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Water-saving potential evaluation of water-receiving regions in Shandong province on the East Route of the South-to-North Water Transfer Project of China

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Abstract: Taking 13 water-receiving areas on the East Route of the South-to-North Water Diversion Project (ERSNWDP) in Shandong Province as the study area, and comparing it with Jiangsu Province on the ERSNWDP and the Middle Route of the South-to-North (MRSNWDP), the current water-saving potential of the water-receiving areas within the municipalities of Shandong was analyzed. Different water-saving scenarios were constructed and analyzed with key water-saving indexes in various industries. These indexes include the effective utilization coefficient of farmland irrigation water, total water consumption of industrial sectors with an added value of over 10 000 RMB, average leakage rate of the urban public water supply pipe network and the penetration rate of water-saving appliances. Based on the scenarios, comprehensive water-saving potential of the 13 water-receiving area cities was calculated. The results show that the water-saving potential of the study area is at a relative high level. However, some cities still have a certain amount of water-saving potential for agriculture and industry to be elevated. Under the recommended water-saving scenario, the water-saving potential is 1.134 billion m^3, accounting for 5.33% of the current total water consumption, of which 460 million m^3 is in agriculture, 600 million m^3 in industry, is and 74.20 million m^3 in urban domestic sector. Comprehensive water-saving measures for the study area were proposed from the aspects of agricultural, industrial and domestic water uses. Agricultural and industrial water saving are more significant. The major cities for agricultural water saving include Jining City, Heze City, Weifang City and Jinan City; the focus cities of industrial water saving mainly include Weihai City, Jining City and Qingdao City and *etc.*; the key water-saving areas for urban use mainly include Zaozhuang City, Jining City and Heze City.

Keywords: East Route of South-to-North Water Diversion Project, Shandong water receiving area, water-saving level, water-saving potential

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Introduction

Water saving is a common challenge around the world. The new era of water governance policy of "water-saving priority, spatial balance, systematic governance, and two-handed effort" requires water saving to be given priority in terms of concepts, awareness, and measures. Levidow *et al*. (2016) combined the economic advantages brought by ecological innovation with the reduced ecological resource burden, and analyzed the driving factors of ecological innovation of large manufacturing companies, as well as the benefits and prospects of water saving and water pollution reduction brought by innovation. Campisano and Modica (2014) used a behavioral model to simulate a long-term

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water balance in rainwater collection (RWH) tanks to assess water-saving and rainwater retention benefits. Ahmad and Prashar (2010) developed a dynamic simulation model for South Florida to analyse the interrelationship between urban water demand and water-saving potential. In China, the research in water-saving potential has primarily focused on agricultural irrigation areas whereas the research on urban production and domestic water saving potential is yet limited. The existing research mainly consists of urban water-saving index system, technical standards, economic policy such as the qualitative level. Furthermore, comprehensive water-saving potential study was relatively few, as there is limited guidance on the setting of water-saving strategic goals and the implementation of measures.

With capita water resources of 322 m^3, water resources shortage has become a prominent bottleneck that restricts the economic and social development in a healthy manner in Shandong Province, due to high population and low land area per capita, together with the influence of economic structure and extreme hydrological events such as flooding hazards. Increasing water resource and reducing water use are two important ways to solve the current conflicts of water shortage. To alleviate the situation, Shandong Province has received 4.6 billion m^3 of water (including 81 million m^3 of water for ecological replenishment) from the East Route of the South-to-North Water Diversion Project (ERSNWDP) in recent years (Shandong Water Resources Department, 2019), which effectively guarantees the demand of the water receiving areas. In terms of water saving, a series of measures have been implemented to promote water conservation in Shandong water-receiving areas in agricultural, industrial, and urban sectors. The measures also include internal potential tapping to increase the water sources, improvement of water-saving technology and water-saving market construction. These measures had promoted national water saving and achieved good results (DIAO Xin-quan *et al*. 2011; CUI Wei *et al*. 2011).

However, water-saving work in the water-receiving areas of Shandong Province still needs to be further improved. The whole society's water-saving production and consumption modes have not been fully realized; the industrial structure and layout of some regions are not in adaptation to the water shortage condition; and the development and utilization levels of regional water resources are both close to upper limit of water resources and the capacity of water environment. To solve these problems, the water-saving management system for the resources quantity and resource use intensity controls needs to be improved; and the awareness of water saving in the whole society needs to be further improved as well (FAN Ming *et al*. 2011; LIU Kai-fei, 2011). Therefore, further researches on water-saving and increasing water-saving efforts are still inevitable choices for the water-receiving areas in Shandong of the ERSNWDP. The purpose of this paper is to provide useful reference and support for water-saving strategic planning and implementing.

