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Challenges for sustainable urbanization: a case study of water shortage and water environment changes in Shandong, China

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Abstract

Water scarcity is one of the most difficult issues challenging the rapid urbanizing China. It has even evolved to a common constraint to urban development in relatively well-urbanized eastern coastal China. This case study presents the urbanization process, water shortage and water environment changes in Shandong in last decades, and discusses the interaction of urbanization and water utilization. The rapid urbanization has brought about increasing growth of urban water use especially domestic water consumption, giving rise to tension in urban water supply and demand. Great changes in water environment have taken place including groundwater depletion and water table falling, river and spring drying up, sea water intrusion, cone of depression expansion and water quality decline. Due to growing domestic water consumption and limitation of industrial water use reduction, total urban water demand will increase continuously along with urbanization progress. For water shortage plagued Shandong and the similar areas to achieve a sustainable urbanization, integrated measures are highly recommended such as constructing inter-city water resource networks, planning urbanization according to local water conditions, readjusting industrial structure, innovating water management, and paying particular attention to local ecological restoration.

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Keywords: urbanization; water shortage; urban water demand; domestic water use; industrial water use

1. Introduction

China’s total water resource availability is estimated about 2800 km\textsuperscript{3} per year, accounting for 6.59% of the world. As it has the biggest population, 1.34 billion or 20% of the world at the end of 2010, its water
possession per capita is only about 2100 m³, less than one-third of the world average. Overall, China is short of water resource; while in particular, the water shortage situation is much more serious in its populous and rapid urbanizing regions such as North China Plain area and eastern coastal provinces. The total water availability in North China Plain is 212 km³, accounting for 7.7% of China; while it is the home of about 500 million people or 37% of China’s total population[1]. The per capita water endowment in the plain is roughly one-fifteenth of the world average and much below the conventional measures of water scarcity. Eastern coastal provinces are China’s priority beneficiary of opening-up and economic reform policy. As economy booms, characterized with expanding cities and growing urban industries, they, without exception, have to face major water shortage and water environment problems.

Rapid urbanization is the dominant social and economic phenomena in China since the late 1970s. The urban population in China increased from 172.45 million in 1978 to 665.58 million in 2010, and its share in total population did from 17.92% to 49.68%. The actual increase in urban population, 493.13 million, is even larger than the sum of the United States’ and Japan’s total population. In particular during 2000-2010, the urban population increased by 207.14 million and its share did by 13.46%. Along with rapid urbanization, urban water demand and consumption kept a record, aggravating the urban water shortage. Up to date, about two thirds of China’s 661 cities are short of water supply, of which more than 110 are suffering from severe water shortage due to urban population increase and urban industries growing. China is experiencing the unprecedented massive and rapid urbanization in world development history. The urban water crisis would come forth with urbanization in one or two decades. It is necessary to study the interaction of urbanization and water utilization in order that those water problems puzzled areas could achieve a sustainable urbanization both economically and ecologically.

Shandong Province is located in eastern coastal China and on the North China Plain with a land area of 157,100 km² and population of 95 million, accounting for 1.6% and 7.1% of China respectively. Of main economic and social indicators, it usually shares a big proportion of the nation or ranks among the top provinces. In 2009, its gross domestic products (GDP) were about $490 billion, 10% of China and the second largest of all provinces; its GDP of primary, secondary and tertiary industry accounted for 9.2%, 12% and 8% of the nation respectively. The province’s output proportion of the country of scores of major farm and industrial products usually exceeds very much its land or population proportion. For example, the grain production of Shandong in 2009 was 8.1% of China, and cotton 14.4%, meat 8.9%, aquatic products 14.7%, electricity 7.7%, refrigerators 14.7%, television sets 11%, chemical fertilizer 13.2%, steel 8.6% and flat glass 10.8%. It is one of the economically leading provinces in China; however, its water resource availability is quite limited in comparison with its population and economy. Water scarcity is a bottleneck problem in its regional development.

Taking Shandong as a case study, the authors present the urbanization process, water shortage situation and water environment changes in last decades, and discuss the interaction of urbanization and water environment deterioration. Our main purpose is to warn local urbanization planners and managers that urbanization has been the major cause for current water shortage and water environment changes; and the deteriorating urban water supply/demand balance arising from massive urban population increase, in turn, can reduce the urbanization quality. The negative effects of urbanization on water resource in the coming decade(s) in populous and rapid urbanizing China cannot be ignored. Such areas as Shandong are highly recommended to adopt urgent measures for a sustainable urbanization and water utilization.

