



Relationship between Water and Vegetation in the Ejina Delta

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Abstract Water is the foundation of an arid ecological system, as the quantity and quality of surface water and groundwater determine its structure and function. The study on the relationship between water and ecosystem is the basis of ecosystem protection. Taking the Ejina delta, an extremely arid area located downstream of the Heihe River in northwestern China, as an example, this article gives an overview of the study in three aspects: (1) the groundwater table and salinity dynamics and their driving factors, (2) the groundwater depth and salt threshold of natural vegetation ecosystem, and (3) the impact evaluation of ecological flow control on Ejina natural vegetation. The authors point out the importance of the research into the relation between water and ecosystem and its key difficulties and weakness, and put forward strategies for promoting the study processes.

Keywords Chinese inland river, extremely arid region, environmental flow control, natural vegetation, groundwater environment



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Water is described as “the source of life, the key factor of production and the foundation of ecosystems” in a document of China’s central authorities in 2011. The arid area usually shows different landscapes such as oasis, desert and saline land depending on water supply conditions. The most severe ecological degradation being faced by inland river basins, such as the Tarim River, the Heihe River, the Shiyanghe River in the arid northwestern China, is closely related to water conditions that are mainly subject to human activities and climate change. The Ejina oasis in the Lower Heihe River is an isolated oasis in an extreme arid desert and an important natural ecology barrier for the Hexi Corridor, northwest China and even the entire North China (CASAD, 1996). The annual precipitation in this area is lower than 50mm. Its water resources mainly depend on the surface water from the Heihe River. Since the 1990s, its groundwater table has kept declining because of the sharp decrease of the inflow amount in the Lower Heihe River. This caused a series of serious ecological problems such as the shrink of the Ejina oasis and the expansion of the desert. In order to restore and rebuild the degrading ecosystem of the Lower Heihe River, the State Council authorized, in 1997, “a water allocation scheme for the different reaches of the Heihe River”, which was implemented for the first time in 2000 to address environmental emergencies. The efforts alleviated the contradictions between the economic growth in the middle reach and the ecology protection in the lower reach.

To achieve the maximum ecology benefit by reasonable water delivery projects is of great importance

especially when the total water resources are extremely limited. However, the effort needs good knowledge of water, ecosystem condition and their relationship. In 2001, the National Natural Science Foundation of China (NSFC) started a key research program Ecology and Environment in Western China, advancing multi-scale experiments and studies in eco-hydrology in northwestern China including the Lower Heihe River (Leng & Song, 2010). The Heihe Watershed Program, one of the five test areas in the CAS Cluster Projects in Western China, mainly concerned the relationship between the socioeconomic growth and natural ecology under water resources management in a watershed level (Cheng, 2009). Supported by the Ministry of Science and Technology, the national key basic research and development project (973 Project) “Oasification and Desertification and their Response and Regulation to the Human Activities and Climate Changes in the Arid Region” was started in 2009. It mainly focused on the interaction mechanism and simulation between hydrological processes and oasification and desertification in arid inland watershed. The NSFC key research program “Ecology-Hydrology Process Integration Research in Heihe River” kicked off in 2011, with the objective of advancing the fundamental researches about the ecology-water-economy relationship in Chinese arid inland watershed. All these projects are aimed to reveal the interactions between the ecosystem and its hydrological conditions, and to improve the comprehensive capacity to analyze and predict the hydrology and ecosystem situations in Chinese arid inland river basins. They are expected to improve fundamental theory and technical support for the local water security,



The course of the Lower Heihe River.



ecological security and sustainable development in arid inland watersheds. The Ejina oasis plays an important role in safeguarding the ecological security of the northern China. The vegetation in Ejina mainly depends on local water conditions, especially river flow and groundwater depth since the precipitation here is scarce. As the kernel

and foundation of the natural ecology protection in the lower inland river, the relationship between water and vegetation and the response mechanism of ecosystem to hydrological conditions, have received extensive attention of researchers. Major research progresses in this regard can be summarized as the following three aspects:

