Sustainable utilization analysis of water resources in Shiyang River Basin based on ecological footprint mode

Qiang Yin [1, 2, a], Hengjia Zhang [1, b, *], Chenli Zhou [1, c],
Xietian Chen [1, 2, d], Haiyan Li [2, e]

[1] College of Agriculture and Biology, Liaocheng University, Liaocheng, Shandong 252059, China;

[2] College of Water Conservancy and Hydropower Engineering, Gansu Agricultural University, Lanzhou, Gansu 730070, China.

[a] 2463715317@ qq.com, [b] zhanghengjia@lcu.edu.cn, [c] 1648607644@ qq.com,
[d] 1767685784@qq.com, [e] lihaiyan@gsau.edu.cn.

Abstract. The contradiction between supply and demand of water resources has become a global issue, which cause that Sustainable utilization of water resources has become an important topic in the world. According to the division of three-level accounts, the ecological footprint and ecological carrying capacity of water resource were calculated by using the ecological footprint model in Shiyang River Basin from 2007 to 2018. On this basis, the ecological surplus and deficit and ecological footprint of ten-thousand-yuan GDP were used to analyze its sustainable utilization. The results showed that the water resources in this region are in an extremely unsafe state of ecological deficit, but the degree of sustainable utilization of water resources is constantly improving. There is a positive correlation between the ecological carrying capacity and rainfall; The ecological footprint of the primary industry is much larger than that of the secondary industry and the tertiary industry, but the utilization efficiency of water resources is the lowest, which is the important reason for the ecological deficit of water resources.

Keywords: Sustainable utilization; Water resources; Shiyang River Basin; Ecological footprint model.

1. Introduction

Water resources is a key parameter that keep between human life, production activities and ecological environment harmonious in production and development of human being. As the basic resource of production and development of human society, water resources play an irreplaceable role in human life, production activities, and the maintenance of ecological environment. However, contradiction between supply and demand of water resources has become a global issue with population and economic growth. Thus, sustainable utilization of water resources is a key link to promote the inconsistency development of population, resources, economics and ecological environment [1-5]. At present, the domestic and foreign scholars has researched many methods on sustainable utilization of water resources. It includes the three-stage DEA method [6], the combination of remote sensing technology and GIS [7], ecological footprint [8]and other methods, which are mainly studied and analyzed on multiple spatial scales. The ecological footprint method, put forward by Ree [9] in 1992, is to measure the ecological sustainability of a region by comparing the demand of water resource with the supply of water resource. Scholars have calculated the ecological footprint of water resources in Henan, Zhejiang, Chongqing, Chengdu of China, etc., which shows that the model has good applicability to regional water resources evaluation.

The Shiyang River Basin is one of the areas that is the most prominent contradiction in water use and the most fragile ecological environment in China's inland river basin. So, it is important to achieve sustainable utilization of water resources for keeping Ecological environment of Shiyang River Basin health. In this paper, the ecological footprint theory is used to measure the sustainable utilization degree of water resources by using two indicators, such as the ecological surplus and deficit of water resources, and the ecological footprint of water resources of 10,000yuan GDP in

Shiyang River Basin from 2007 to 2018, in order to provide suggestions for the sustainable utilization of water resources in Shiyang River Basin.

2. Study site description

2.1 Study area

Originated on the northern slope of the Qilian mountain and ended at the Minqin oasis, the Shiyang River Basin is the third largest inland river in Hexi corridor of Gansu Province in China (101°41′E~104°16′E,37°41′N~42°42′N), whose basin area is 40852 km². It has an extremely complicated natural landscape ecological system in Shiyang River Basin, which includes glacial areas, forestland, grassland, cropland and desert. Less precipitation and strong evaporation are the largest climate's characteristics of Shiyang River Basin. The average annual precipitation is 170 mm while the evaporation is 700~2600 mm, which is a typical resource based water-deficient area.

2.2 Data sources

The data related to the development and utilization of water resources in the study area was obtained from the 'Gansu Water Resources Bulletin' and the 'Shiyang River Basin Water Resources Bulletin'. The data included, for example, diverse types of water consumption, total amount of water resources, population, economic development, precipitation, etc.

