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The influence of water regulation on vegetation in the lower Heihe River

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Abstract: Water regulation has been carried out by the Heihe River Bureau since 2000, which aims to address the existing eco-environmental problems in the lower Heihe River. In the past nine years, great changes in spatial-temporal distribution of water resources took place in the lower Heihe River. In order to objectively evaluate the influence of water regulation on the eco-environment, the changes of groundwater table, typical vegetation, landscape types as well as East Juyan Lake have been analyzed in the lower Heihe River, by means of field surveys and remote sensing. These results indicate that there are obvious effects of water regulation on the eco-environment, which has been improved toward sustainability in the lower Heihe River.

Keywords: water regulation; ecosystem; groundwater; the lower Heihe River

1 Introduction

The Heihe River is the second longest inland river in China, which is called "the Mother River" by the Hexi people. With a total drainage area of 142,900 km^2 and a total length of 821 km, the Heihe River originates from the north of the Qilian Mountain and flows through Qinghai Province, Gansu Province and Inner Mongolian Autonomous Region (including 11 counties or banners). Its upper reach is from the above Yingluo Gorge, the middle reach is between Yingluo Gorge and Zhengyi Gorge, and the lower reach is from Zhengyi Gorge downwards. The length of the lower reach is 333 km, and the drainage area is 80,400 km^2. The lower reach is about 176 km from Zhengyi Gorge to Langxin Mountain, and is divided into the East River and the West River downwards from the diversion in Langxin Mountain. Finally it flows into the East Juyan Lake (Suoguonuoer) and the West Juyan Lake (Gashunnuoer) respectively. The Ejina Delta oasis formed around the East and West rivers in the interior of the Gobi desert has been an important ecological defense against the sandstorms in

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Northwest China.

According to historical records, there was abundant vegetation in the lower Heihe River. Furthermore, the famous ancient Juyan-Black City Oasis Culture was fostered in this region in the 1000 years from the Han Dynasty to the Yuan Dynasty. During the period 1928–1932, the water area of the East Juyan Lake and the West Juyan Lake spanned 35 km^2 and 190 km^2 respectively, when the Chinese-Swedish Northwest Survey Team investigated the region. In 1958, a wet year, the water area of the two lakes spanned 35.5 km^2 and 267 km^2 respectively. At that time, many species of plants, such as *Populus euphratica*, *Elaeagnus angstifolia, Tamarix* sp., *Haloxylon ammodendron, Nitraria sibirica*, *Glycyrrhiza uralensis*, *Phragmites communis* etc., flourished on both banks of the Ejina Delta and around the East Juyan, West Juyan and Gurinai lakes. In the past 50 years, owing to water extraction in the upper and middle reaches, water supply for industrial and agricultural purposes, although the discharge in Yingluo Gorge has not significantly changed, the flow in Zhengyi Gorge has decreased rapidly since the 1980s (Figure 1), and less water entered into the lower Heihe River. Owing to the lack of water in the lower Heihe River, the oasis became seriously desertified, lakes dried up, and the water quality deteriorated. The carrying capacity of pasture declined sharply and several rare animals disappeared (Zhong *et al.*, 2002; Cao *et al.*, 2004; Yang *et al*., 2005; Zhang *et al*., 2002; Wang *et al*., 1998; Luo *et al*., 2003; Tang *et al.*, 2009).

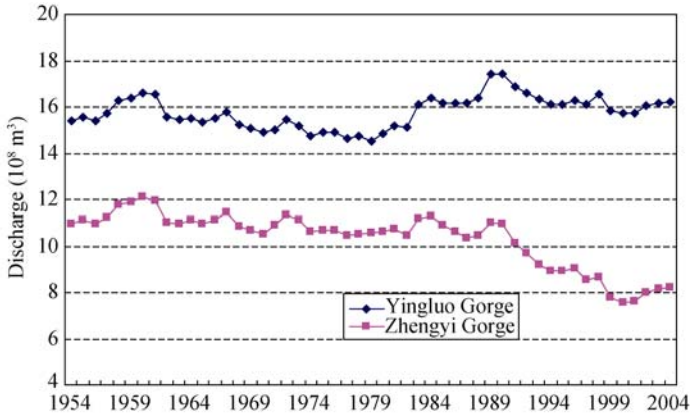

Figure 1 The 10 years moving average flow of Zhengyi Gorge and Yingluo Gorge from 1954 to 2004