1. Groundwater level, salinity dynamics and its driving forces

The shallow groundwater environment, especially its water-salt dynamics, is the basis for the survival of various plant formations in the arid region, and also the key aspect to recognize the eco-hydrological processes of the arid inland river basin. Recently, shallow groundwater table depth ranges between 2-4 meters; however, the water table is still decreasing in the irrigated oasis areas, with some sites reaching more than 6–8m in depth. In addition, the shallow groundwater has a significant zonation in salinity along the regional flow direction from the recharge area to the discharge area (Wang, *et al.*, 2011a). Analysis of the observed and collected data indicated that the decrease of surface water in lower Heihe River since the 1990s has led directly to the continuous decline of shallow groundwater level, and in some areas the decline was more than 1.5m. After the beginning of the environmental flow controls, which is aimed at delivering a set amount of surface water to East Juyan Lake and the Ejina Oasis, the shallow groundwater table in the riparian areas along the Donghe

and Xihe Rivers has been rising for 0.5-1m. However, the groundwater level of the particular irrigated oasis continues to decline, some of them up to 1m. During the period of 2001-2009, the overall mineralization and salinity of shallow groundwater were both increasing significantly throughout the region, especially in the depocenter of the Ejina Basin, where the groundwater salinization was even more evident, and in some sites the groundwater salinity exceeded 3% (Wang, *et al.*, 2011a).

Groundwater level and salinity dynamics are mainly determined by the structure of groundwater system, the distribution of groundwater flow, as well as groundwater recharge-discharge conditions (Wu, *et al.*, 2002). The isotopic analysis of ^3H and ^{14}C , as well as IAEA model calculations showed that the shallow groundwater in the Ejina Basin is mainly replenished by “modern water”, being not more than 50 years; however, the deep groundwater in the confined aquifer is older (Zhang, *et al.*, 2005). In addition, people have found that the groundwater in the



Underground water sampling.

Ejina aquifer was recharged by multi-sources by using hydrochemical and environmental isotopes tracer technique, and the surface water from Heihe River was the main recharge source in this region. Besides, the replenishment of the shallow groundwater in the lower Heihe River is also influenced by groundwater recharge from Badain Jaran desert, adjacent basins, as well as lateral groundwater inflow from the adjacent mountains (Wu, *et al.*, 2002; Qian, *et al.*, 2005). Although groundwater in the Ejina aquifer has a diversity of supply sources, the infiltration of surface water from the Heihe River still is the main shallow groundwater recharge source, and is the key factor which maintains the ecological environment in this region.

Thus, in recent years, researchers have gradually focused their attention on the mechanism behind surface-groundwater interaction, which controls the groundwater level and salinity dynamics. Since 2000, Chinese scientists have used geophysical exploration, penetration tests and other methods to identify the interaction between the shallow groundwater and the surface water in the lower Heihe River. Their results indicate that there exists a fault zone in the Dingxin-Shaomaying valley, and lots of surface water from the Heihe River recharges the shallow aquifer though this fault zone (Wu, *et al.*, 2000, 2004). Besides, some researchers analyzed the

spatial distributions of the hydrochemical compositions that exist in shallow groundwater of the downstream along the both sides of the Heihe River (<1km; 1-10 km; >10 km). According to this study, the groundwater recharge zones by river water were preliminarily identified (Wen, *et al.*, 2005). There are also many scientists who use environmental isotope technique, together with hydrochemical analysis, to study the impact of the environmental flow controls on the shallow groundwater environment as well as its evolution (Chen, *et al.*, 2006; Su, *et al.*, 2009; Zhu, *et al.*, 2010), then inferred the relationship of water transformation between the groundwater and the river water. In relation to the impact of the volume and duration of runoff on water table changes, there are some scientists who with the help of linear regression methods to determine the relationship between shallow groundwater table and total runoff (Li, *et al.*, 2006; Hu & Song, 2007). However, further comprehensive investigations are needed to fully quantify the groundwater recharge areas, as well as its temporal-spatial variations under the human controlled conditions, and also to identify the influence of riverbed cross-section form and hydraulic conductivity of riverbed and aquifer on transformation of water flux and salinity between surface water and groundwater.

2. The threshold of groundwater depth and salinity of natural vegetation

One of the key ecological factors in arid areas, the groundwater table controls the changes and composition of plant communities, and has a significant impact on composition, development and stability of an inland river basin ecosystem in arid areas (Ma & Gao, 1997). Many studies had confirmed that soil moisture and salinity influenced the growth and restoration of natural vegetation and was closely related to groundwater depth (Liu, 1996; Ma, 1997; Liu, 1984). In a sense, groundwater depth determines the distribution, growth, population succession of natural vegetation in arid areas, and even the survival of the whole oasis. According to the relationships between groundwater table and vegetation dynamic changes, our researchers defined the groundwater depth within 1m as the swamping groundwater depth, 1-2m as salinization groundwater depth, 2-4m as proper ecological groundwater depth, 4-6m, which produces stress on plant growth and