3. Methodologies

The ecological footprint of water resource (EFw) is to turn the values of the consumption of water resources into land used for water resources, obtain equilibrium values that can be used for comparison between different regions of the globe [10]. It can be divided into three-leavl accounts to the water resource account, whose result is in Table 1.

Table 1. Division of the accounts of ecological footprint of water resource.

Primary account	Second account	Tertiary account
The ecological footprint of water resource	water production	Primary industry
		Second industry
		Tertiary industry
	water consumption	Life of urban residents
		Life of rural residents
	ecological water	Urban environment
		Rural ecology

3.1 The ecological footprint of water resources

The ecological footprint of water resource (EFw) is to turn the values of the consumption of water resources into land used for water resources, obtain equilibrium values that can be used for comparison between different regions of the globe [11]. It can be divided into three-level accounts to the water resource account, whose result is in Table 1. So, the formula of EFw is as follows:

$$EF_w = \mathrm{N} \times ef_w = N \times \gamma_w \times \left(\mathrm{W_p} + \mathrm{W}_l + \mathrm{W}_e\right) / P_w \tag{1}$$

Where EF_w is the ecological footprint of water resources (hm^2); N is population; ef_w is the ecological footprint of water resources per capita (hm^2/person); γ_w is global equilibrium factors of water resources, according to WWF 2002, γ_w =5.19; W_p is the consumption of water for production (m^3); W_l is the consumption of water for living (m^3); W_e is the consumption of ecological water use (m^3). P_w is the g-lobal average productivity of water resources, P_w=3140 m^3/hm^2 .

3.2 The model of water resources carrying capacity

The ecological carrying capacity of water resources (EC_w) indicates the maximum water resources supply to maintain the sustainable development capacity of society, economic support, and ecological environment in the study area in a certain period , which can be expressed as:

$$EC_w = (1-0.6) \times ec_w = 0.4 \times \psi \times \gamma_w \times Q / P_w \quad (2)$$

where, EC_w is water resources carrying capacity (hm^2); ec_w is the water resources per capita (hm^2/person); ψ is the yield factor of water resources. According to the average water production modulus of Shiyang River Basin from 2000 to 2018, it is 422.32m^3/hm^2, ψ=0.13; Q is the yield of water resources (m^3).

3.3 Indicators evaluating the sustainable utilization of water resources

3.3.1. Ecological surplus and deficit of water resources

Ecological deficit of water resources (E_d) is the difference between EF_w and EC_w, which can be used to judge the sustainable utilization of water resources in the region. Its formula can be expressed as:

$$E_d = EF_w - EC_w \quad (3)$$

Where if $EC_w > EF_w$, it means that the water resources in this area are abundant and the sustainable state of water resources is good; $EC_w = EF_w$ represents the balance state of water resources; When $EC_w < EF_w$, it means that the water resources in this area are deficient and unsustainable.

3.3.2. The ecological footprint of water resources of 10,000yuan GDP

The ecological footprint of water resources of 10,000yuan GDP(EGDP) is the ratio of water resources ecological footprint to GDP in ten thousand yuan, which can be used to measure the water resources utilization efficiency of the region. If the value is smaller, it means that the water resources utilization efficiency is higher, whereas is lower. The calculation formula is as follows:

$$EGDP = EF_w / GDP \quad (5)$$

4. Results and discussion

According to the water resources ecological footprint model (formula (1)-(5)) established above, EF_w, EC_w, E_d, and E_{GDP} in Shiyang River Basin from 2007 to 2020 were calculated.

4.1 Ecological footprint of water resources

It can be seen from Fig. 1, EF_w in Shiyang River Basin showed a downward trend on the whole. In 2007-2010, the decline was the largest, with a decrease of 61.37×10^4 hm^2 and then declined slowly in 2012-2019, with a decrease of 61.22×10^4 hm^2.On the other hand, in 2010-2012 and 2019~2020, it increased slightly, with an increase of 22.18×10^4 hm^2 and 44.31×10^4 hm^2. In three accounts of the Ecological footprint of water resources, the footprint of water production has the largest proportion of the ecological footprint of water resources, accounting for 95% with a water consumption footprint.

