Wetlands Dynamics in Yinchuan Plain, China from 1989 to 2009

Xiaoqin Wang[1], Wenkai Li[1], Zoltan Vekerdy[2], Yunzhi Chen[1], Rumiana Vatseva[3]

(1. Spatial Information Research Center of Fujian Province, Fuzhou University, Fuzhou, 350002, P.R. China;

2. Faculty of Geo-Information Science and Earth Observation, University of Twente, The Netherlands;

3. National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, Bulgaria)

[1]wangxq@fzu.edu.cn

Abstract—**Wetlands, as a basic source to maintain agriculture and oasis ecosystem, is important to Yinchuan Plain, which locates in arid and semi-arid areas of northwest of China. To protect, manage and rationally develop wetland resources, three scenes of Landsat TM and ETM+ images, acquired in 1989, 1999 and 2009, were used to classify wetlands in Yinchuan Plain by hierarchical and object-oriented classification methods. With the classification results, the dynamic changes of wetland from 1989 to 2009 were analyzed, including the spatial distribution characteristics and the temporal evolution of wetland landscape pattern, the changes between wetland and non-wetland, and the changes between natural and artificial wetlands. The results show that, from 1989 to 2009, the wetland ecological system of Yinchuan Plain had great changes. In recent 20 years, the wetland area was halved from 656.45 km^2 to 332.56 km^2. The natural wetland area had a sharp reduction, especially the area of Yellow River, decreasing from 342.42 km^2 to 98.13 km^2, whose average annual decreasing rate was 6.59% in 1989-1999. The area of natural wetlands dominated in 1989, accounting for 75%, but the percentage was less than 60% in 2009. The area of artificial aquaculture was doubled from 30.51 km^2 to 70.3 km^2 in recent 20 years, especially developed in 1999-2009, in which the average annual increasing rate was 6.24%. Most of the decreases of natural wetlands were reclaimed to agricultural land, aquaculture land and other land use. The wetlands landscape change pattern is the interactional result of climate warming, the inflow decrease of yellow river, population increase and economic development.**

Keywords— **wetlands, Yinchuan Plain, dynamics, remotely sensed data**

I. INTRODUCTION

Wetlands are valuable land resources that provide a range of ecosystem services. Even though wetlands occupy only about 6% of the earth's surface, they are among the most productive ecosystems. They provide a host of goods and services, including water quality maintenance, agricultural production, fisheries, recreation, floodwater retention, provision of wildlife habitat, and control of soil erosion [1].

Remote sensing is essential tool for monitoring the current wetlands distribution and spatial-temporal dynamic variety. Some researches mainly focus on the wetland monitoring and dynamics, the interactions of various elements of wetland, wetland ecological function, and the driving forces of the changes of wetland ecosystem, etc [1-6].

Wetlands in Yinchuan plain, compared with the wetlands in eastern plain and the Qinghai-Tibet Plateau in China, has its own unique properties. In the arid and semi-arid regions of the northwestern China, wetlands were described as the "heart" of oasis, for they are the elements of the maintenance of agricultural and oasis ecosystem[7], for they play an irreplaceable role in improving the regional microclimate and keep the anti-interference ability of ecosystem. Yinchuan Plain is well-known for its many lakes in history. However, under the effects of climate and anthropogenic activity, the area of wetlands decreased rapidly over the last few decades[8]. Bai et al(2011) analyzed the dynamic changes of wetland landscape pattern in Yinchuan plain[8]. Most studies of Yinchuan plain wetland mainly focused on the qualitative description, the quantitative analysis and comparison for different periods of wetland landscape pattern[7-10].

In this paper, we used three images to monitor the spatial distribution of wetland resources and analyze the temporal changes in Yinchuan plain, during 1989-2009. The remainder of this paper is organized as follows. In section 2, study area and method are described. Section 3 presents the results and discussion. Section 4 discuses the driving forces. Finally, the main conclusions of this paper are given in Section 5.

II. STUDY AREA AND METHOD

A. Study area

Yinchuan Plain lies in the north of the Ningxia Hui Autonomous Region in northwest China, which is located 105°49′-106°53′E, 37°29′-39°53′N. It is almost composed of the plains on both sides of Yellow River, surrounded by vast hungriness. Yinchuan Plain has a total area of 6141km^2, approximately 50 km from east to west, and 160km from north to south. It has flat terrain, with an average altitude of 1100m. Yinchuan Plain belongs to temperate continental arid climate, annual precipitation around 180 mm, while annual evaporation around 2000 mm. The Yellow River runs through

Yinchuan Plain from southwest to northeast, which makes irrigated agriculture developed in Yinchuan Plain. It is one of important commodity grain bases, and the largest aquaculture bases in northwest China.