In order to increase water supply and avoid deterioration of the ecosystem in the lower Heihe River, the unified management system and the new regulation were implemented in the Heihe River. In 1999, the Heihe River Bureau of the Yellow River Conservancy Commission (YRCC) under the Ministry of Water Resources (MWR)was authorized and founded. Since 1999, the water resources in this basin have been managed and regulated uniformly. Since the end of 1999, water resources uniform regulation has been initiated, and the water user in the middle Heihe River reduced and more water delivered to the lower Heihe River. After several years of water regulation, the spatial-temporal distribution of water resources has changed dramatically in the lower Heihe River. The outflow from the middle reach has increased year by year. In terms of the relation of water diversion curve, it is calculated that when the average inflow at Yingluo Gorge is 1.58 billion m^3, the average outflow at Zhengyi Gorge increased from the average discharge of 0.73 billion m^3 before

water regulation during the period 1997–1999 to 0.80 billion m^3 in 2000, 0.83 billion m^3 in 2001, 0.90 billion m^3 in 2002, and 0.95 billion m^3 in 2003 after water regulation. Especially the runoff reached the capital of Ejina town in 2001, to East Juyan Lake with the maximum water area of 23.5 km^2 in 2002 (where there has been no water for 10 years), and to West Juyan Lake in 2003 (where there has been no water for 40 years) (Si *et al*., 2005; Yang *et al*., 2003).

By means of the unified water regulation for several years, the spatial-temporal distribution of the water resources has significantly changed in the lower Heihe River, which has produced positive effects on the ecosystem in the lower reach. In this paper, by field surveys and applying remote sensing data, the influence on the vegetation has been analyzed in the lower Heihe River. The results provide scientific basis for the further water regulation and the improved restoration of the ecosystem in the lower Heihe River.

2 Influence of water regulation on the groundwater level

2.1 Influence of water regulation on the groundwater level

The observation wells in the lower Heihe River were established in 1988 (Feng *et al*., 1998). These wells were mainly distributed in the oasis along the East and West rivers and rarely on the edge of the oasis or the desert. These wells are more concentrated near the Langxin Mountain in the upper reaches of both the East and West rivers, Jirigelangtu in the lower reaches of the East River and near Saihantaolai in the lower reaches of the West River (Figure 2). Figure 3 shows the variation of groundwater level in several typical wells in the upper reaches of the East and West rivers, near Jirigelangtu and Saihantaolai in the lower reaches of the East River, as well as in the Ejina Oasis (1995–2004). It can be seen that the slow descending trend of groundwater level in the lower Heihe River has been held back after water regulation for 5 years (Figure 3). Particularly, the groundwater level has been rising to some degrees in the lower Heihe River since 2002. In 2004, the groundwater level has increased to near the historical maximum since 1995. Comparing the figure in 2004 with that in 2002, the groundwater level rose by 0.22 m both in the East and West rivers, by 0.79 m in Jirigelangtu, by 0.5 m in Saihantaolai, and by 0.42 m in the whole Ejina Oasis.

2.2 Relationship between groundwater level and vegetation

Many surveys indicate that there is a significant correlation between the evolvement of natural vegetation and groundwater level (Table 1). This is because rainfall is scarce, and the groundwater is required to maintain the normal growth of the large variety of natural vegetation. Therefore, it is necessary to meet this water demand for maintaining the normal growth of natural vegetation. Natural vegetation in the lower Heihe River could be protected and rehabilitated effectively, if water demand of natural vegetation is met by scientific water regulation (Feng *et al*., 1998; Zhang *et al*., 2004; Wang *et al*., 2003).