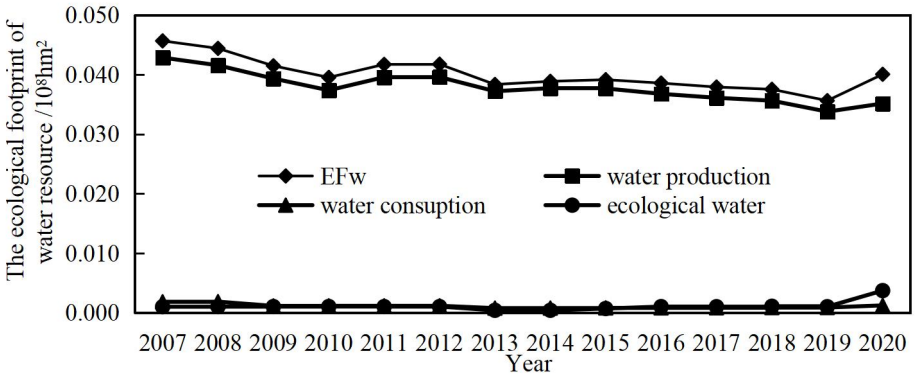


Fig. 1 Water resources for production, consumption, and ecology from 2007 to 2020

It can find out from Fig. 2 that the three major industries of the footprint of water production also has a different proportion. Primary industry is much higher than other industries, accounts for 92.4% with the footprint of water production. Second industry and Tertiary industry has a lower proportion, showing a steady trend. The main reason is that the State Council approved *'the Key Management Plan of Shiyang River Basin*' in December 2007. With the implementation of the Plan, The Shiyang River Basin will intensify water conservation, intensify the adjustment of agricultural planting structure, and improve the water use efficiency. Reducing the area of water distribution and the total amount of water lead to a significant decline in the ecological footprint.

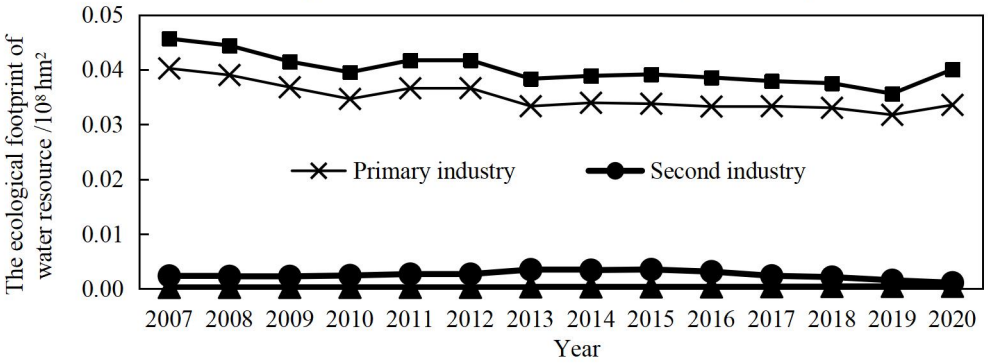
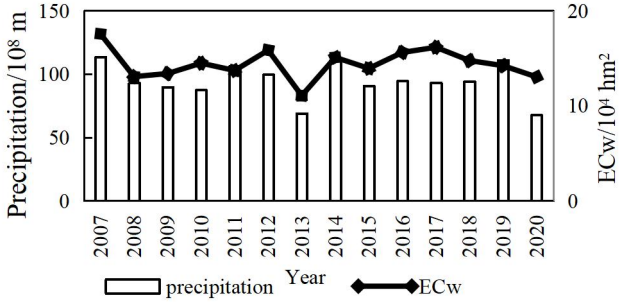


Fig. 2 Variations of three major industries in the water footprint for production from 2007 to 2020.

4.2 Water resources carrying capacity

It can be seen from Fig. 3 that the ecological carrying capacity of water resources showed a slow increasing trend, with the lowest value of 24.32×10^4 hm^2 in 2013 and the highest value of 38.59×10^4 hm^2 in 2007. It shows that there is a positive correlation between water resources carrying capacity and precipitation in Shiyang River Basin from figure 2, and the correlation coefficient is 0.727.The precipitation in 2007 was 113.517×10^8m^3, which was 31.0% higher than the average precipitation. The precipitation in 2013 was 68.88 $\times 10^8$m^3, which decreased by 20.5% compared with the average precipitation. Except the extreme weather in 2007 and 2013, the ecological carrying capacity of water resources showed a upward trend.



