Global NEST Journal, Vol 24, No 3, pp 401-406

Eco-water diversion project is not a simply measure to improve the ecological environment

Zhao C.Y.[1,2]* Qin J.[1,2], He X.H.[1,2], and Zhou M.D.[1,2]

[1]Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, No. 320 West Dong gang Road, Lanzhou 730000, Gansu Province P. R. China.

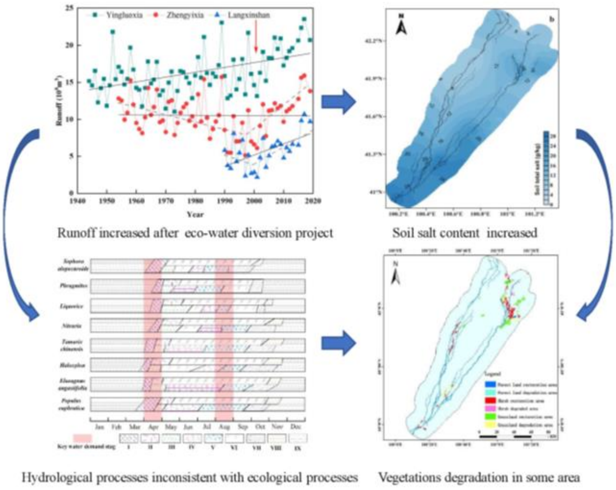
[2]Key Laboratory of Ecohydrology of Inland River Basin, Chinese Academy of Sciences, Lanzhou 730000, China

Received: 25/02/2022, Accepted: 16/05/2022, Available online: 15/06/2022

*to whom all correspondence should be addressed: e-mail: zhaochunyan627@163.com

https://doi.org/10.30955/gnj.004293

Graphical abstract



Abstract

The Heihe River is the second longest inland river in China, which is one of the most important inland river basins in the northwest area. The effect of drought on ecological environment can be exacerbated by climate change. Eco-water diversion project was implemented since 2000 to solve the increasingly serious problem of ecological environment deterioration in the lower reaches of Heihe River Basin. In order to reveal whether the eco-water diversion project solve the ecological environment deterioration thoroughly, the change of hydrology and vegetation were investigated and compared by using the remote sensing data, field surveys, monitoring and statistics data. Our results showed that the soil water content, groundwater level and vegetation coverage increased after eco-water diversion, especially in 0-20cm, the value increased 30.05%, which results vegetation restoration in some area. However, the seasonal distribution of eco-water diversion is extremely uneven, 70% of the runoff is mainly concentrated in January to March, and September to October. Water was seriously insufficient in the critical water demand period of plants such as germination and fruit period due to river cutout. Moreover, some areas were degraded due to salinization. In addition, the extreme change of soil water is not conducive to plant growth, but will increase the waste of water resources due to the increasing of ineffective surface evaporation. It is difficult to improve the quantity of discharged water in the upper reaches of Heihe River, so the distribution time and mode is very important for stable and healthy development of vegetation in the downstream. Therefore, eco-water diversion project is not a simply measure to improve the ecological environment. We suggested that hydrological processes should be consistent with ecological processes in the lower reaches of Heihe River, otherwise, the most important significance of eco-water diversion project will be lost. Exploring this will be helpful in formulate scientific and reasonable water dispatching scheme, achieve water resources allocation and water demand matching, improve ecological benefits.

Key words: Eco-water diversion project, soil water, groundwater level, salinization, ecological process

1. Introduction

The Heihe River is the second longest inland river in China, which is one of the most important inland river in arid area of Northwest (Feng *et al.,* 2008). Drought is a very devastating and costly disaster in the Heihe River, especially in the lower reaches of Heihe River. Future the effect of drought on ecological environment can be exacerbated by climate change (Lu *et al.,* 2020). Ejina oasis is located in the lower reaches of Heihe River, which is a typical water resource shortage area. It is an important barrier to maintain the ecological security of Alxa and Hexi Corridor, as well as the whole Northern China and eastern Asia (Yan *et al.,* 2018). Water condition controls the composition and structure of oasis vegetations. However, the discharge of water has decreased significantly since the 1960s in the area due to the large-scale development of oases in upper and middle reaches of Heihe River (Guo *et al.,* 2009). The rivers in the region of Ejin Oasis are seriously cut off, which results a series of ecological environment problems, such as the terminal lakes dried out, groundwater level drop and vegetation degradation (Cheng *et al.,* 2014).