2. Review and prospect of urbanization progress in Shandong

As one of the earliest beneficiaries of China’s reform and opening-up policy, Shandong has gained a noteworthy success in social and economic development. Its average annual growth rate of GDP was higher than 12% during the last three decades. The per capita GDP in 2010 was about $4000, equivalent
to the upper middle income country’s economic level. Promoted by economic boom, urbanization in Shandong has experienced a rapid progress simultaneously. The cities in Shandong had evolved from 9 in 1978 to 18 in 1982 and 48 at present. In 1978, its urban population was 9.74 million, accounting for 13.6% of its total residents. With new cities and towns established and local economy improved, it expanded to 23.08 million, 27.03% of the total, in 1990. Since then, Shandong has accelerated its urbanizing pace. The 2000 national census showed that the urban population was 34.33 million, accounting for 38.15% of the total. A decade later, it further increased to 47.55 million, sharing 49.64% of total population as reported by the 2010 national census. During 1990-2000, the average annual increase of urban population was 1.13 million and that of urbanization rate was 1.08%; while during 2001-2010, the average annual increase of urban population was 1.31 million and that of urbanization rate was 1.15%. So, rapid urbanizing is a typical social-economic development feature of the province in last decades (see Table 1).

Table 1. Urban population and urbanization rate increase in Shandong 1978-2010 (population: million)

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<tbody>
<tr>
<td>Total</td>
<td>71.6</td>
<td>74.42</td>
<td>84.39</td>
<td>89.97</td>
<td>90.41</td>
<td>90.82</td>
<td>91.25</td>
<td>91.8</td>
<td>92.84</td>
<td>93.09</td>
<td>93.66</td>
<td>94.17</td>
<td>94.7</td>
<td>95.79</td>
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<tr>
<td>Urban</td>
<td>9.74</td>
<td>14.19</td>
<td>23.08</td>
<td>34.33</td>
<td>35.44</td>
<td>36.6</td>
<td>38.14</td>
<td>39.93</td>
<td>41.62</td>
<td>42.91</td>
<td>43.79</td>
<td>44.83</td>
<td>45.76</td>
<td>47.55</td>
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<tr>
<td>% of Urban</td>
<td>13.6</td>
<td>19.07</td>
<td>27.34</td>
<td>38.15</td>
<td>39.2</td>
<td>40.3</td>
<td>41.8</td>
<td>43.5</td>
<td>45</td>
<td>46.1</td>
<td>46.8</td>
<td>47.6</td>
<td>48.32</td>
<td>49.64</td>
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Source: Shandong Statistical Yearbooks and 2010 China national census data.

According to urbanization rules and the current urbanizing trend, it is predictable that Shandong will go on rapid urbanizing during next one or two decades. It is estimated that the province’s total population will be close to 100 million in 2020 and most of which will live in cities and towns. On the basis of local government’s urbanization development planning, the urban population will increase to 53 million in 2015 and 59 million in 2020, while the urbanization rate will rise to 55% in 2015 and 60% in 2020. In other words, about 1.5 million villagers will join in the urban residents each year in the following decade. The number of large cities that each has more than half million residents will grow from 16 in 2010 to 35 in 2020, and the number of small towns that each has more than 30,000 residents will increase from 45 in 2010 to 150 in 2020. In the next decade, urban residents in each of its all 48 cities will most probably be doubled, and there will be 12 large cities of which each will have more than 1 million urban residents. Qingdao and Jinan, currently the province’s two largest cities, will develop to two super metropolises with more than 5 million urban residents respectively in 2020.

3. Water resource availability and water shortage in Shandong

The recently completed national water resources investigation reveals that the average annual amount of water resources in Shandong is 30.3 billion m³, accounting for 1.1% of China. Comparing with its 1.6% of land area, 7.1% of population and close to or more than 10% of the main agricultural and industrial products of the nation, the province's water resource is in absolute scarcity. When we taking its huge population and population density into account, its average annual water availability per capita is merely 320 m³, which is less than one-sixth that of China’s average or about one twenty-sixth that of world average. According to the world widely recognized UNDP water stress indices, a region with annual water resource per capita less than 1,700 m³ is considered water-stressed, 1000 m³ of annual water resource per person is the water scarcity criterion, and 500 m³ per person per year is an absolute threshold of water resource scarcity [2]. As water resource availability in Shandong is far below the conventional measures of water scarcity, it has to seek help of external water sources to meet its growing consumption. For the time being, the water supply ability of Shandong is 21.99 billion m³, including 11.96 billion m³ of
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surface water, 9.71 billion m³ of groundwater and 333 million m³ of other sources such as sea water use. Of the 11.96 billion m³ of surface water, 6.06 billion m³ or 50.66% is diverted from the Yellow River, which is currently the major water source for the province’s cities along the river and its transfer project.