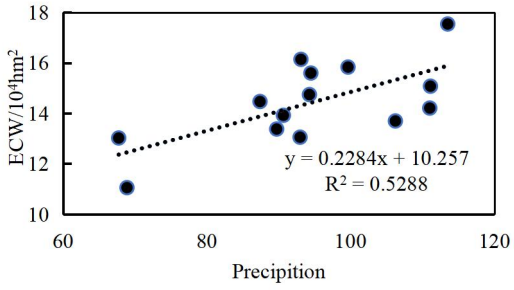


Fig. 3 Correlation between precipitation and ecological carrying capacity of water resources

4.3 Dynamic indexes of water resources

4.3.1 Ecological deficit

It can be seen from Table 2 that the water resources in Shiyang River Basin have been in an ecological deficit state from 2007 to 2020, showing a steady upward trend, from -0.044×10^8 hm^2 in 2007 to -0.039×10^8 hm^2 in 2020, with an increase rate of 11.82%. This shows that a series of water-saving measures have been implemented in Shiyang River Basin, and the ecological environment in this area has improved since 2007.

Table 2. The ecological deficit of water resource from 2007 to 2020 in Shiyang River Basin

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
E_d (hm^2)	-0.044	-0.043	-0.040	-0.038	-0.040	-0.040	-0.037	-0.037	-0.038	-0.037	-0.036	-0.036	-0.034	-0.039

4.3.2 Ecological footprint of water resources of 10,000yuan GDP

It can be seen from Fig. 4 that the ecological footprint of water resources of 10,000yuan GDP in Shiyang River Basin decreased year by year, from 1.18hm^2 in 2007 to 0.54 hm^2 in 2015. The degree of water resources development and utilization and efficiency in Shiyang River Basin have been continuously improved, and the degree of increasing is large. It shows a decline trend for the three major industries of EGDP. The value of the primary industry is larger than that of the second and third industries, and its value also declines the most, from 7.25 in 2008 to 2.49 in 2015, which indicating that the utilization efficiency of water resources in the primary industry is the lowest and its utilization rate increases the most. The value of the secondary industry is stable and around 0.06. EGDP of the tertiary industry decreased by 48% from 2008 to 2015, and the rate of improvement of utilization rate was not as fast as that of the primary industry, which maintained at around 0.03 on average. The economic development structure of Shiyang River basin is based on the primary industry.

The demand of water in agricultural is larger than that of the secondary and tertiary industries, but the tertiary industry contributes the most to GDP and has less demand for water resources. Therefore, it is indicated that the tertiary industry has the highest utilization efficiency of water resources among the three industries. In regions with insufficient water resources, it should vigorously develop the tertiary industry and improve the utilization efficiency of water resources according to local conditions to promote economic development.

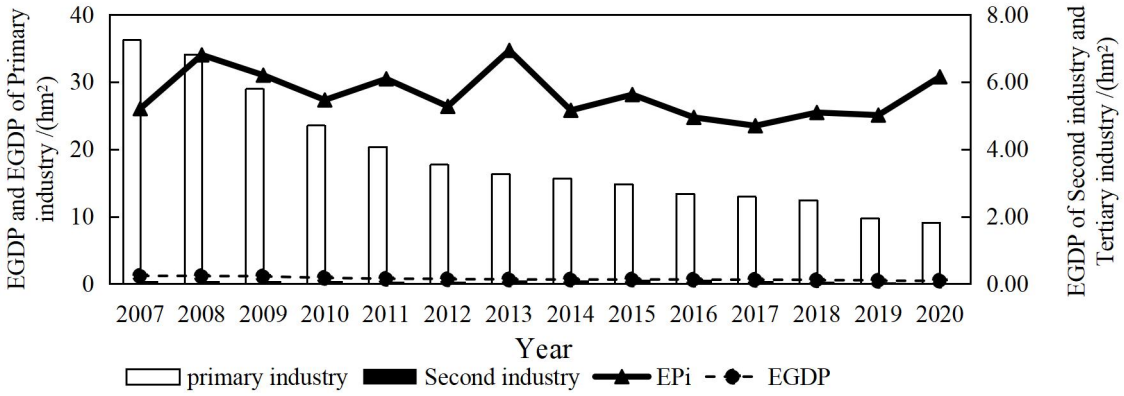


Fig.4 Variations of three major industries in the footprint of water resources of 10,000 yuan GDP from 2007 to 2020.