1 Study area

Water-receiving areas of the ERSNWDP in Shandong Province include the water preservation facilities of Nan-si Lake, and Dong-ping Lake in the southwest, Tuhai Majia River Plain in the north, and 13 cities in the Shandong peninsula, namely Zaozhuang, Jining, Heze, Liaocheng, Dezhou, Jinan, Qingdao, Binzhou, Yantai, Weihai, Zibo, Weifang, Dongying, *etc.* (Fig. 1).

According to the relevant planning reports, the water receiving area of the South-to-North Water Diversion Project in Shandong Province is located at 114°36′~122°43′ east longitudes and 34°25′~38°23′ north latitudes, covering an area of 113 000 km^2, accounting for 73.7% of the Province's total land area and 85% of the cities in the Province. The study area is located in the middle latitude with a warm temperate monsoon climate characterized as semi-arid and semi-humid. The average annual temperature is 11.7°~14.5°, and the average annual precipitation is 680.5 mm. In 2017, the utilization rate of local surface water was 28.8% and groundwater extraction rate was 48.2%, with a comprehensive water resource utilization rate of 45.6%. In 2017, the total water consumption was 20.949 billion m^3, among which agricultural water consumption was the largest, accounting for 64%. Industrial and domestic water consumption accounted for 13.77% and 12.89% respectively. Urban public and ecological environment water consumptions are

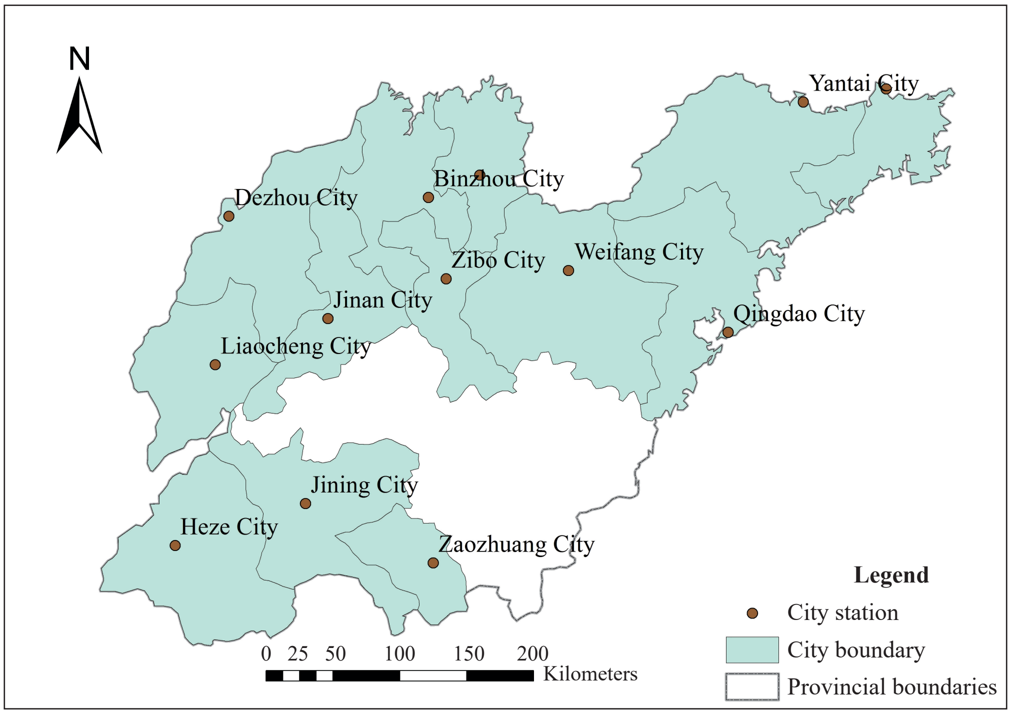

Fig. 1 Study area for water-saving potential evaluation

relatively small, accounting for 7.57% and 12.02% respectively.

The first phase of the ERSNEP draws water from the main channel of the Yangtze River downstream. The planned project scale is to pump 500 m^3/s water from the river, of which 100 m^3/s is delivered into Dong-ping Lake, 50 m^3/s across the Yellow River, and 50 m^3/s to Shandong peninsula areas. After the completion of the project, the average amount of water pumped from the river was 8.766 billion m^3; the amount of water transferred to the lower lake was 2.970 billion m^3 (Water Resources Department of Shandong Province, 2019) and the amount of water passing through the Yellow River was 442 million m^3; and the amount of water reaching Jiaodong was 883 million m^3, according to the planning of South-to-North Water Diversion Project (2002). The water volume allocated for Shandong Province is 1.467 billion m^3 of the ERSNEP.