3 Influence of water regulation on typical plants

3.1 Response of *Populus euphratica* to water regulation

According to the survey, after water regulation for 5 years in the Heihe River, the lateral

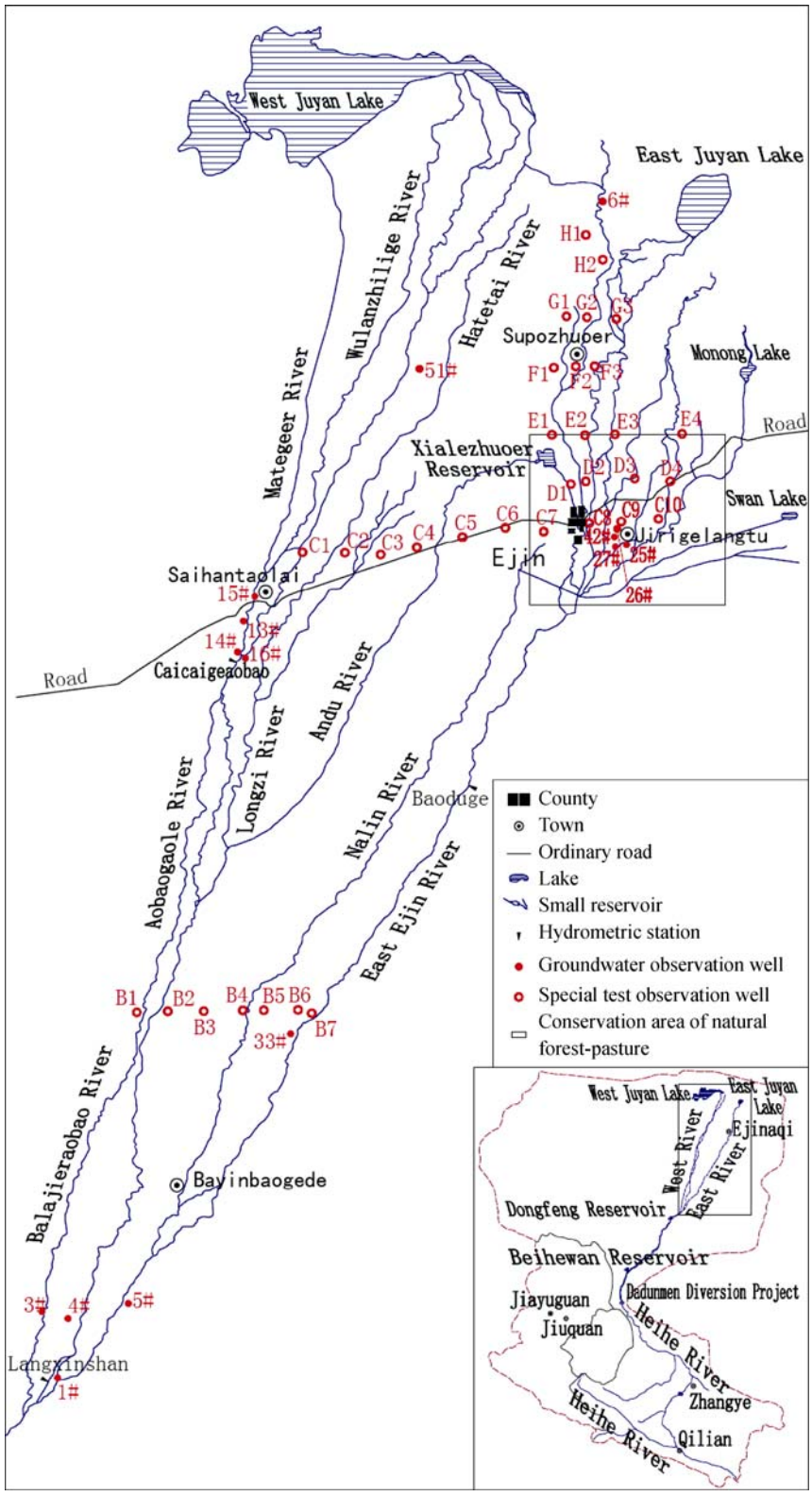

Figure 2 The distribution of the observation wells in the lower Heihe River

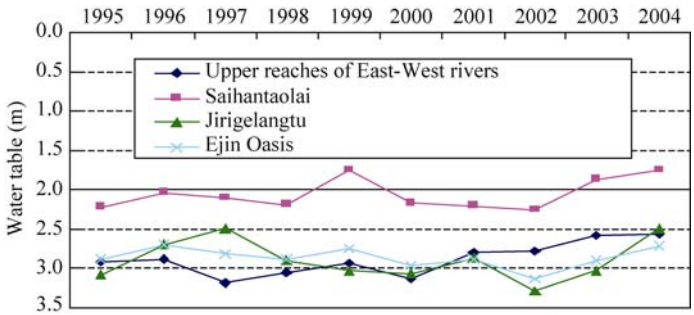

Figure 3 Inter-annual variations of groundwater level in the major regions of the lower Heihe River

Table 1 Relation between water level and the growth of plants in Ejin banner

Vegetation community	Water table and growth condition			
Populus euphratica	< 4 m normal growth	4–6 m, hidebound, bald, the leaves fade even few plants die	6–10 m, most of the plants blast	>10 m, all the plants die
Elaeagnus angstifolia	2–3 m normal growth	4–5 m, hidebound, blasted, even few plants die	5–6 m, most of the plants blast and degraded	>6 m, most of the plants die
Tamarix sp. *Nitraria sibirica*	< 5 m normal growth	5–7 m, degradation, blasted, even few plants die	7–8 m, degraded seriously, most of the plants die	>8–10 m, all the plants die

affected area of water regulation on *Populus euphratica* extends to 800 m away from the watercourse. Furthermore the affected area of water regulation on *Populus euphratica* changes with different distances to the watercourse in different periods. During the 2nd year of water regulation, 2001, the indexes of *Populus euphratica* within the region (100 m away from the watercourse), such as the average height and the thorax diameter etc., increased markedly. During the 3rd year, 2002, the indexes of *Populus euphratica* within the region (100–200 m away from the watercourse) reached their peak. During the 4th year, 2003, *Populus euphratica* within the region (200–300 m away from the watercourse) grew rapidly. Tables 2–6 show the growth of *Populus euphratica* before or after water regulation at different sites of the East and West rivers in terms of the field survey in August. 