The annual precipitation in Shandong is about 550-850 mm, equivalent to 193 mm of surface runoff depth, which is more than the 150 mm threshold of ecological water scarcity criterion [2]. Apart from the high population density, monsoon climate, mountainous topography and yearly precipitation changes all contribute to the water shortage seriousness. Shandong belongs to the East Asia monsoon climate region. 75-90% of annual rainfall comes in summer. The mountains and hill landforms are widely distributed in its central and peninsula parts, making river courses short and difficult to use. Shandong saw a severe drought in 2002 when the precipitation was only one third as much as in a conventional year. In addition, the high rate of water exploitation, about 55.6%, has made the water ecosystem more vulnerable. Along with economic growth since late 1970s, especially with rapid urbanization since mid-1990s, Shandong has suffered from growing water shortage. In fact, perennial or seasonal water shortage exists in most of its 48 cities and some towns. Usually the larger the city is, the worse the water resource situation. The water shortage has seriously affected both domestic activities and industrial production as well.

4. Water resource and water environment changes along with urbanization

4.1. The dwindling total water resource availability

Industrial and urban growth is important outcome of urbanization, increasing competition for limited land and water in such areas as Shandong province. With more housing complexes, industrial parks, power stations and other projects being built on land converted from agriculture, with urban built-up area repeatedly invading the outskirts of cities and towns, and with the limited water resource being exploited excessively, the land use and land cover changes take place accompanied by rapid urbanization. Because underlying surface condition is an influential factor of regional climate characteristics, urbanization could be one of the reasons of dwindling total water availability in China’s well-urbanized places. The recently completed national water resource survey of China reported that, concerning the four north river basins (the Yellow River, Huaihe River, Haihe River and Liaohe River basins), the average annual precipitation and surface water resource during 1980-2000 were 6% and 17% less respectively than those during 1956-1979. In Shandong during 1956-1979, the average annual precipitation was 111 billion m³, surface water resource 26.4 billion m³ and total water resources 33.5 billion m³; while during 1956-2000, they decreased to 106 billion m³, 19.8 billion m³ and 30.3 billion m³ respectively[3]. What is more, the mean annual precipitation, surface water resource and total water resources in Shandong during 1999-2009 further reduced to 105.1 billion m³, 19.7 billion m³ and 29.3 billion m³ respectively. Urbanization should be a major contributor to the water resource dwindling, which deserves more professional attention.

4.2. The increase of urban water consumption

Urbanization generates the increase of urban water demand in two aspects, the expansion of urban water users and the growth of water consumption per urban resident. Total urban water demand and consumption increase along with urbanization progress because urban population increases and urban residents’ living conditions improves. According to the provincial statistics, during 1995-2009, the urban population of its all 48 cities expanded from 13.92 million to 26.48 million; and the urban water consumption increased from 2.243 billion m³ to 2.756 billion m³. When urban population doubled, the urban residential water consumption almost doubled from 655 million m³ to 1246 million m³. There is no doubt that the residential water demand in cities and towns will keep growing in accompany with
urbanization. In recent a few years, the urban residential water consumption growth seemed to halt though the urban population kept expanding, and a similar changing trend existed in total urban water use, which means the close correlation of urban residential water consumption and total urban use. In addition, though the average annual industrial water use in 2000s had no absolute decline, it is obviously less than that in late 1990s (see Fig.1).

The factors leading to such water-saving trend in recent years include the limited water availability, rising water price and improved industrial water use efficiency. But, comparing the urban water use of Shandong with that of China, we find that the potential of urban water saving in Shandong is quite limited. The water use per unit industrial added output value of Shandong and that of total China have all decreased notably in last decade, but Shandong used much less water to produce same amount of industrial added output value. In 2009 the water use per 10,000 RMB, equivalent to about $150, of industrial added output value of Shandong was 15 m³ while it was 103 m³ of total China. The daily urban residential water use per person of Shandong is also much less than that of China average. For instance, it was 146 litres vs. 212 litres in 2009[4] (see Fig.2). As there is little potential to reduce industrial water use, and the residential water consumption will increase with livelihood improving if water supply is adequate, urban water demand will undoubtedly increase when more people migrate from rural to urban.