2 Methodology

Firstly, the key indexes were used to characterize current water-saving level and water-saving potential for different industries. Effective utilization coefficient of farmland irrigation water was selected to analyze the level of agricultural water saving. Water consumption index of industries with an added value of more than 10 000 RMB was selected to analyze industrial water-saving level. The urban and rural daily water uses per capita, which included the water uses for urban construction, the publics and public facilities, were selected to analyze the level of domestic water saving level.

Secondly, the reference area to compare current water-saving level of the study area was determined. Taking into account the shortage of water resources, the levels of economic and social development and the similarity of related policies, the main cities in Jiangsu Province of the ERSNEP and the MRSNEP were selected as reference areas for water-saving levels evaluation (Planning of South-to-North Water Diversion Project, 2002).

Thirdly, determine the calculation method of water-saving potential. Water-saving potential is defined as the difference between the water-saving target achieved by various water-saving measures and the current situation of water-saving. At present, the calculation methods mainly include technical assessment method, quota comparison method, comprehensive evaluation method and the calculation formula proposed by the Department of Water Resources Management of the Ministry of Water Resources of China. The technology assessment method is only suitable for calculating water-saving potential in a small study area with limited water industrial and water sectors. Quota comparison method is subjective to determining the water level and water quota reference of advanced cities. The comprehensive evaluation method assesses the water-saving potential by establishing the evaluation indexes of a research area. The evaluation process generally includes the selection of indexes, the determination of weight factors and the selection of evaluation methods. This method involves the selection of indexes and the determination of weights in the process of establishing the prediction model which is not widely applied due to many influencing factors such as data availability and complicated procedures. The calculation formula of water-saving potential divides the calculation of water-saving potential into three aspects: Agriculture, industry and urban domestic water-saving potential (CHEN Yin *et al*. 2005; LIU Fan *et al*. 2018). Through detailed comparison and analysis, this formula is hence used in this study to determine the water-saving potential, owing to its advantages in data collection, easy operation and wide application, especially in calculating annual water-saving potential at a planning level (SONG Guo-jun *et al*. 2017; MA Su-ying *et al*. 2008; Ministry of Water Resources of China, 2004).

Finally, construct different water-saving scenarios to calculate the water-saving potential. This was done for different industries in the study area (LIU Chang-ming *et al*. 2009; SHEN Fu-xin *et al*. 2002; XU Zhen-min *et al*. 2014; LIU Hong-li *et al*. 2013). Combined with the relevant planning and policy requirements of the water demand areas, the recommended water-saving scenarios were proposed from the aspects of target accessibility and *etc*. As a result, the comprehensive water-saving potential was determined and corresponding water-saving measures were put forward.

3 Result and analysis

3.1 Analysis of current water saving level

3.1.1 Current agricultural water saving level

Due to the influence of climate, water resources condition, crop composition, water-saving level and other factors, the agricultural water consumption indicators of the study area are different from the reference areas (Fig. 2). In the study area, the coefficient of effective utilization of farmland irrigation water is above 0.62, which is generally higher than most of cities in the reference areas. However, the average per ha irrigation water consumption of arable land in the study area varies greatly. For example, in Qingdao, this value was only 780 m³/ha, while it can reach 3 000 m³/ha in Zibo, Jining, Dezhou, and Binzhou. This suggests that there is a great water-saving potential for agriculture in these cities.

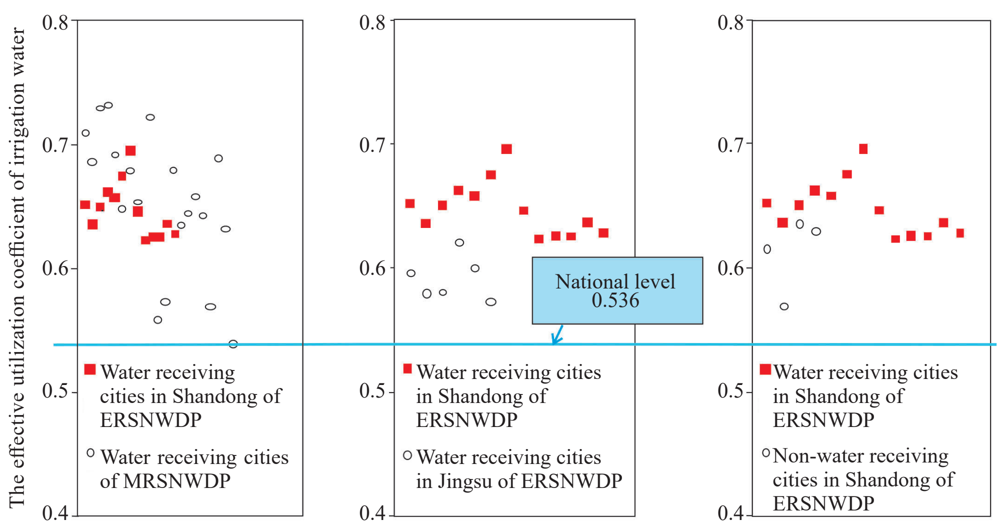

Fig. 2 Comparison of the effective utilization coefficient of irrigation water between the study area and the reference areas in 2015