B. Data sources

The remote sensing data include two TM images acquired on July 3, 1989 and July 17, 2009, and one ETM+ image acquired on June 28,1989, with orbit number of path 129 row 033 and path 129 row 034. After geometric correction, registration and mosaic on the remote sensing imageries, we obtain the images of study area through a mask calculation by a vector boundary. Other data were derived from *Ningxia Water Resources Bulletin*[11], *Yellow River Water Resources Bulletin*[12], and other climate , social and economic statistical data.

C. Wetlands classification

On the basis of intrinsic properties of remote sensing images and the actual condition of study area, comprehensive classification methods were used. Wetlands in Yinchuan Plain were divided into natural wetlands and artificial wetlands, according to the cause of wetlands formation. The natural wetlands included rivers (permanent river and marsh river) and lakes, based on landscape characteristics. While artificial wetlands included ponds/canals and aquacultures, based on its purpose. The non-wetland were classified into agricultural land and other land uses (including residential area, saline-alkali soil, and wasteland).

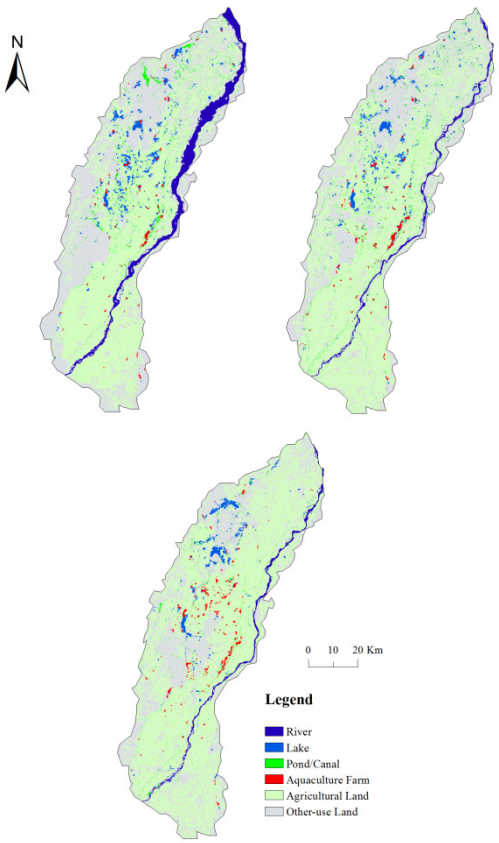
Object-oriented classification technology was adopted for wetlands classification. Spectrum and spatial characteristic of wetlands types were analysed based on the sample points by field trip during 2010-2011. First, water bodies were identified with Modified Normalized Difference Water Index (MNDWI)[13]. Water body patches were segmented, and the wetland types were classified based on support vector machine method. Normalized Difference Vegetation Index (NDVI) was used for classifying non-wetlands. Finally, the wetlands classification results were revised based on human-computer interaction visual interpretation, according to the field observed data, Google Earth, and literatures studied in Yinchuan Plain[7-10]. The overall accuracy were above 80% all. The classification results are shown in figure 1.

III. RESULTS AND DISCUSSION

C. Spatial pattern and areas of wetlands

As can be seen from the figure 1, lakes and aquaculture are found mainly in the northern area, and aquaculture increase was especially prominent. Agricultural lands mainly lies on both sides of Yellow River and the area increased. During 1989-2009, Yellow River has been reduced to a great degree (images were all acquired in wet season, and the seasonal differences are not significant). Other land uses distributed mainly in the west of study area, and the area decreased, while it showed a reverse trend to that in middle of study area.

The area and percentage of wetlands are shown in Table I. During 1989-2009, the wetland ecosystem of Yinchuan Plain had great changes. The amount of wetlands halved from 656.45 to 332.56 km^2. Natural wetlands area dominated in 1989, accounting for 75%, but the percentage decreased to 60% in 2009. The areas of natural wetlands decreased sharply, especially the area of Yellow River, from 342.42 to 98.13 km^2, and far greater than artificial wetlands. The area of Yellow River affects other wetlands greatly on area and distribution. For artificial wetlands, during 1999-2009 ponds/canals declined remarkably, while they increased equably during 1989-1999. The area of aquaculture was doubled from 30.51 to 70.3 km^2 in recent 20 years, especially from 1999 to 2009, which was the results of human intervention.