4.3. The Increase of Wastewater Discharged from Urban

Due to excessive exploitation, the local water ecosystem becomes very vulnerable to water pollution. Most of the rivers through cities or towns in Shandong are heavily polluted. In 2009, Shandong cities discharged 3.87 billion m³ of wastewater, 1.83 billion m³ from industrial operation and 2.04 billion m³ from domestic water consumption. It is 1.69 times and 2.83 times the urban wastewater discharged in 2000 and in 1990 respectively. Along with rapid urbanization, the annual wastewater discharged from domestic consumption increased in a much faster speed than that from industrial operation (see Table 2). The increasing discharge of urban wastewater has polluted most of the surface water, leading to more serious mismatch between urban water demand and supply. It was surveyed that, in 2009, the surface water with class I, class II and class III water quality together in Shandong was merely 42.2% of the
total samples. On the contrary, 39.4% of the surface water was severely polluted with class V or poorer water quality, no longer qualified for residential, industrial or even agricultural application [5].

Table 2. The increase of urban wastewater discharged in Shandong 1990-2009

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<tbody>
<tr>
<td>Total</td>
<td>1366</td>
<td>1587</td>
<td>2290</td>
<td>2353</td>
<td>2307</td>
<td>2458</td>
<td>2640</td>
<td>2804</td>
<td>3026</td>
<td>3343</td>
<td>3589</td>
<td>3867</td>
</tr>
<tr>
<td>Industrial</td>
<td>876</td>
<td>962</td>
<td>1103</td>
<td>1152</td>
<td>1067</td>
<td>1159</td>
<td>1287</td>
<td>1391</td>
<td>1444</td>
<td>1666</td>
<td>1770</td>
<td>1827</td>
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<tr>
<td>Domestic</td>
<td>489</td>
<td>625</td>
<td>1187</td>
<td>1200</td>
<td>1240</td>
<td>1298</td>
<td>1353</td>
<td>1413</td>
<td>1583</td>
<td>1677</td>
<td>1819</td>
<td>2041</td>
</tr>
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4.4. The groundwater depletion and cone of depression spreading

As surface water is always not enough for industrial and urban residential use, groundwater has been the dominant source of urban water supply in most Shandong cities. For decades, the amount of groundwater pumped from the aquifer has exceeded the amount naturally recharged. Excessive withdraw of groundwater has resulted in wide area of water tables falling and aquifer depletion[6]. The carbonate stratum in Jinan, Zibo and Weifang in central Shandong is rich in groundwater and there were once many springs flooding in all seasons. But now, most of the springs flood less or dried up. The groundwater sinking area in Jinan, a well known “Spring City” as springs once were everywhere in the city proper, is about 200 km² now and most of the springs have stopped flooding or dried up. In 2009, the groundwater depression cones in Shandong covered an area of 13,119 km², accounting for 83.5% of its total territory; but they covered only 2,831 km² in 1979. Shandong has China’s second and third largest groundwater cones of depression, Zibo-Weifang cone of depression in east and Shenxian-Xiajin cone of depression in west, covering 5,475 km² and 4,004 km² respectively[4,5]. The former expanded by 4,075 km² in last 30 years from 1,404 km² in 1979. Shandong’s current exploitation of groundwater is either at or beyond sustainable level. The rapid urbanization is mostly to blame, directly or indirectly, for the groundwater depletion and cone of depression spreading in the province.

4.5. Sea water and salt-water intrusion in coastal cities

Sea water and salt-water intrusion is closely related to the excessive groundwater withdraw in coastal cities and towns. When fresh water is withdrawn faster than it can be recharged in the coastal area, the interface of fresh water and salt water moves towards inland and the groundwater quality degrades. Sea water and salt-water intrusion in Shandong started in later 1970s in a quite limited area. It has moved rapidly since late 1980s. From 1992 to 2002, the sea water and salt-water intrusion area spread from 982.4 km² to 1,653.3 km² with an annual invading speed of 67.1 km²[3]. At present, the seawater and salt-water intrusion in Shandong occurs in 19 coastal municipal districts and towns, and the seawater intrusion area still exceeds 1,100 km², though great efforts have been taken to avoid excessive groundwater exploitation in coastal areas. Sea water and salt-water intrusion deteriorate local fresh water, destroy farmland, and result in fresh water crisis to industry, agriculture and residential water supply.
5. Strategies for sustainable urbanization and water exploitation

5.1. Planning urbanization according to local water conditions

Currently, extensive urban growth and rash advancing rural-urban migration are commonplace in Shandong. A more practical urban scale structure should be scientifically planned to guide the future urbanization development. Based on the local water resources and environmental conditions, population size and urban area of the provincial and prefecture-level leading cities should be properly controlled. As water shortage and water environment problem is much more serious in larger cities with bigger urban population and larger industry economy, the number of megacities and the population size of each megacity of the province should be strictly controlled; while medium-sized cities and small towns must be supported to develop in particular. Interactive development of urban and rural or urban-rural integration is an ideal mechanism of the province’s social and economic development.