3.1.2 Current industrial water-saving level

The industrial water-saving level in the study areas was analyzed, by using water consumption indexes extracted from the industrial sectors with an added value of 10 000 RMB (Fig. 3). Fig. 3 shows that the unit water consumption is 4.1~19.9 m^3/10 000 RMB, which is slightly lower than that of Jiangsu water receiving area; and most cities are lower than that of the Middle Route water receiving areas. Similar to agricultural water use, there is a large gap in the industrial sectors, such as those in Dongying and Zibo cities, which may save a lot of water resources during their daily operation.

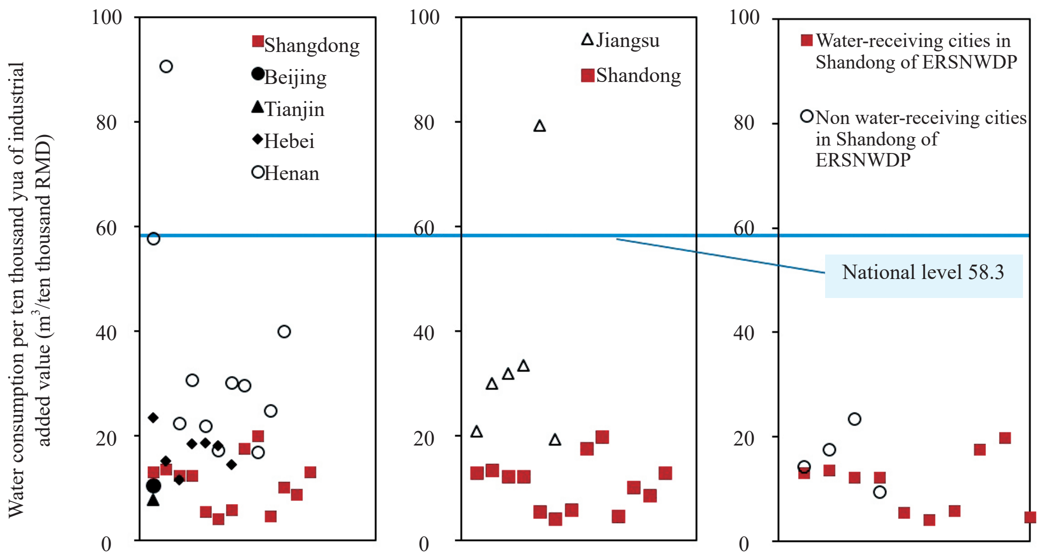

Fig. 3 Comparison of water consumption of 10 000 RMB of industrial added value between the study area and the reference areas in 2015

3.1.3 Current water-saving level for domestic water use

The daily water use of urban and rural residents were respectively selected to analyze the level of domestic water saving in the study area, with results shown in Fig. 4 and Fig. 5, respectively. The per capita daily domestic water use of urban residents in the water-receiving areas of the study area was 92.4 L and that of rural residents was 52.2 L, both of which were slightly lower than levels in cities in the receiving areas of Jiangsu Province and far below that of cities along the middle line of the water transfer project.

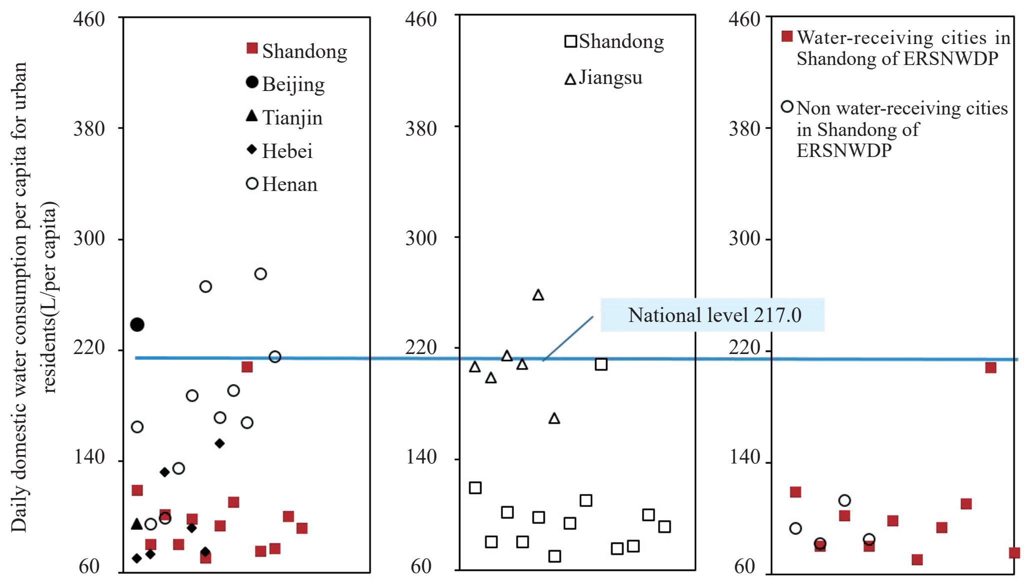

Fig. 4 Daily domestic water consumption per capita for urban residents in the study area and the reference area in 2015