In order to solve the increasingly serious problem of ecological environment deterioration in the lower reaches of Heihe River Basin, eco-water diversion policy was made in 2000(Lu *et al.,* 2015). The intensity of wind erosion and frequency of sandstorm was significantly reduced after eco-water diversion. Several significant and practical benefits related to this artificial water delivery project also have been substantiated, e.g. the rise of groundwater levels, the restoration of vegetation, and the increase of oasis area (Liu *et al.,* 2008; Tian *et al.,* 2015; Ding *et al.,* 2017).

However, the effects of eco-water diversion project on the water and salt in this area, especially the long-term growth status of vegetation under the change of water and salt is still unclear. Moreover, plant physiological activity is not the most active under the sufficient water condition, but under the appropriate water range (Mielke *et al.,*2000). Waterlogging during dormancy will affect negatively shoot and root phenology and growth during the following growing season (Roitto *et al.,* 2019). The duration and timing of waterlogging during the annual cycle of plants are decisive for the impacts in shoots and roots (Domisch *et al.,* 2021). Repo *et al.,* 2016 also found that waterlogging lasting longer than three weeks during the growing season had adverse effects on plant, and was lethal if lasting longer than five weeks. We do not know whether the ecological restoration after water transfer can achieve the expected effect in the extremely arid areas if ecological water regulation only emphasizes the total amount of water discharged. Moreover, most of studies did not consider the complex relationship of ecological and hydrological processes. Exploring this will be helpful in formulate scientific and reasonable water dispatching scheme, achieve water resources allocation and water demand matching, improve ecological benefits.

Therefore, the objectives of this study were (1) to clarify the variation of runoff in lower reaches of Heihe River Basin after eco-water diversion; (2) to explore the effect of eco-water diversion project on water and salt; (3) to identify the effect of eco-water diversion project on plants; and (4) to determine the relationship between ecological and hydrological processes. Our findings can provide an important guidance for policy makers to schedule which months are the best timing to eco-water diversion, especially for the dry areas with limited access to water.

2. Dates and methods

2.1. Study area

The study area is located in the lower reaches of Heihe River basin which is a typical inland river basin in northwestern China (Figure 1). The area is controlled by a typical continental arid climate that is severely cold in winter and extremely hot in summer. The mean annual precipitation is only 38 mm, for which 75% of rainfall occurs between June and August. The potential evapotranspiration is more than 3500 mm, which is greater than precipitation by a factor of 90 (Zhao *et al.,* 2017). The dominant vegetation types are composed of desert plants, including *P. Euphratica*, *Tamatix ramosissima*, *Achnatherum splendens*, *Sophora alopecuroides*, and *Karelinia caspica* (Yu *et al.,* 2013). The main type of soils is grey brown desert soil.

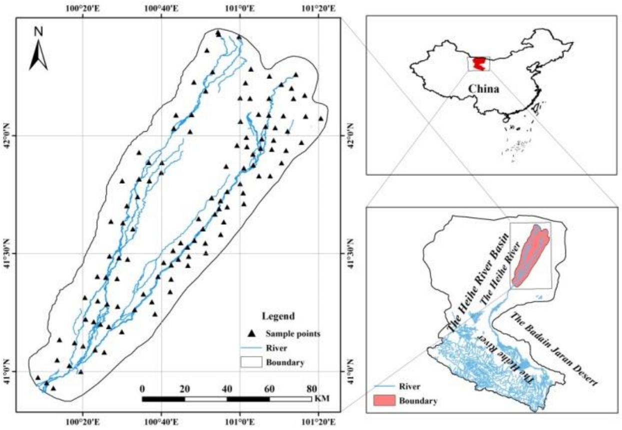


Figure 1 The study area.