2005. The degree of growth is an important quantitative index to evaluate the recovery of *Populus*

Table 2 Survey results of the growth indexes for *Populus euphratica* at the cross section near Weitong Bridge in Dongfengchang before and after water regulation

Distance to the watercourse (m)	Age of *Populus euphratica* (year)	Growth degree for 5 years before water regulation (mm)	Growth degree for 5 years after water regulation (mm)		Concomitant vegetation
100	11	14.2	16.1		*Phragmites communis* *Tamarix* sp. *Achnatherum splendens* *Sophora alopecuroides*
260	8	/	2000	2.5	*Tamarix* sp. *Achnatherum splendens* *Sophora alopecuroides*
			2001	3.2	
			2002	3.1	
			2003	3.5	
			2004	3.2	
500	16	12.3	13.2		*Tamarix* sp. *Sophora alopecuroides*
1000	13	10.8	10.9		*Tamarix* sp.

Table 3 Survey results of the growth indexes for *Populus euphratica* at the left cross section of Yidao River near Daxi'aobao before and after water regulation

Distance to the watercourse (m)	Age of *Populus euphratica* (year)	Growth degree of the thorax diameter for 5 years before water regulation (mm)	Growth degree of the thorax diameter for 5 years after water regulation (mm)	Water level before water regulation (m)	Water level after water regulation (m)
0	85	11.5	15.0	2.27	1.32
100	26	10.5	14.2	2.64	1.87
200	24	7.5	10.0	3.18	2.55
300	12	8.3	9.5	3.52	3.05
500	22	9.8	10.2	4.11	3.98
1000	35	7.4	7.5	4.67	4.55

Table 4 Survey results of the growth indexes for *Populus euphratica* at the right cross section in the middle reaches of the Liudao River before and after water regulation