development, as ecological warning groundwater depth, and more than 6m as desertification groundwater depth (Fan *et al.*, 2004). Satellite remote sensing decipherment and groundwater dynamics analysis in the lower reaches of the Heihe River showed that the suitable groundwater depth of typical vegetation growth in Ejina Delta is 2-5m (Wang, *et al.*, 2011b; Jin, 2010). Quantitative classification and analysis of relationships between plant communities and their groundwater environment in the Ejina oasis indicate that increasing groundwater depth, due to groundwater environmental degradation such as groundwater salinity increase, is the main reason causing changes in community distribution and type in the region (Zhu *et al.*, 2011a). Zhu *et al.* (2011b) performed two-way indicator species analysis (TWINSPAN) to determine vegetation types in 31 plant plots (155 squares), combining the results of the TWINSPAN classification with practical ecological

significance, 6 plant community types were obtained in the Ejina oasis. Through analysis of relationships between spatial distribution of community types, species diversity and groundwater depth, salinity, they considered that the proper range of groundwater depth to maintain the present natural vegetation is 2-5m, the proper range of mineralization is 1.8-4.2 g/L. It is worth noting that there is a complex relationship between the groundwater table and vegetation dynamics in arid zone, the determination of a reasonable ecological groundwater depth relates to a dynamic equilibrium among groundwater, soil moisture and vegetation. Therefore, the study on a reasonable ecological water level or ecological threshold is still in continuous exploration stage.



Researchers conducting an *in situ* measurement of hydraulic conductivity of the Lower Heihe River bed.

In addition to groundwater table, the groundwater salinity change is also the key factors affecting the pattern of ecosystem. Under natural conditions, the dynamic change of groundwater depth and salinity is a relatively slow

process, but large areas of groundwater exploitation and farmland recharge will seriously undermine this variation, increasing soil salinization, and bringing the direct impact to spatial pattern of ecosystem (Davis, *et al.*, 2003). There is great evaporation potential in arid areas in Northwest China. With the increase of water usage in the upper and middle reaches of inland rivers, groundwater recharge from surface water decreases in the lower reaches. Because of unbalanced groundwater recharge and discharge, plus artificial groundwater exploitation and irrigation recharge, groundwater level change is usually accompanied by changes in salinity. The increase in groundwater salinity will inevitably result in the accumulation of salt in soil, thereby causing plant physiological drought, damaging plant tissue, and affecting the normal nutrient absorption in plants (Zhou, 2004). The growth and extinction of natural vegetation in arid areas largely depended on the changes of groundwater table and salinity (Froend, *et al.*, 1987). When the groundwater salinity is lower, the growth and development of a typical arid plant is usually better (Tang *et al.*, 2001). Through correlation analysis between natural vegetation and groundwater quality, it showed that groundwater salinity was lowest, when groundwater table at about 5m, vegetation coverage at this time was much larger than the critical coverage of desertification (Chen *et al.*, 2006). However, from the ecological point of view, the mechanism of salinity effects on the vegetation growth is not yet clear, especially there are relatively few studies on the salinity threshold of vegetation in arid areas. We should strengthen study on the relationships between plant communities and spatial heterogeneity of salinity in the future.

3. Effects of environmental flow control on natural vegetation

The Ejina Delta locates in the lower reaches of the Heihe River. Its natural vegetation largely depends on the surplus water in the upper and middle reaches. But with the increase of water usage in the upper and middle reaches, river runoff into the Ejina Delta decreased sharply during the 1990s, leading to natural ecosystem degeneration and the disappearance of a large area of natural vegetation. In order to protect the Ejina oasis, environmental flow control to the lower reaches of the Heihe River was started in 2000. Much more attention has been paid and research has been done by scientists to the recovery of vegetation

after environmental flow control in the Ejina Delta. Some studies considered that environmental flow control played an effective role in vegetation restoration in this region (Guo, *et al.*, 2009), especially at both banks of the river and around the East Juyan lake- a river ending lake; however, other studies showed that there was no obvious vegetation restoration, and even continued degradation (Du Wala *et al.*, 2008), such as *Populus euphratica* in the lower reaches of the Donghe River. The main reason behind the opposite conclusions in previous studies was the difference in research scale and method (Zhang *et*