2.2. Soil water and salinity measurement

Due to the implementation of the eco-water diversion project in 2000, the study period was divided into two stages: the first stage was before the eco-water diversion project (1998), and the second stage was the eco-water diversion project had been implemented 20 years (2018). A total of 107 soil sampling were collectd along the lower reaches of Heihe River basin (Figure1). Measurement of soil water content by drying method. Soil samples from the 0-20, 20-40, 40-60, 60-80, 80-100 and 100-120 cm were collected in triplicate,respectively. Soil samples were used for the preparation of the 1:5 soil-water suspensions to detect the content of HCO_3^-, Cl^-,$SO4^{2-}$, Ca^{2+}, Mg^{2+}, K^+ and Na^+ .

2.3. The change of vegetations

The land cover data was selected to evaluate the change of vegetations in the lower reaches of Heihe River basin. The two period land cover data in 1998 and 2018 were obtained by remote sensing, including satellite TM and ETM+ data. The data were converted with ARC/INFO and EARDS IMAGE software to images based on 1:100,000 topographic maps. Land cover data included six categories: shrub, grassland, forest, water, desert and residential area (Feng *et al.,* 2011).

3. Results

3.1. The variation of runoff in the Heihe River after eco-water diversion project

The Yingluoxia Hydrological Station and Zhengyixia Hydrological Station divide the Heihe River into upstream, midstream, and downstream respectively.Water discharged from Zhengyixia Hydrological Station is the most important water resource in the lower reaches of Heihe River basin. Our result showed that the annual discharge of Zhengyixia Hydrological Station increased significantly after the implementation of eco-water diversion project. That directly led to the annual runoff in the lower reaches of Heihe River increased significantly since 2000 (Figure 2). However, the seasonal distribution of runoff is extremely uneven, 70% of the runoff in the lower reaches of Heihe River is mainly concentrated in Spring and Autumn, which results water seriously insufficient in key water requirement period of plants (Figure 3).

Table 1. The vertical variation of soil water content after eco-water diversion project

Year	0-20cm	20-40cm	40-60cm	60-80cm	80-100cm	100-120cm
1998	1.34	2.12	4.25	4.37	6.15	7.29
2018	4.69	5.04	6.19	7.21	8.33	9.27

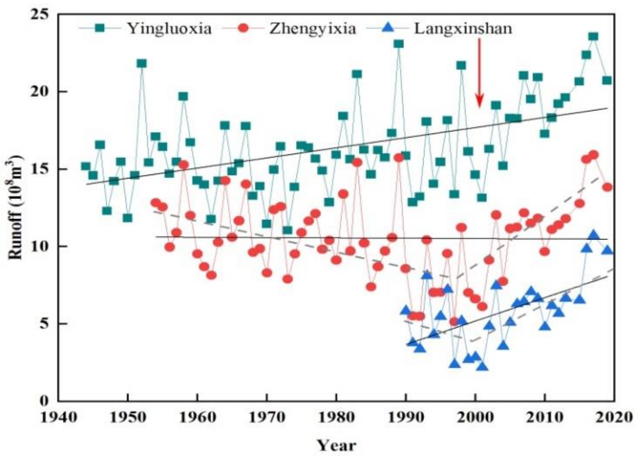


Figure 2. The annual variation of runoff after eco-water diversion project in study area.

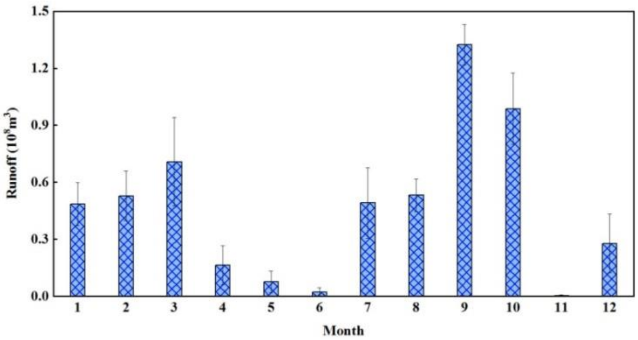


Figure 3. The monthly variation of runoff after eco-water diversion project in study area.