(a)1989

(b)1999 (c)2009

Fig.1 Wetlands distribution in Yinchuan Plain from 1989 to 2009

TABLE I AREA (KM^2) AND PERCENTAGE (%) OF WETLANDS

Wetlands types		1989		1999		2009	
		Area	Percentage	Area	Percentage	Area	Percentage
Natural	River	**342.4167**	**52.17**	109.9494	26.64	**98.1324**	29.51
	Lake	151.9551	23.15	127.2609	30.84	103.7772	31.20
	sum	494.3718	**75.32**	237.2103	**57.48**	201.9096	60.71
Artificial	Pond/Canal	126.5616	19.28	132.1929	32.03	60.3459	18.15
	Aquaculture	**35.5131**	5.40	43.2774	10.49	**70.3017**	21.14
	Sum	162.0747	24.68	175.4703	42.52	130.6476	39.29
Total		**656.4465**	100	412.6806	100	**332.5572**	100

D. Land use change rate

Land use change rate makes possible to describe quantitatively the change rate over certain period. It can be calculated by the following formula.

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \qquad (1)$$

Where K is the change rate of certain land use type over the study period, U_a and U_b are land use areas at the beginning and end of the study period, T is study period.

Using the formula (1), annual change rate of wetlands were calculated and shown in figure 2. The annual change rates for wetlands type were different.

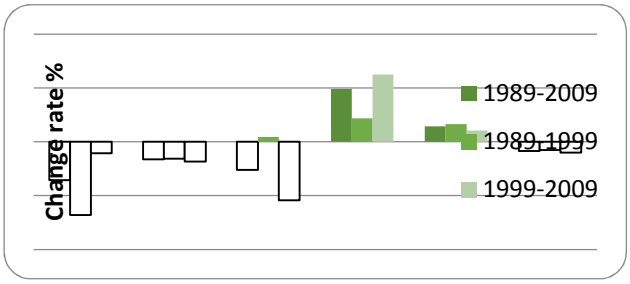


Fig.2 Annual land use change rate of wetlands

The annual change rates of aquaculture, river and pond/canal were large during 1989-2009 and fluctuated wildly during 1989-1999 and 1999-2009. Area of aquaculture increased rapidly and its average annual change rate achieved 4.9%, especially during 1999 to 2009, it increased dramatically, and its change rate achieved at 6.24%, while in 1989-1999, its annual change rate was 2.19%. Yellow River area decreased abruptly, its average annual decreasing rate of 1989-1999 (6.59%) was much larger than that of 1999-2009 (1.07%). The area of pond/canal mainly decreased during 1999 and 2009, whose annual decreasing rate was 3.57%, while in 1989-1999, its annual change rate was only 0.44%. The annual change rate of lake, agriculture and other land use changed slightly during the two periods. The decreasing rate of lake was 1.62% during 1989 and 2009, and the rate difference between 1989-1999 and 1999-2009 was only 0.26%. Agriculture area increase slightly and its average annual rate was 1.42%, and the rate difference between the two periods was only 0.58%.

E. spatial and temporal changes of wetland

Using the spatial analysis technology of GIS, the change maps during different periods were acquired (Figure 3) and the transfer matrixes of different land use were calculated (Table II, III, and IV).

From 1989 to 2009, 344.96 km^2 natural wetlands have been converted to non-wetland, in which the Yellow River and lakes decreased mostly. It's mainly due to the plummeting inflow of Yellow River, climate change and over-exploitation on natural wetlands. The changes mainly happened along Yellow River and natural lakes in

Yinchuan city. Because of the implementing of natural wetlands protection project, non-wetlands have been reformed into wetlands, mainly in the northwest of study area. There were respective 3.3 km^2 lakes and 11 km^2 non-wetlands were turned into aquaculture land. The largest land use change was other land use being cultivated to agricultural land with 1090.58 km^2, closely associated with the developed irrigation system from the Yellow River. On the other hand, 563.51 km^2 agricultural lands was transformed to other land use, most of them were used for built-up area in the regions of Yinchuan, Qingtongxia, Wuzhong and Lingwu.

The change pattern between 1989-1999 and 1999-2009 was different.

From 1989 to 1999, 227.11km^2 river area was converted into non-wetland, and river areas decreased rapidly, due to the plummeting inflow of Yellow River and the reclaiming for flood land. For the climate warming and drying, and excessive farmland from lakes, 71.82 km^2 lakes was turned to non-wetland, which mainly lies in north of study area. Because many ponds and canals were built for the irrigation from the Yellow River, 83.08 km^2 non-wetland was transformed into pond/canal. The total area of agriculture land increased steadily, and 818.63 km^2 other land use was reclaimed into agriculture land. The change area mainly happened in the edge of the Yinchuan Plain. The cultivated intensity was more deeply in this period than that of 1999 - 2009.