al., 2011a). Zhang *et al.*, (2011b) analyzed MODIS/NDVI time series covering the Ejina Delta during 2000-2009, indicating: (1) the vegetation in 80.4% of the oasis regions and 91.5% of the desert regions showed an increasing or recovering trend; (2) the statistically significant increasing trend of desert vegetation mainly appeared in the middle and lower Xihe River basin and the lower Donghe River basin; and (3) the vegetation degradation generally took place along artificial canals and intercepted rivers and mainly appeared in woodland. The main reason for vegetation recovery in a large scope is that groundwater environment totally turned well and some ecological protective measures were implemented (Wang, *et al.*, 2011b). At the same time, reduced surface water in some areas due to the current environmental flow control schemes has also led to a partial degradation of the vegetation. Environmental flow control changes surface water and groundwater environment, and then affects the survival of natural vegetation, essentially through artificial regulation and flow distribution of water quantity into the downstream river. Therefore, further studies should focus on the changes of surface water and groundwater flow in recent years in the lower reaches of the Heihe River, and their effects on plant growth, population succession and vegetation coverage, by establishing a correlation model between total vegetation coverage and groundwater depth (Zhong, *et al.*, 2002). On the other hand, natural vegetation changes could be analysed by using remote sensing data in the lower reaches of the Heihe River, thereby establishing the correlation model between plant growth and groundwater depth based on the theory of ecological suitability, and building the relationships



A sampling plot investigation is conducted on the local vegetation.

between the typical vegetation and water, such as the proper groundwater interval of typical vegetation in arid areas and its tolerance to environmental factors (Zhang, *et al.*, 2002, 2004). In the macroscopic level, by means of satellite data, taking normalized vegetation index (NDVI) as the index, we could analyze the correlativity between oasis evolution and annual runoff, groundwater depth, obtaining the proper groundwater depth in oasis zone by using vegetation coverage (Xue, *et al.*, 2006).

The more common views about the relationships research between water and ecosystem in the Ejina Delta at present studies are: ecosystem restoration and reconstruction must be based on the restoration of shallow groundwater environment, that is to maintain appropriate ecological groundwater level as well as to prevent groundwater salinization influences on vegetation growth; meanwhile, an understanding of the interaction between surface water and groundwater both volume and salinity during the environmental flow control must be strengthened.

4. Study difficults and problems

At present, difficulties for the study of the relationship between water and ecosystems lie in the fact that the mechanism of eco-hydrological processes is still very weak and the dynamic relationship of distribution patterns of natural vegetation with groundwater environment (water table, salinity) in arid areas is not clear (Zhao & Cheng, 2001). Especially, under the conditions of flow control, further studies are needed as to how the exchange of surface water and groundwater makes an impact on the balance of volume and salinity of groundwater and its

ecological effects in the arid areas. At present, the dynamic relationship of ecosystem and movement/distribution of water and salt has not been accurately addressed based on available data and knowledge.

Although a number of important academic achievements have been made in the eco-hydrological processes and their interactions in the Ejina Delta, much more work should be done due to the following facts. Firstly, the Ejina Delta has a vast territory with an enormous difference in hydrological conditions and a significant temporal and spatial variation.



Researchers conducting an *in situ* measurement of the local water quality.

Secondly, the previous research is relatively weak in the region, where historical data regarding hydrological and ecological monitoring are insufficient and the existing data do not match either in space or time. Specially, research is weak on process mechanisms, such as the interaction both in quantity and quality between surface water and groundwater, the interactions among surface water, groundwater and vegetation under the environmental flow controls, because of the sporadic and discontinuous field survey and monitoring in ecology and hydrology, and lack of detail field ecohydrological process experiment with multiple approaches.

5. Measures and suggestions

To promote study process based on the background in the Ejina Delta, it is advisable to enhance the field monitoring and experiments of eco-hydrological process as the first step. There is an urgent need for the establishment of a hydrological and ecological monitoring network system within the scope of the entire study area to address such issues as in-time monitoring surface water both volume and quality, groundwater levels, groundwater salinity as well as chemical composition, soil organic matter and salt contents, vegetation community structure and growth status, in order to obtain long time series data of space and time continuous monitoring. Secondly, efforts should be made to enhance process mechanism study and quantitative analysis on the basis of observation and measured data, including quantitative evaluation on the quantity and quality of surface water and groundwater in time, to reveal the dynamic features of surface water and groundwater systems, to reveal the spatial distribution

patterns of plant individual and community and their driving force, to enhance the mechanism of groundwater-soil-vegetation ecological coupling relationships and to simulate the change and response mechanism of water and ecosystem under different environmental control scenarios. Thirdly, more attention should be paid to the combination and application of multi-source information and techniques such as the water and vegetation relationship at a regional scale, regional water cycle characteristics, and impacts on ecological vegetation under different water allocations. Finally, a good job should be made to strengthen integrated studies and simulation of water - ecosystem, to establish and develop the regional-scale simulation platform, to achieve multi-process coupled simulation and quantitative analysis of the ecological processes and hydrological processes, to better reveal the interaction between water and ecosystem under climate change and human activities.

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