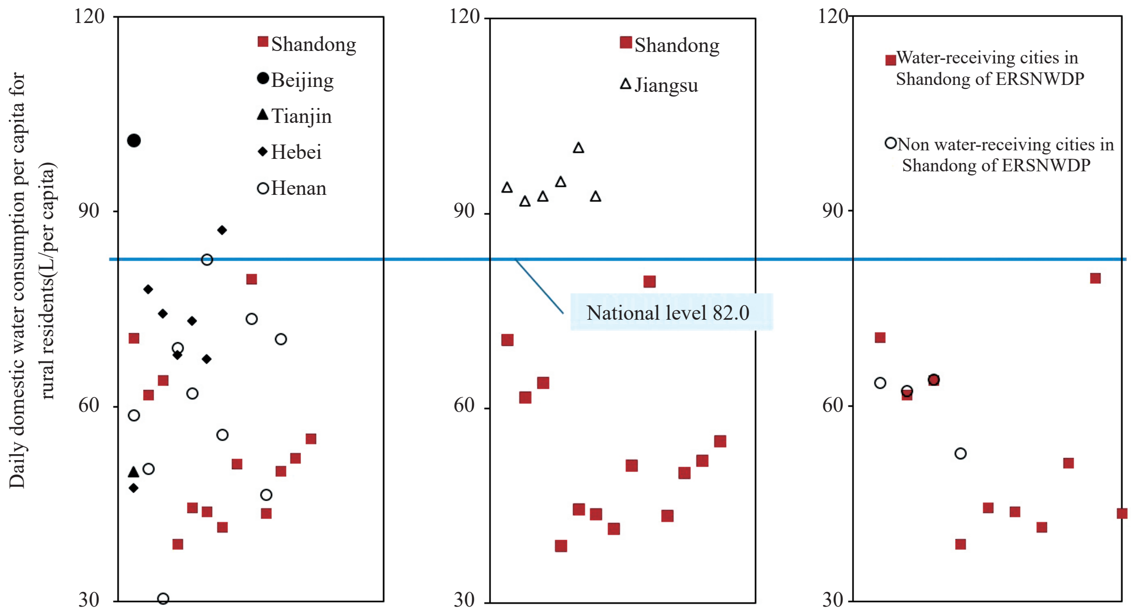

Fig. 5 Daily domestic water consumption per capita for rural residents (L/per person) in the study area and the reference area in 2015

3.1.4 Analysis on key directions of water saving work

In general, the study area has supported the sustained and rapid development of the social economy since the reform and opening to outside world, with limited water resources by strengthening water conservation and developing water-saving industries. The water saving level of various industries in the study area is at an advanced level in China (LIU Chang-ming *et al.* 2009), and water saving work has entered a stage of overcoming difficulties. The key directions of future water saving work are described as follows.

In terms of agriculture, the water saving level of the study area is at a relatively high level. However, the average irrigation water consumption for per unit cultivated land varies greatly. For example, the average irrigation water consumption of cultivated land in Qingdao is only 52 m^3/mu (as one mu equals 667 m^2), while that of Zibo, Jining, Dezhou, and Binzhou are more than 200 m^3/mu. Therefore, some cities still have great water-saving potential. Measures such as agricultural water-saving policies, improved irrigation methods, and optimized planting structure should be formulated to further tap the agricultural water-saving potential of these cities.

With regard to industrial sectors, the water-saving level in the study areas is much higher than the national level and also higher than most cities in the reference areas. Similar to agricultural water use, there is a relatively large gap of water saving in the industrial sectors among the 13 cities of the study areas, such as Dongying, Zibo and other cities. Measures should be taken to improve water-saving technology, optimize industrial layout and increase the reuse rate of industrial waste water, so as to further elevate their water-saving potential.

In respect of domestic water use, urban and rural per capita daily domestic water uses are both far lower than the national level and the reference area. In some cities of the study area, both urban and rural water consumptions are much higher than the average, such as Zaozhuang. where there is a big space to explore their water saving potential. To solve this problem, it is necessary to populate the water-saving facilities, increase the reuse rate of household water and to enhance the public awareness of water saving.

