in Xi'an, and it may establish the foundation for the sustainable development of Xi'an.

The technology of water usage has already reached the realm of drip irrigation in Israeli. The utilization percent of water of the drip irrigation can be up to 95%, and the output is very high too. Moreover the cost of this kind of drip irrigation is not high, if this kind of original binding equipment of Israel are imported, only 2000 Yuan RMB is required to be invested by each mou (1mou=666.7 m²) land, and it can be used for 15-20 years. Agriculture is one of the key sectors of water consuming, and the potentiality of water saving is relatively large. The unreasonable irrigation system of countryside not merely wastes a large number of water resources, but also leads to the serious secondary salinization of soil. We should popularize such advanced water-saving irrigation techniques of agriculture as sprinkling irrigation, drip irrigation, etc. in a more cost-effective manner in the countryside. The water for industrial use will be a key sector of the water consuming of Xi'an in the future. In order to make the limited water resources use effective, we need to improve the handling rate and the recycling utilization ratio of municipal sewage and industrial wastewater. The climate of Xi'an is arid, and the water resources are little in total amount, but if we establish the consciousness of saving water and improve the efficiency of water use, the existing water resources in Xi'an can bear the pressure of lack of water resources that restrains the development of west regions.

Controlling pollution and strengthening wastewater disposal

While examining and approving new industrial buildings, extensions and reconstructions, we should fully consider their environmental benefits. We need to control emission of pollutants in the production process of industrial enterprise and adopt advanced technological process and technology to substitute outmoded craft and equipment. Secondly we can deal with the key pollutants inside the factory according to the emission characteristic of pollutants of every enterprise. The facilities for the central disposal of urban sewage need to be built, and we can use sewage after the secondary treatment for urban industry and municipal administration. With the progressively increasing of the recycle amount of sewage, around 2010, it can be carried out
that the amount of recycle-water accounts for 50% of the total amount of sewage which is treated.

**Rainwater collection and harvest**

The scientific and technological collaborative project launched by our government and Germany held the meeting in Beijing in September of 2001, with the subject “sustainable utilization of urban water resources — storm collecting and the recharge of groundwater”. The experts pointed out that the utilization of rain flood should pursue to keep the rainwater on the ground and underground, and setting up the relevant industries of rain flood (Tan, 2001). According to the goal of sustainable development, we could alleviate the pressure of the water resources of Xi`an further. It is a feasible method to carry out rainwater recycles treatment, because it has the following advantages in Xi´an (Song, 2002).

**Condition of rainfall**

The annual average rainfall is 580.2 mm in Xi´an, rainfall resources are abundant, but because of the rainfall maldistribution within the year, nearly 70% of the rainfall is concentrated on summer and autumn. Moreover the rainfall is mostly storm that lasts short and rainwater can not soak into soil in time. It causes run off in a large amount, but these characteristics of the rainfall have offered the extremely convenient condition for collecting and holding rainwater. Through carrying out rational rainwater collection, storing, stepping quarter, and splitting year in rainy season, we can improve the recycle treatment degree of rainwater in order to alleviate the contradiction between the supply and need of water, and improve the utilization efficiency of urban rainwater resources.

**Advantageous landform**

The east and the south of Xi´an are high and the urban area is low. Hillside fields where the angle of slope is 6°-30° account for 43.3% of the total area, and that with slope angle greater than 30° for 6.4%. Such characteristic with high terrain around and low terrain in centre makes the rainwater collect rainwater easily.

**Fine collecting condition of rainwater**

The soil in Xi´an city relies mainly on loess, the soil layer is deep, the texture is even, and water permeability is good, so it has very good property of water impounding and conservation. It is indicated according to research that 1m thick loess layer can collect 200-300 mm rainwater to hold, 2 m thick soil layer can collect and hold 300-600 mm. especially in the plateau district of the southeast where the loess layer is thick, and we can strengthen afforesting
of the vegetation. There the loess layer from 90-200 mm can be regarded as the “soil reservoir”; the rainwater permeates the “soil reservoir” from the ground surface in rainy season and is stored. The “soil reservoir” has very large ability of regulating and storing; it can solve the contradiction of storing water in rainy season and consuming water in dry season.

**Large Area of public land and perfect drainage pipeline networks**

The areas of the land such as the park, meadow, forestland, square, and road etc. are large in Xi’an, and these unused areas can be rebuilt into a stream interface for collecting rainwater. Meanwhile, the system of underground drainage pipeline networks of urban area is perfect, the rainwater is separated from sewage, the pipe networks of rainwater help the rainwater to be collected and dealt with.

**Controlling scale of urban development and lightening pressure to the demand of water resources**

The urban area of Xi’an has already been in the operation state of ultra load at present. The water shortage takes place again and again, it is difficult to give play to the urban function normally, and the urban ecosystem loses stabilization gradually. Since the foundation of China, Xi’an has expanded nearly 10 times in the urban area, and population has increased by more than 4 times. With the further development of Xi’an, the question of water shortage will become outstanding day by day. In order to make harmony between the supplying ability of the water resources and urban development, in the respect of water resources, besides water-saving and water diversion, pollution controlling, sewage disposal strengthening, and rainwater collection, it also needs to control the scale of development of the urban area progressively, and focus on the construction on the satellite cities and towns which we can shift some functions of the urban area to; We must lighten the big pressure of demand to the water resources of urban area. Thus we can guarantee the sustainable development of Xi’an, and realize the sustainable utilization of the water resources.

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