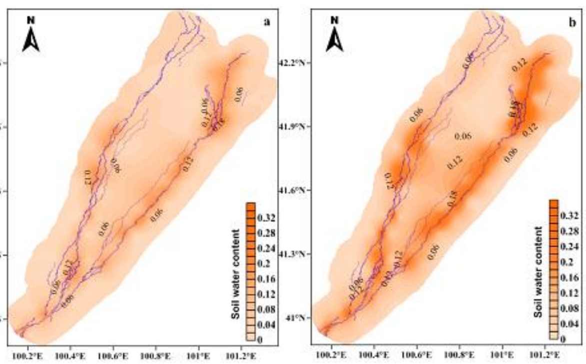


Figure 4. The spatial change of soil water content in study area (a-before eco-water diversion project; b- after eco-water diversion project).

3.2. *The effect of eco-water diversion on soil water and groundwater*

The soil water content increased significantly after eco-water diversion compare with before, especially in the middle and lower reaches of the East River (Figure 4). Moreover, surface soil water content increased most obviously, the value increased 2.5 times in 0-20cm compare with that before eco-water diversion (Table 1). The groundwater level in the study area also rise after eco-water diversion, and the groundwater level near the East and West rivers is shallower than that far away from the river channels (Figure 5). However, the groundwater level in August and September reached the lowest level, which seriously threatens vegetations growth. Thus, large amount of water is needed to restore the groundwater level in this period. (Figure 6).

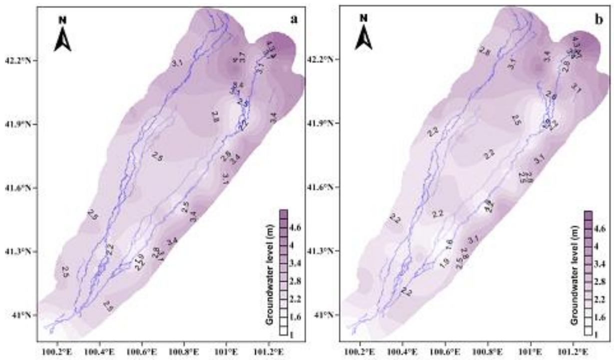


Figure 5. The spatial change of groundwater level in study area (a- before eco-water diversion project; b- after eco-water diversion project).

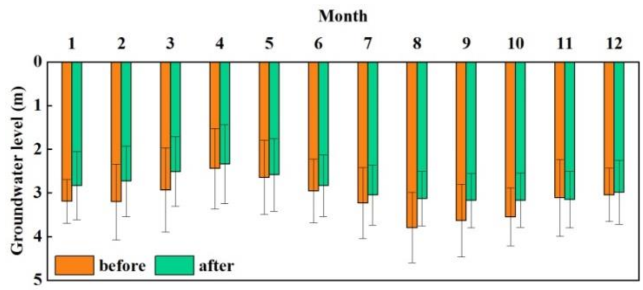


Figure 6. The monthly variation of groundwater level in study area(before- before eco-water diversion project; after- after eco-water diversion project).

3.3. *The effect of eco-water diversion project on soil salinity*

The soil salt content increased significantly after eco-water diversion compare with before, especially in the lower reaches of the West and East River (Figure 7). Moreover, Cl^{-} and Na^{2+} increased most obviously compared with that before the eco-water diversion, it increased by 18.63% and 27.77%, respectively (Table 2). The surface soil salt content increased significantly, especially in 0-20cm, the value increased 30.05% compare with that before eco-water diversion, the soil salinity showed obvious surface accumulation characteristics (Table 3). The relationship between soil salt content and groundwater level in different soil layers was analyzed.

The result shown that siol salt content decreases with the increase of groundwater level, and the fitting curves of soil salt content and groundwater level of each soil layer reached significant level (Figure 8). This indicated that the increase of soil salinity is mainly caused by the rise of groundwater level after eco-water diversion.