3.2 Water saving potential calculation

According to the water-saving potential calculation formula as mentioned above (Ministry of Water Resources of China, 2004) and based on the current water-saving level and water-saving plan of the Shandong Province, different water-saving scenarios with various goals were set to calculate the water-saving potential of different industries and the comprehensive potential of the study area.

3.2.1 Agricultural water saving potential

Taking the highest level of agricultural water use efficiency in the water-receiving areas of the MRSNWDP as agricultural water-saving target with a target value of 0.732, the water-saving scenario 1 for agriculture is defined, while the average level of the agricultural water use in the same area with a target value of 0.653 is defined as water-saving scenario 2. Similarly, the highest level of agricultural water use efficiency in the water receiving area of the ERSNDP with a target value of 0.69 is defined as the water-saving scenario 3; and the average level of the ERSNDP with a target value of 0.63 is then the water-saving scenario 4. The target of agricultural water use efficiency proposed by the 13th Five-Year Plan for the construction of water-conserving society in Shandong Province is taken as goal for scenario 5 with a target value of 0.646. On the basis of the water saving target scenarios, the calculated agricultural water-saving potential for each city in the study area is shown in Fig. 6.

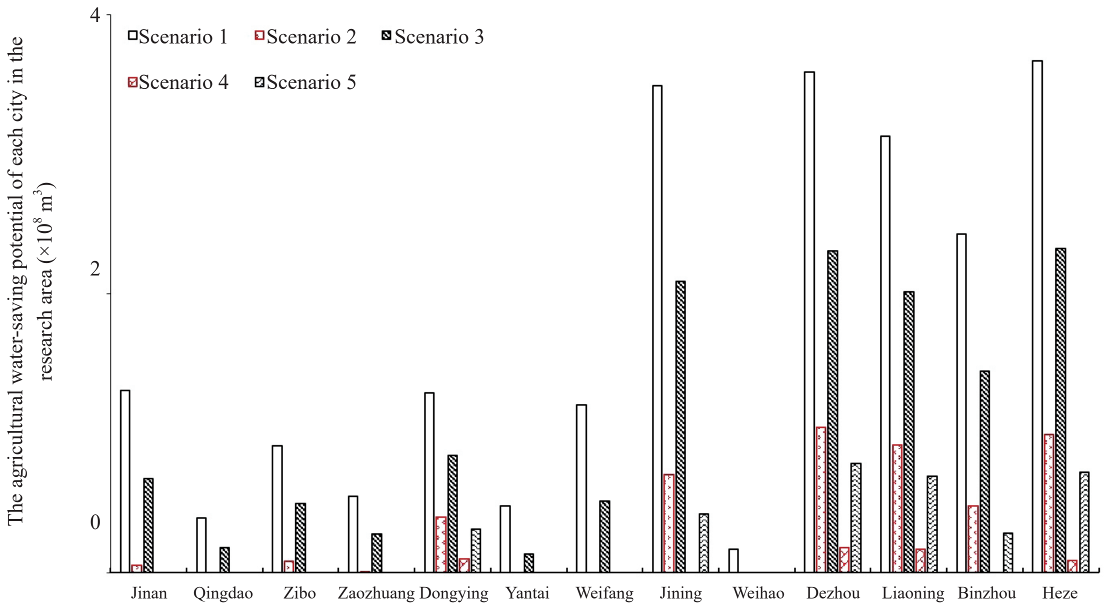

Fig. 6 Agricultural water-saving potential in different cities under five scenarios

According to the calculated result, in the case of scenario 1, each city in the study area can save the most quantity of water due to the highest water use efficiency, which is 2.26 billion m³, with a water saving rate of 12.8%. All cities in the water-receiving area need to carry out the plan of agricultural water saving. For scenario 2, the agricultural water-saving potential is 460 million m³, with water-saving ratio 2.6%. As to scenario 3, the water-saving potential is 1.07 billion m³, with a water-saving ratio of 6.1%. Under scenario 4, the potential is 50 million m³, with a water saving ratio of 0.3%. Under scenario 5, the potential is 320 million m³, with a water-saving ratio of 1.8%. The agricultural water-saving potential of Jinan, Qingdao, Zibo, Zaozhuang, Dongying, Yantai, Weihai and Weifang is low, while the five cities of Jining, Dezhou, Liaocheng, Binzhoun and Heze have a low agricultural water use efficiency and should be treated as key areas for agricultural water saving.