5.2. Adjusting and upgrading industry structure to control industrial water use

Signs hints that the decrease of industrial water use has slowed down since the start of 2000s, and even a noticeable increase of it crept back in last a few years. That changing trend in industrial water use is endangering the urban water safety. To reduce industrial water use, the government should guide each city to adjust and upgrade local industrial structure. Manufacturing is the dominant industry and has obvious advantages in Shandong. Different manufactures should be distributed in accordance with each city’s local water conditions. Intercity cooperation is necessary in the development of regional manufacturing industry. Hi-Tech industries and water-saving manufactures should be encouraged and supported, while high water consumption and heavy pollution factories must be strictly prohibited. Shandong has the predominance to develop tertiary industry such as financial and insurance services, tourism, real estate, modern transportation, convention and exhibition, and information and consultation. The local government should pay more attention to over-all planning of modern service industries preferentially, for modern services rarely rely on water resource to develop and discharge less wastewater.

5.3. Constructing modernized water networks and exploiting non-traditional water sources

As local water resource is always insufficient and unevenly distributed, it is necessary to establish an advanced intercity water networks to reallocate water resources, regulate water supply and consumption, and purify and recycle the waste water within the province. The networks could rely on the two existing large interbasin water diversion projects, Water Diversion Project from Yellow River to Qingdao diverting the Yellow River water to most parts of the province and Shandong Branch Line of South to North Water Transfer Project conducting the Yangtze River water to the peninsula, as frame and include each city’s local water supply systems. With the water networks, all kinds of water resources, surface water, flood, groundwater, flowing-in water, water from Yellow River and Yangtze River, desalted seawater and purified sewage, could be integrated and reallocated among cities and industry sectors. As the east part of Shandong extends into the sea, sea water utilization is a vast potential non-traditional water source. Rain and flood in monsoon summer, if gathered and well purified, can also add to water resource reserves.
5.4. Innovating water management to regulate water consumption

It is necessary to control water consumption by reforming the water allocation and management policy. Economic means could be introduced to water management practice. Those who withdraw water from natural water bodies must pay water resource fee once the application of water drawing permit is approved. The water bureaus are expected to formulate or update the policy of water use right transfer and its specifications. The transfer of water use right should be compensated. When water is conducted from rural to urban or between cities, the new user should compensate the original for water resource export. Water pricing is an effective measure in water resource management. It is recommended to expedite the water pricing reform and water industry development. Besides making water prices based on the balance of supply and demand, the government and water managing sectors should practice different water prices according to season and time, different water sources (surface water, groundwater, desalted seawater, purified sewage…), various water use purposes (production or living; industrial, residential or ecological use…), water quality and water consumption quantity as well.

5.5. Improving ecological conditions and local water generating capacity

In the long term, improving local ecological conditions and water generating capacity is the fundamental approach to alleviate water poverty and water environment problems. There was seldom water shortage or water environment problems in Shandong before it started the rapid urbanization and industrialization a few decades ago. It is the human exploitation activities that disturbed the nature’s water generating capacity and reduced water resource quantity and quality. A harmonized nature and human relationship needs to be rehabilitated step by step. Compensatory forestation should be well planned and put into practice as soon as possible for water and soil conservation. The cultivated land on hill sides in the upper reach of rivers should be transformed to garden plot, forestry or grassland gradually. It is urgent to prohibit groundwater over-pumping and take engineering measures to help groundwater recharge. Urban industries must improve water recycling technology, and draw less freshwater and discharge less wastewater as well. When ecological balance rebuilt and water generating capacity improved, additional water could be reserved to increase local water endowment.

In rapid urbanizing China, water shortage and water environmental problems exist in most cities and towns. Urbanization results in increasing growth of urban water demand and consumption; water shortage or water crises and water environment deterioration will, in turn, risk the urbanization quality. For such water shortage and water environment problems perplexed as Shandong to achieve a sustainable urbanization, it is necessary to take comprehensive measures from the aspects of urbanization planning, water resource protection, water management, ecological restoration and much else besides.

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