Distance to the watercourse (m)	Age of *Populus euphratica* (year)	Growth degree of the thorax diameter for 5 years before water regulation (mm)	Growth degree of the thorax diameter for 5 years after water regulation (mm)	Water level before water regulation (m)	Water level after water regulation (m)
0	14	9.6	12.3	2.83	1.54
100	31	8.2	10.5	3.14	2.01
200	18	10.4	11.3	3.31	2.89
300	20	9.3	9.8	3.85	3.64
500	62	7.9	8.1	4.53	4.32
1000	84	6.5	6.5	5.36	5.28

Table 5 Survey results of the growth indexes for *Populus euphratica* near the right cross section near Ebeichagan in the upper reaches of the East River both before and after water regulation

Distance to the watercourse (m)	Age of *Populus euphratica* (year)	Growth degree of the thorax diameter for 5 years before water regulation (mm)	Growth degree of the thorax diameter for 5 years after water regulation (mm)	Water level before water regulation (m)	Water level after water regulation (m)
0	15	14.3	16.1	1.32	1.28
100	13	12.5	13.4	1.98	1.88
200	21	13.7	14.3	2.54	2.46
500	30	8.5	9.0	3.15	3.12
1000	52	7.8	7.9	3.63	3.58
1500	62	7.2	7.2	4.69	4.64

Table 6 Survey results of the growth indexes for *Populus euphratica* at the left cross section near Saihantaolai in the West River both before and after water regulation

Distance to the watercourse (m)	Age of *Populus euphratica* (year)	Growth degree of the thorax diameter for 5 years before water regulation (mm)	Growth degree of the thorax diameter for 5 years after water regulation (mm)	Water level before water regulation (m)	Water level after water regulation (m)
0	20	13.2	16.9	2.15	1.28
100	25	11.8	13.9	2.88	1.88
200	19	9.7	11.6	3.52	2.46
500	32	10.5	11.8	4.05	3.12
1000	24	8.5	8.8	4.38	4.02
1500	58	6.2	6.3	4.99	4.64

euphratica. According to the survey results, the year of 2000 is the turning point of the influence on *Populus euphratica*'s growth. The nearer *Populus euphratica* is to the watercourse, the more rapid its growth. There is a clear correlation between the growth degree and the water level. However, the influence of water regulation on *Populus euphratic* is not significant in the region which is more than 1000 m away from the watercourse.

3.2 Influence of water regulation on *Tamarix* sp.

According to the field survey, the transverse influence of water regulation on *Tamarix* sp. is also evident in that past 5 years. This influence changes according to the distance from the area where the *Tamarix* sp. develops to the river course. Tables 7 and 8 show the growth indexes of *Tamarix* sp. at the cross sections of the East River and Yidao River before and after water regulation.

As shown in the two tables, when compared with the data before water regulation, the growth degree of the thorax diameter of *Tamarix* sp. at the section of the East River is a little larger than that at the section of the Yidao River. Similarly, at the cross section, the difference in the growth degree of the thorax diameter is quite small when the distance away from the watercourse is longer.

Table 7 Survey results of the growth indexes for *Tamarix* sp. at the cross section of the East River before and after water regulation

Distance to the watercourse (m)	Age of *Tamarix* sp. (year)	Growth degree of the subaerial diameter for 5 years before water regulation (mm)	Growth degree of the subaerial diameter for 5 years after water regulation (mm)	Coverage (%)	Concomitant vegetation
100	10	11.3	11.5	70	*Sophora alopecuroides*
200	17	10.8	12.1	50	/
300	11	10.5	11.9	47	/
400	12	10.8	11.7	50	*Sophora alopecuroides*
500	11	11.0	11.7	40	*Sophora alopecuroides*
600	14	10.1	10.6	43	*Sophora alopecuroides*
1000	10	10.2	10.3	35	/

Table 8 Survey results of the growth indexes for *Tamarix* sp. at the cross section of the Yidao River before and after water regulation