Table 2. The change of ion content after eco-water diversion project

Year	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+	Na^+
1998(g· kg^{-1})	0.18	3.97	5.36	0.72	0.76	0.23	3.10
2018(g· kg^{-1})	0.24	4.71	5.40	0.92	0.85	0.27	4.57

Table 3. The vertical variation of soil salt content after eco-water diversion project

Year	0-20cm	20-40 cm	40-60 cm	60-80 cm	80-100 cm	100-120 cm
1998(g· kg^{-1})	15.54	14.39	10.57	8.51	8.40	5.54
2018(g· kg^{-1})	20.21	16.33	13.25	10.21	8.93	6.27

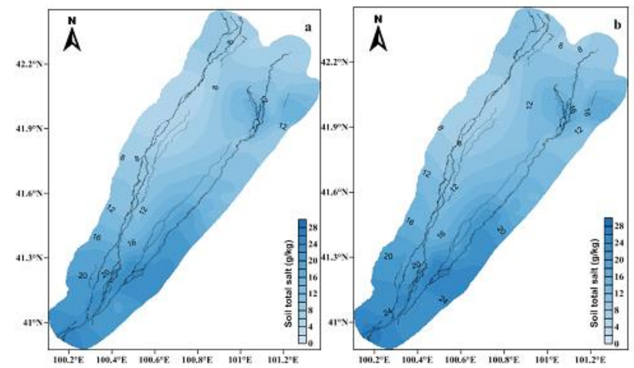


Figure 7. The spatial change of soil salt content after eco-water diversion project in study area(a- before eco-water diversion project; b- after eco-water diversion project).

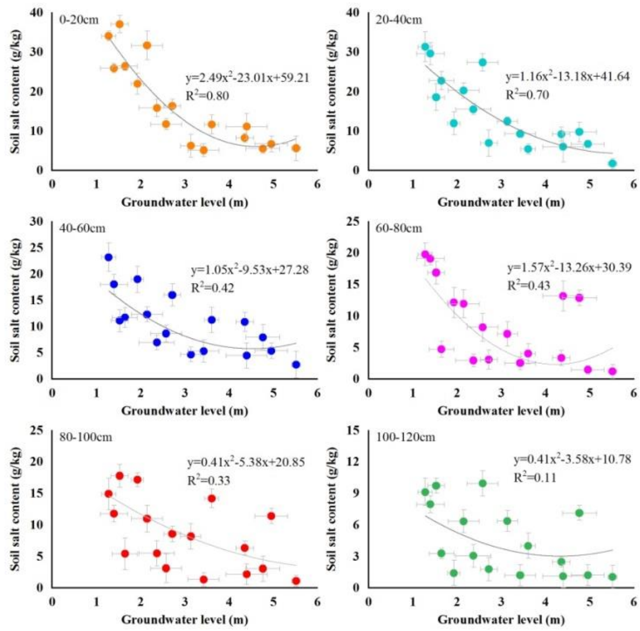


Figure 8. The relationship between soil salt content and groundwater level.

3.4. The effect of eco-water diversion project on plants

The vegetation coverage in the study area increased significantly after eco-water diversion, especially in the lower reaches of East river (Figure 9). The shrub, grassland and tree were increased 12.84%,14.33% and 8.12%, respectively (Figure 9). However, the increase of vegetation in West River was not obvious, and some areas were degraded due to salinization (Figure 10).

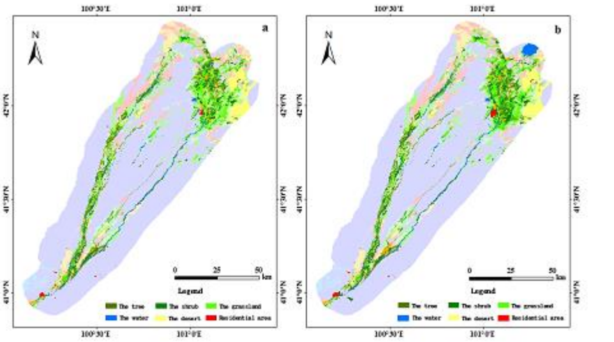


Figure 9. The spatial change of vegetation in study area(a- before eco-water diversion project; b- after eco-water diversion project).