3.2.2 Industrial water-saving potential

For the determination of industrial water-saving potential, there are also five scenarios set up for various water use efficiency cases in the industrial sectors with the water-receiving area. In the water-receiving areas of the MRSNDP, the industrial water saving scenario 1 is defined as the case of highest water use efficiency with the water use quantity of 7.7 m^3 per ten thousand RMB industrial production value, while the average level of industrial water use efficiency with a target value 21.7 m^3/10 000 RMB is taken as scenario 2. Similarly, in the Shandong water-receiving areas of the ERSNDP, the highest level of industrial water use efficiency with a target value of 4.1 m^3/10 000 RMB is defined as water saving scenario 3, while the average level of industrial water use efficiency with a target value of 10.57 m^3/10 000 RMB is taken as the water saving scenario 4. The target of industrial water use efficiency proposed by The 13th Five-Year Plan for the construction of water-conserving society in Shandong Province was taken as goal for scenario 5 with target value 9.5 m^3/10 000 RMB.

The industrial water-saving potential of each city under each water-saving scenario is shown in Fig. 7.

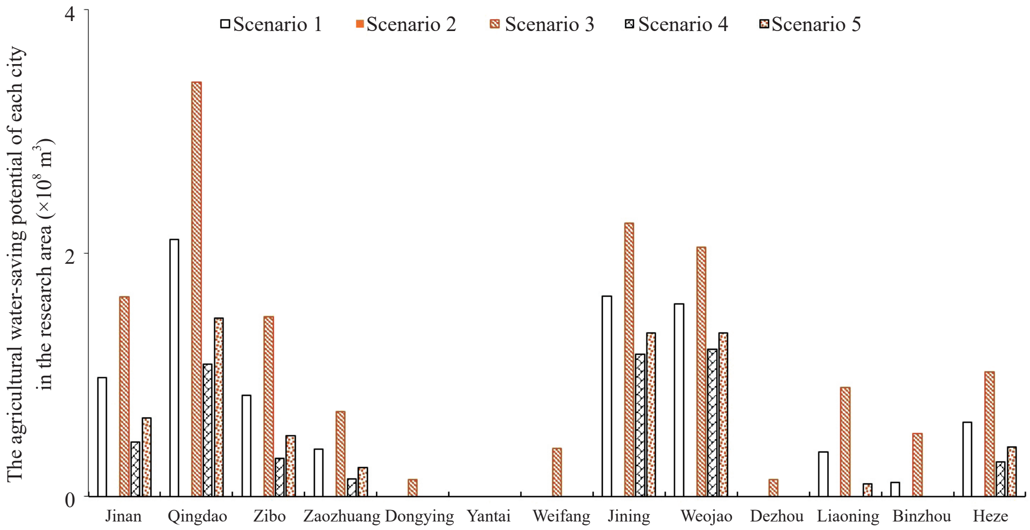

Fig. 7 Industrial water-saving potential in different cities under five scenarios

Under the water-saving scenario 1, the calculated industrial water-saving potential for each city in the study area is 860 million m^3, and the water-saving ratio is 34.8%. Under scenario 2, as the current industrial water use efficiency is higher than the target value, no city needs to carry out industrial water-saving work. Under scenario 3, the industrial water saving potential is 1.51 billion m^3, and the water saving ratio is 61.2%. Under scenario 4, the industrial water saving potential is 470 million m^3, with a water saving ratio of 19%. Under scenario 5, the potential is 600 million m^3 with the ratio of 24.2%. Yantai City has the lowest water consumption per 10 000 RMB, which does not need to implement water saving solution in these five cases. Jining and Weihai's industrial water consumption per 10 000 RMB is relatively high in the study area; and they can be regarded as a key area for industrial water saving solution. On the other hand, the cities as Jinan, Qingdao, Zibo, Zaozhuang and Heze have low industrial water use efficiency; and there is still great potential for them to improve industrial water saving measures.

3.2.3 Water-saving potential for domestic use

The leakage rate of the water supply pipe network is used as the domestic water use efficiency index. Three scenarios with different target leakage rates are set for analyzing the domestic water saving potential. Among them, scenario 1 takes the average leakage rate of 13.5% as a target. Similarly, the target values for scenario 2 and 3 are 12.15% and 9.2, respectively, according to the report titled the 13th Five-Year Plan for the construction of water-conserving society in Shandong Province. The calculated results for the domestic water-saving potential of each city under each scenario, are shown in Fig. 8.

Fig. 8 shows that, under scenario 1, the water-saving potential for domestic use in the study area is 209.5 million m^3, with a water saving ratio of 2.4%; under scenario 2, the living water-saving potential is 0.415 million m^3, with a water saving ratio of 3.3%; and under scenario 3, the potential is 74.2 million m^3, with a water saving ratio of 6.0%.