Distance to the watercourse (m)	Age of *Tamarix* sp. (year)	Growth degree of the subaerial diameter for 5 years before water regulation (mm)	Growth degree of the subaerial diameter for 5 years after water regulation (mm)	Concomitant vegetation
0	10	11.3	12.5	*Populus euphratica*
100	14	8.9	10.0	*Populus euphratica* *Kareliniacaspia* (*Pall.*) *Less.*
200	12	8.6	9.5	*Populus euphratica*
300	12	8.9	9.5	*Kareliniacaspia* (*Pall.*) *Less.* *Sophora alopecuroides*
500	15	9.6	10.0	*Populus euphratica*
1000	19	7.9	8.1	*Populus euphratica*

4 Influence of water regulation on vegetation near the East Juyan Lake

The vegetation had been seriously degraded in or around the East Juyan Lake since the lake was drying up in 1992. And there were a few of sapless Phragmites communities in the lake and lots of dead *Tamarix* sp. around the lake before water regulation in July 2002. After the flow entered East Juyan Lake for the first time in July 2002, the water had been regulated to the East Juyan Lake 6 times in the following 3 years, and even the maximal water area was nearly 40 km^2, being the most obvious affected region in vegetation change by water regulation. According to the field survey, vegetation in the lower reaches has changed evidently, when compared to the start of water regulation with that of before water regulation. All the survey results are shown in Tables 9 and 10.

Table 9 Survey results of vegetation in and around the East Juyan Lake before water regulation

Specimen position	Dominant vegetation	Coverage (%)	Concomitant vegetation	Other features
In the lake (dry)	*Phragmites communis*	1	/	The average height is 6cm
Around the lake	*Tamarix* sp.	13	*Nitraria sibirica*	65% bald die

Table 10 Survey results of vegetation around the East Juyan Lake after water regulation

Specimen position		Dominant vegetation	Coverage (%)	Concomitant vegetation	The average height (cm)
Southwestern bank	Within 100 m to lake bank	*Kalidium foliatum* (*Pall.*) *Moq. Tamarix* sp.	10		11
	100 m away from lake bank	*Tamarix* sp.	8	*Suaeda heteroptera Kitag*	
Southern bank	Within 60 m to lake bank	*Kalidium foliatum* (*Pall.*) *Moq.* *Tamarix* sp. *Phragmites communis* *Tamarix* sp.	37	*Kareliniacaspia* (*Pall.*) *Less.* *Suaeda heteroptera Kitag* *and so on*	
	Within 60–120 m to lake bank	*Kalidium foliatum* (*Pall.*) *Moq.*	8	*Phragmites communis* *Nitraria sibirica* *Suaeda heteroptera Kitag*	13
	120 m away from lake bank	*Tamarix* sp.	18	*Nitraria sibirica*	28
30 m from bank to center in the lake		*Phragmites communis*		/	54
Southeastern bank	Within 60 m to the lake edge	*Kalidium foliatum* (*Pall.*) *Moq.* *Suaeda heteroptera Kitag*	17	*Tamarix* sp. *Nitraria sibirica* *Kareliniacaspia* (*Pall.*) *Less.*	
	60 m away from lake bank	*Tamarix* sp.	35	*Alhagi sparsifolia* *Nitraria sibirica* *Suaeda heteroptera Kitag*	17
Within 100 m to both sides of the water inlet		*Tamarix* sp.	56	*Suaeda heteroptera Kitag*	86

It can be concluded from Tables 9 and 10, before water regulation, the coverage of vegetation was low with less plant varieties, the categories were few, and most of the vegetation was sapless in or around the East Juyan Lake. However, after water was regulated for three successive years, both the coverage and varieties of plant increased evidently, and all the vegetation grew well. The reasons are that after water flowing into the East Juyan Lake, both the lateral and vertical infiltration caused the increase of soil water content and groundwater level around the lake. Accordingly, water demand for the normal growth of vegetation was met, and consequently the vegetation was successively improved.

5 Remote sensing analysis for the influence of water regulation on the ecosystem

As an important measure in monitoring the changes of geo-environment, satellite remote sensing has played an increasingly important role in geo-environment monitoring. In order to further analyze the influence of water regulation on the eco-environment of the oasis in the lower Heihe River Basin, remote sensing is applied to analyze the area and coverage of pasture, *Populus euphratica*, shrub together with the variation of coverage of vegetation in different regions of the lower reaches, as well of the area changes of Gobi desert and salinized land. before and after water regulation.