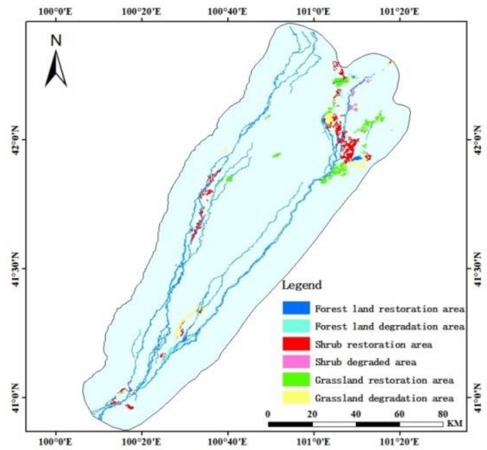


Figure 10. The degradation area of different vegetations in study area.

3.5. The relationship between ecological and hydrological processes

The germination of main plant species in the lower reaches of Heihe River mainly occurred in April (Figure 11). It is crucial to meet the water demand during this period due to germination is the most important stage for the life of vegetation. However, the ecological water supply in April was obviously insufficient, which seriously affected the germination. Moreover, August is the fruit ripening period of the main plant species in the lower reaches of Heihe River (Figure 11), the seeds lose the chance of germination under water shortage condition, which inevitably leads to the failure of sexual reproduction in the seed stage. Therefore, hydrological processes should be consistent with ecological processes in the lower reaches of Heihe River.

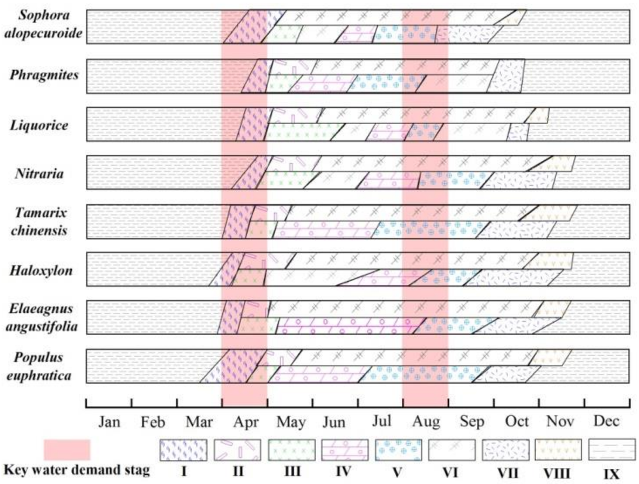


Figure 11. The phenophase and key water demand stage of plant in the lower reaches of Heihe River (I- germination stage, II - leaf spreading stage, III - flowering stage, IV - young fruit stage, V - fruit ripening stage, VI- leaf stage, VII - leaf yellow stage, - VIII - defoliation stage and IX - dormancy stage).

4. Discussion

Water is the most important factor to maintain the ecological process of oasis in inland river basin, and it is necessary to allocate the limited water reasonably to make the oasis healthy and sustainable development. The eco-water diversion project of Heihe River has played an important role in the ecological restoration. Our results showed that the annual runoff of the lower reaches of Heihe River has increased significantly since the implementation of the eco-water diversion project in 2000, which resulting the soil water content and groundwater level increased obviously. However, the seasonal distribution of runoff is extremely uneven, which results water seriously insufficient in key water requirement period of plants. Germination and fruiting period are the most important reproductive phenological periods of plant, and the seeds will lose the chance of germination if water deficit, thus resulting in the failure of sexual reproduction(Zhang *et al.,* 2005). So eco-water diversion project must ensure sufficient water supply in this period.