5. Conclusions

(1) 2007 to 2018 showed an ecological deficit of water resource, indicating an unsafe state. However, the total ecological footprint of water resources has been decreasing since 2007, while the ecological carrying capacity of water resources is slowly rise on the whole and the gap between supply and demand has been gradually reduced. And the ecological footprint of water resources of 10,000yuan GDP is decline, which indicating that the sustainable utilization of water resources is improving. There was a positive correlation between the water resources carrying capacity and precipitation in Shiyang River Basin, and the water resources ecological carrying capacity decreased in the year of drought.

(2) Among the three accounts of the ecological footprint of water resources in Shiyang River Basin, the ecological footprint of water production accounted for the largest proportion, while the ecological footprint of ecological water accounted for the smallest. The water production occupied the water consumption and the ecological water, which was unfavorable to the ecological environment management. Among the three industries of the footprint of water production, the primary industry accounts for the largest proportion of water production, but the primary industry has the lowest utilization rate of water resources. Although the proportion of consumption in the secondary and tertiary industries is small, the utilization ratio of water resources is high.

Acknowledgment

This work was mutually supported by the National Natural Science Foundation of China (No. 51669001, 52269008), the Natural Science Foundation of Shandong Province (No. ZR2024MC190), the Industrial Support Plan Project of Gansu Provincial Department of Education (No. 2022CYZC-51), the Key Research and Planning Projects of Gansu Province (No. 18YF1NA073), the Science Foundation of Shandong Province (No. ZR2024MC190), and the Scientific Research Foundation for High-level Talented Scholars of Liaocheng Universtiy (No. 318042401).

References

[1] Alshalalfeh, Z., Napier, F.&Scandrett, E.2018 Water nakba in Palestine: sustainable development goal 6 versus Israeli hydro-hegemony. Local Environment 23 (1), 117–124.

[2] Haider, H., Singh, P., Ali, W., Tesfamariam, S.&Sadiq, R.2015 Sustainability evaluation of surface water quality management options in developing countries: multicriteria analysis using fuzzy UTASTAR method. Water Resources Management 29 (8), 2987–3013.

[3] Giupponi, C.&Gain, A.K.2017 Integrated spatial assessment of the water, energy, and food dimensions of the Sustainable Development Goals. Regional Environmental Change 17 (7),1881–1893.

[4] Proskuryakova, L.N., Saritas, O.& Sivaev S.2018 Global water trends and future scenarios for sustainable development: the case of Russia. Journal of Cleaner Production 170, 867–879.

[5] Zayed, I.S.A.&Elagib, N.A.2017 Implications of non-sustainable agricultural water policies for the water-food nexus in large-scale irrigation systems: a remote sensing approach. Advances in Water Resources 110,408–422.

[6] Jiang, L.L., Zhao, M.2018 Utilization efficiency of water for production in Jiangsu Province. Journal of Economics of Water Resources，37(3) : 72-77.

[7] Rao,D.P.2001 A remote sensing-based integrated approach for sustainable development of land water resources .Transactions on Systems, Man and Cybernetics: Part C: Applications and Reviews,31(2) : 207-215 .

[8] Huan, H.H, Gan, S.W&Xu, H.2018 Water ecological footprint and sustainable development of water resources in Wuxi City. Journal of Economics of Water Resources,36(4) : 58-62 .

[9] Rees, W.E.1992 Ecological footprints and appropriated carrying capacity: what urban economics leaves out. Environment and Urbanization 4 (2), 121–130.

[10] [Huang, L.N, Zhang, W.X&Jiang, C.L.2008 Ecological footprint method in water resources asse-ssment. Acta Ecological Sinica.28(3),1280-1286 .

[11] Hoekstra, A.Y. 2017Water footprint assessment: evolvement of a new research field. Water Resources Management 31 (10),3061–3081.