According to the statistic analysis of remote sensing, it is found that there are great changes on the area and coverage of both the pasture and the shrub, as well as the area of Gobi Desert and salinity, when comparing the statistic data in 1998 with that in 2004 (Table 11). The conclusions can be drawn as follows: (1) After water regulation, the growth of forest and pasture in Dingxin irrigation area became worse because of the decrease of water supply from the Heihe River. At the same time, the area of salinized land reduced due to the decrease of groundwater level. (2) The growth of forest and pasture in Dongfengchang changed little except for those along the river, because there was no more water supply to Dongfengchang after water regulation. (3) The eco-environment in the East and West rivers has been greatly improved since water regulation in the Heihe River. For example, the areas of *Populus euphratica*, pasture and shrub increased; the growth condition of vegetation was improved; and the areas of Gobi and desert decreased when compared with those before water regulation. The oasis in the East and West rivers is the core region in the lower Heihe River, and improvement of the eco-environment in the oasis indicates that the continuous deterioration of the eco-environment in the lower reaches has been controlled effectively. (4) The benefits are the most obvious in the lake area, especially around the East Juyan Lake. Not only the water surface and water body always remained larger throughout the year of

Table 11 Increment statistics of remote sensing data in the lower Heihe River between 1998 and 2004 (unit: km^2)

Item	Dingxin area	Dongfengchang area	East-West rivers area	Two lakes area
Pasture area with larger coverage	1.75	0.19	2.15	1.19
Pasture area with middle coverage	6.45	0.04	2.96	7.15
Pasture area with smaller coverage	3.34	–0.1	1.71	7.29
Shrub area with larger coverage	—	1.7	22.07	5.9
Shrub area with middle coverage	—	–1.45	–6.05	–0.39
Shrub area with smaller coverage	0.01	–0.1	–11.6	–0.82
Populus euphratica area with larger coverage	—	0.05	6.35	—
Populus euphratica area with middle coverage	—	–0.06	–0.82	—
Populus euphratica area with smaller coverage	—	–0.1	0.89	—
Other forest area	0.8	0	0.05	—
Gobi area	–0.42	–0.03	–10.77	–9.99
Desert	–5.53	–0.03	–1.67	–12.92
Salinized land	–1.03	0	—	—

2004, but also the ecosystem around this region has been improved greatly. For instance, the dead and drying up *Phragmites communis* and *Achnatherum splendens* for years began to flourish. In summary the oasis in the lower Heihe River, where the pasture, *Populus euphratica* and shrub grow, increased by 40.16 km^2, of which pasture was 8.16 km^2, *Populus euphratica*, 4.84 km^2 and shrub 25.33 km^2. All these indicate that the desertified area was decreasing, while the area of oasis was increasing after water regulation. The trend of shrinkage of the oasis in the lower reaches has been held back after water regulation.

6 Conclusions

Based on the above analysis, the conclusions are summarized as follows:

(1) The trend of continuous decrease of groundwater level has been held back in Ejina Oasis after water regulation in the lower Heihe River. Even the groundwater level went up again in some sites. Especially, the groundwater level in the lower Heihe River has increased to some extent since 2002. In 2004, the groundwater level was near or up to the historical maximum since 1995. Comparing the figure in 2004 with that in 2002, groundwater level have increased by 0.22 m both in the East and West rivers, by 0.79 m in Jirigelangtu, by 0.5 m in Saihantaolai, and by 0.42 m in the whole Ejina Oasis.

(2) The influence of water regulation on *Populus euphratica* and *Tamarix* sp. was obvious. The rate of growth became higher. According to the survey for the growth CONDITIONS of *Populus euphratica* and *Tamarix* sp. within the affected region before and after water regulation, it is found that the rates of growth of both *Populus euphratica* and *Tamarix* sp. became obviously higher than those before water regulation. Moreover, the nearer the distance is to the watercourse, the better the growing conditions.