The eco-water diversion project of Heihe River adopts the principle of centralized discharge. The physiological process of plant will be disturbed when the soil moisture exceeds the upper limit of plant water threshold due to the oxygen supply of root system is blocked. An immediate effect of waterlogging is the decrease in soil oxygen concentration due to filling of soil pores with water (Greenway *et al.,* 2006; Kozlowski *et al.,* 2007). The timing and duration of waterlogging are decisive for the impacts in roots and shoots(Wang *et al.,* 2013). Domisch *et al.,*(2021) found that waterlogging decreased fine root survival probability, and soil CO_2 and CH_4 concentrations increased immediately after waterlogging. Morever, the extreme change of soil water content during the eco-water diversion period is not conducive to the growth of plant, but will increase the waste rate of water resources due to the ineffective surface evaporation. Such as wind drift and evaporation losses, and these losses can range from 0% to 50% (Faci *et al.,* 2001; Rajan *et al.,* 2015; Sheikhesmaeili *et al.,* 2016). Ma *et al.* (2017) found that although eco-water diversion project increased the groundwater level in the lower reaches of Heihe River, the utilization rate of water resources in plant did not improve, and the net ecosystem productivity was even reduced. An important reason was that the energy yield from carbohydrates is much lower under hypoxic or anoxic conditions as compared to aerobic conditions (Pucciariello *et al.,* 2012).

Moreover, the eco-water diversion aggravated salinization due to the rise of groundwater level, which resulting the subsoil salt moving upward and accumulating in the topsoil as a function of strong evaporation (Yu *et al.,* 2013). The study between salt accumulation rate and groundwater level also shown that the soil salt accumulation had a positive exponential relation with groundwater level. As a result of eco-water diversion, salinization has inevitably damaged vegetation health. Our result showed that some vegations in the lower reaches of Heihe River has degraded due to salinization.

In all, eco-water diversion project played an important role in protection and regeneration of vegetation. However, it only curbs the rate of deterioration, and does not fundamentally solve the ecology environment problems in the lower reaches of Heihe River. So the distribution mode and time of eco-water diversion project is very important for the long-term stable and healthy development of plant. Moreover, as water availability pose serious constraints to irrigation (Elliott *et al.,*2014; Blanc *et al.,* 2017), key water demand stage of vegetation is a concern when distributing the time of eco-water diversion. Thus, it is necessary to follow the ecological characteristics and water demand process of vegetation, and making the hydrological processes consistent with ecological processes. Otherwise, the most important significance of water diversion will be lost.

Author contributions

Chunyan Zhao designed the study and wrote the manuscript. Material preparation and data collection were performed by Jie Qin. All authors analyzed data, edited the writing and approved the final manuscript.

Funding

This study was provided by the National Natural Science Foundation of China "Nighttime transpiration and its eco-hydrological effects in typical desert vegetation (42001038).

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare no competing interests.

References

Blanc É. (2017). Aggregation of gridded emulated rainfed crop yield projections at the national or regional level. *Journal of Global Economics,* **2**, 112–127.

Cheng G., Li X., and Zhao W.(2014). Integrated study of the water–ecosystem–economy in the Heihe River Basin. *National Science Review,* **1***,* 413–428.

Domisch T., Qian J., and Izabela S. (2021). Here comes the flood! Stress effects of continuous and interval waterlogging periods during the growing season on Scots pine saplings. *Tree Physiology.*

Ding J., Zhao W., and Daryanto S. (2017). The spatial distribution and temporal variation of desert riparian forests and their influencing factors in the downstream Heihe River basin, China. *Hydrology and Earth System Sciences,* ***21****,* 2405–2419.

Elliott J., Deryng, D., Müller, C., Frieler K., Konzmann, M., Gerten, D., and Glotter, M. (2014). Constraints and potentials of future irrigation water availability on agricultural production under climate change. *In: Proceedings of the National Academy of Sciences,* ***111***, 3239–3244.

Feng Z., Jiang L., and Zhang, J. (2011). Progress on Studies of Land Use/Land Cover Classification Systems. *Resources Science,* **33***,* 1195–1203.

Faci J.M., Salvador R., Playán E., and Sourell H. (2001). Comparison of fixed and rotating spray plate sprinklers. *Journal of Irrigation and Drainage Engineering,* **127***,* 224–233.

Feng Q., Liu W., and Xi, H.Y. (2008). Hydrological Characteristics of the Heihe River Basin in the Arid Inland Area of Northwest China. *Sciences in Cold and Arid Regions,* **1***,* 80–91.