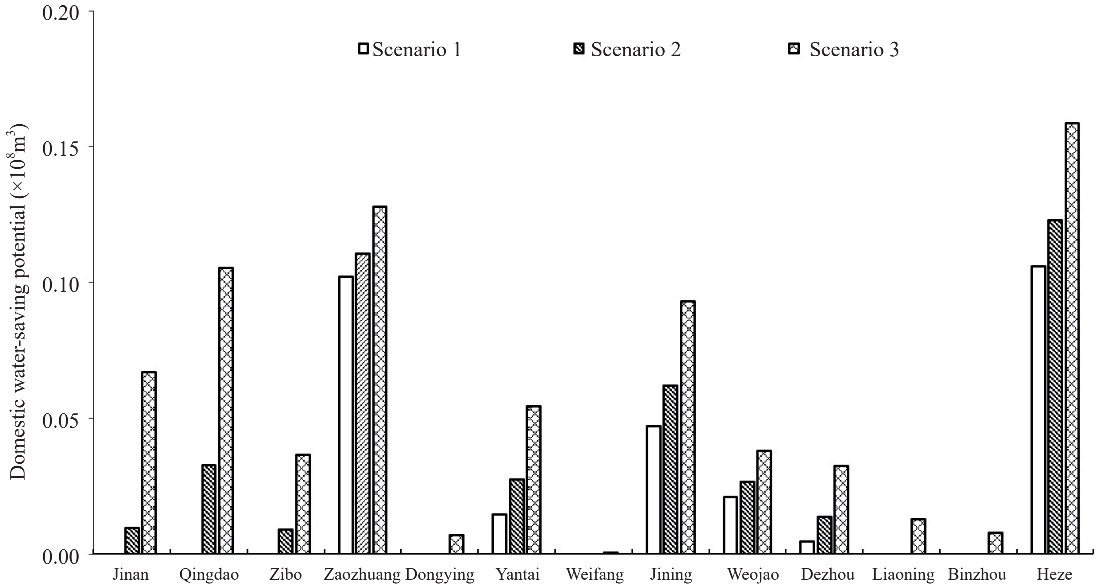

Fig. 8 Domestic water-saving potential in different cities under three scenarios

3.2.4 Comprehensive water saving potential

Considering the socio-economic development status and the water-saving society construction requirements of each city in the study area (SUN Ai-jun, 2009; Shandong Development and Reform Commission,2016; Water Resources Department of Shandong Province, 2010), analyzing the target accessibility and the water-saving level that could be achieved, it is agreed that the above scenario 2 for agricultural water-saving with the proposed efficiency coefficient of 0.653 is more reasonable than the other ones. The scenario 5 of industrial water-saving is more reasonable, where the water consumed for the increment production value of RMB 10 000 Yuan is 9.5 m^3. The scenario 3 is recommended for domestic water saving, with the pipe network leakage rate of 12.15%, which is decrease by 10% compared with that in 2015.

According to the calculated results, for each recommended water-saving scenario, the comprehensive water-saving potential of the study area is 1.134 billion m^3, accounting for 5.33% of the current total water used in this area. Among them, the agricultural water-saving potential is 460 million m^3, the potential of industry is 600 million m^3 and the urban domestic water use is 74.2 million m^3.

In this study area, agricultural and industrial water saving is a key issue in the future due to their high amount of water used and low amount of water saved on a daily basis. Based on the analytical results, the cities prioritized for saving irrigation water through agricultural activities include Jining Heze, Weifang and Jinan; and the cities prioritized for saving industrial water mainly include Weihai, Jining and Qingdao; the key water-saving areas for urban life mainly include Zaozhuang, Jining and Heze City (Water Resources Department of Shandong Province, 2016; MA Ji-gang *et al*. 2011) .

4 Conclusions

The following conclusions can be drawn from the research:

In the water receiving area of the ERSNDP in Shandong Province, the water-saving work is at a much higher level, in comparison with most cities in the reference area. However, there is still a certain water-saving potential to be tapped in the study area, due to large differences in the quantity of water used by various industries in the cities studied. As indicated by the analytical result, industrial and agricultural sectors hold large space to improve their water-saving measures in the future. The key areas for agricultural water saving include Jining, Heze, Weifang and Jinan; the key areas for industrial water saving mainly include Weihai, Jining and Qingdao; and the key areas for urban water saving mainly include Zaozhuang, Dongying and Heze.

In the recommended scenarios, the water-saving potential of the study area is in total 1.1342 billion m^3, accounting for 5.33% of current total water consumption. Among them, the agricultural water-saving potential is 460 million m^3, the industrial potential is 600 million m^3, and domestic potential 74.2 million m^3.

It is necessary to further develop practical and feasible comprehensive water-saving measures. The publicity of water-saving should be further strengthened, and water-saving measures should be further formulated from the aspects of agriculture, industry and life, development and utilization of non-traditional water sources and transferred water construction of water-saving communities should be vigorously promoted and water-saving work in rural areas should be actively promoted.

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