(3) The trend of shrinkage in vegetation at the Ejina Oasis in the lower Heihe River has been held back, and the biodiversity has increased as well. The area of *Populus euphratica* around the East and West rivers, or in the lower Heihe River increased from 366 km^2 before water regulation to 375 km^2 after water regulation. The area of pasture and shrub increased by 6.8 km^2 and 5 km^2 respectively, while the area of Gobi and sandy land decreased by 1.67 km^2 and 10.77 km^2 respectively. Especially, the eco-environment has changed most obviously in the East Juyan Lake. Not only the water area of the lake always maintained a larger surface throughout the year of 2004, but also the eco-environment around the lake was improved dramatically. During the period 1998–2004, the area of pasture and shrub increased by 15.6 km^2 and 14.5 km^2 respectively, and the area of Gobi and sandy land decreased by 9.99 km^2 and 12.92 km^2 respectively. The biodiversity has been increasing in the Juyan Lake because many wild animals rehabitated the region.

(4) Some achievements have been obtained since water regulation in the lower Heihe River. The trend of continuous deterioration of the eco-environment has been held back in the Ejina Oasis, however, as the restored vegetation is located near the river, so the vegetation which is far from the river made little progress. Hence it is necessary to allocate water resources in the lower Heihe River, and get more ecological benefit with limited water resources.

References

Cao Wenbing, Wan Li, Zhou Xun, *et al*., 2004. Effects of variation in water environment on ecosystem in the lower reaches of the Heihe watershed. *Hydrogeology and Engineering Geology*, (5): 21–25. (in Chinese)

Feng Qi, Chenf Guodong, Tang Zhigang, 1998. Study on relationship of vegetation growth and groundwater level in Ejina oasis. *Journal of Desert Research*, 18(1): 107–109. (in Chinese)

Luo Geping, Zhou Chenghu, Chen Xi, 2003. Process of land use/land cover change in the oasis of arid region. *Acta Geographica Sinica*, 58(1): 63–72. (in Chinese)

Si Jianhua, Feng Qi, Zhang Xiaoyou *et al*., 2005. Vegetation changes in the lower reaches of the Heihe River after its water import. *Acta Botanica Boreali-occidentalia Sinica*, 25(4): 631–640. (in Chinese)

Tang Deshan, Jiang Xiaohui, 2009. Post-estimate of the Effect on the Lower Heihe River of Governance and Water Diversion. Chinese Water Conservancy and Hydro-power Press. (in Chinese)

Wang Genxu, Chen Guodong, 1998. Changes of hydrology and environment during late 50 years in Heihe River. *Journal of Desert Research*, 18(3): 233–238. (in Chinese)

Wang Liming, Zhang Chouliang, Yin Jiyan, 2003. Study on the growth pattern and bio-productivity of the *Populus Euphratica* forest stand in Ejina. *Journal of Arid Land Resources and Environment*, 17(2): 94–99. (in Chinese)

Yang Denghua, Wang Hao, Qin Darong *et al*., 2005. The ecological evolution driven by water in the lower reaches of Heihe Basin. *China Environmental Science*, 25(1): 37–41. (in Chinese)

Yang Guoxian, He Hongmou, Yang Lifeng, 2003. Groundwater circulation law and its ecological impact on the lower reaches of Heihe River. *Water Resources and Hydropower Engineering*, 34(2): 27–29. (in Chinese)

Zhang Wuwen, Shi Shengsheng, 2004. Study on the relation between groundwater dynamics and vegetation in Ejina oasis. *Journal of Glaciology and Geocryology*, 24(4): 421–425. (in Chinese)

Zhang Xiaoyou, Xiao Honglang, Li Xiaoyan, 2002. Environmental chances of Ejina region in the lower reaches of Heihe River. *Advances in Earth Science*, 17(4): 491–496. (in Chinese)

Zhong Huapin, Liu Heng, Wang Yi *et al*., 2002. Relationship between Ejina oasis and water resources in the lower Heihe River Basin. *Advances in Water Science*, 13(2): 223–228. (in Chinese)