Guo Q.L., Feng Q., and Ren S.F. (2009) The impact of the water import on the vegetation in the heihe river. *China Rural Water and Hydropower,* **3***,* 36–43.

Greenway H., Armstrong W., and Colmer T.D. (2006). Conditions leading to high CO2 (>5 kPa) in waterlogged–flooded soils and possible effects on root growth and metabolism. *Annals of Botany,* **98***,* 9–32.

IPCC. (2013). Climate Change 2013: the Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Kozlowski T.T., and Pallardy S.G. (2007). Physiology of Woody Plants, Academic Press.

Liu L.L. (2008). Study on main ecological factors response of water transfer along a river area in the Ejina Oasis. *Inner Mongolia Agricultural University*.

Lu J. Y., Carbone G. J., and Huang X. (2020). Mapping the sensitivity of agriculture to drought and estimating the effect of irrigation in the United States, 1950–2016. *Agricultural and Forest Meteorology,* 292–293.

Lu Z., Wei Y., and Xiao H.(2015). Trade-offs between midstream agricultural production and downstream ecological sustainability in the Heihe River basin in the past half century. *Agricultural Water Management,* **152***,* 233–242.

Mielke M.S., Oliva M.A., and de Barros N.F. (2000). Leaf gas exchange in a clonal eucalypt plantation as related to soil moisture, leaf water potential and microclimate variables. *Trees,* **14***,* 263–270.

Ma X.H., Feng Q., and Su Y.H. (2017). Characteristics of CO2 exchange in net ecosystem of Populus euphratica forest. *Journal of Arid Land Resources and Environment,* **31***,* 108–115.

Rajan N., Maas S., Kellison R., Dollar M., Cui S., Sharma S., and Attia A. (2015) .Emitter uniformity and application efficiency for centre-pivot irrigation systems. *Irrigation and Drainage,* **64***,* 353–361.

Roitto M., Sutinen S., Wang A., Domisch T., Lehto T., and Repo T. (2019). Waterlogging and soil freezing during dormancy affected root and shoot phenology and growth of Scots pine saplings. *Tree Physiology,* **39***,* 805–818.

Repo T., Launiainen S., Lehto T., Sutinen S., Ruhanen H., Heiskanen J., Laurén A., Silvennoinen R., Vapaavuori E., and Finér L. (2016).The responses of Scots pine seedlings to waterlogging during the growing season. *Canadian Journal of Forest Research,* **46***,*1439–1450.

Sheikhesmaeili O., Montero J., Laserna S.(2016). Analysis of water application with semi-portable big size sprinkler irrigation systems in semi-arid areas. *Agricultural Water Management,* **163***,* 275–284.

Tian Y., Zheng Y., and Zheng C. (2015). Exploring scale-dependent ecohydrological responses in a large endorheic river basin through integrated surface water-groundwater modeling. *Water Resources Research,* **51***,* 4065–4085

Wang A.F., Roitto M., Lehto T., Zwiazek J., Calvo-Polanco M., and Repo R. (2013).Waterlogging under simulated late-winter conditions had little impact on the physiology and growth of Norway spruce seedlings, *Annals of Forest Science* **70***,* 781–790.

Yu T.F., Feng Q., and Si J.H. (2013). Patterns, magnitude, and controlling factors of hydraulic redistribution of soil water by *Tamarix ramosissima* roots. *Journal of Arid Land,* **5***,* 396–407.

Yan H., Zhan J., and Yang H.(2018). Wind erosion reduction by water diversion in the lower Heihe River Basin, Northwest China. *Land Degradation & Development,* **29***,* 1906–1914.

Zhao C.Y., Si J.H., and Feng Q.(2017). Comparative study of daytime and nighttime sap flow of Populus euphratica. *Plant Growth Regulation,* **82***,* 353–362.

Zhang Y.B., Li J.W., Zhang H., *et al.,*(2005). Analysis on the factors cause the failure of *populus euphratica* sextual regeneration in nature. *Science, technology and Engineering,* **8***,* 467–472.