From 1999 to 2009, 120.25 km^2 natural wetlands was transformed to non-wetlands, and the change area was found in the northern of study area. In this period, human activities, such as the mass development of wetland tourism and the building of aquaculture, played a leading role in wetlands decreasing. About 101.05 km^2 non-wetlands was converted to natural wetlands, which mainly locates in the north-western of Yinchuan Plain. Some natural wetlands protection project have taken hold, and the decreasing trend of natural area was contained to some degree. Respectively, 15.21 km^2 lakes and 20.16 km^2 non-wetlands were reclaimed into aquaculture land. The change distributed mainly in and around Yinchuan city. With the rapid urban sprawl, 550.32 km^2 agriculture land was built to other land use.

IV. Driving Forces

The dynamic of wetlands in Yinchuan Plain was the interaction results of natural and human factors. In this area, the natural factors associate with climate and inflow of yellow river. Correspondingly, the increasing population and economy style are the main human factors.

F. The influence of climate change

Since 1990s, Yinchuan Plain has mostly suffered from global climate warming. From the collected meteorological data [14,15] of the area, it showed that the air temperature and the precipitation fluctuated during the 20 years, but the change trends were different. The temperature went up, while the precipitation went down (Figure 4), which made the climate drier in Yinchuan Plain.

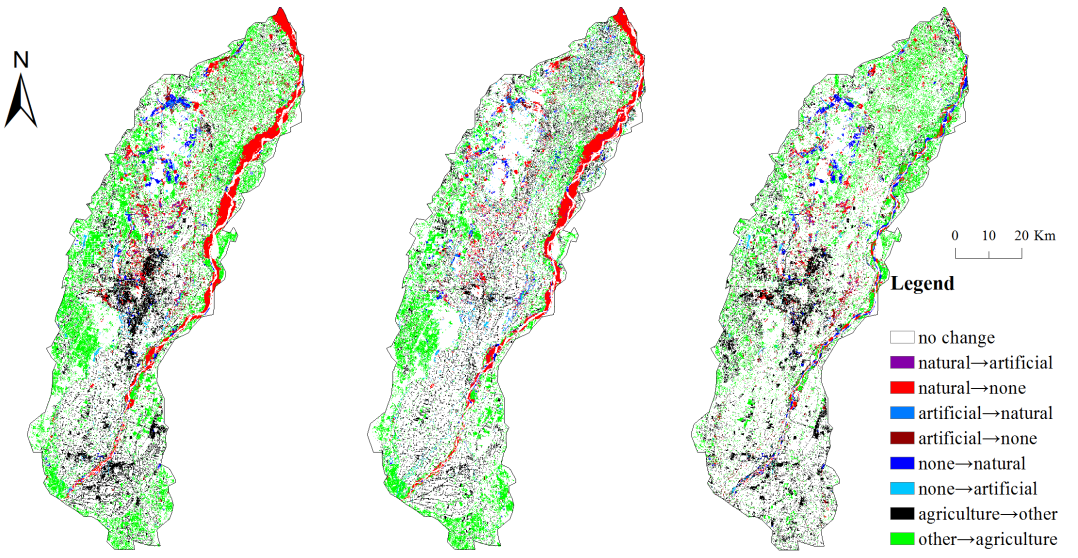


Fig.3 Spatial-temporal dynamic change of wetland in Yinchuan Plain during 1989 and 2009

TABLE II TRANSITION MATRIX DURING 1989 AND 2009 (KM2)

	River	Lake	Pond/Canal	Aquaculture	Agriculture	Other	Total
River	89.5797	0.0081	0.1728	0	1.8351	6.5367	98.1324
Lake	2.7657	27.9882	7.3809	3.3750	**13.635**	**48.6324**	103.7772
Pond/Canal	4.4991	6.6420	9.1917	1.2906	7.6860	**31.0365**	60.3459
Aquaculture	0.3051	17.6220	6.3837	19.8594	7.6608	18.4707	70.3017
Agriculture	**168.4503**	**60.9921**	**56.6712**	4.0950	2170.7838	1090.5768	3551.5692
Other	**76.8168**	**38.7027**	**46.7613**	6.8931	563.5143	1523.3967	2256.0849
Total	342.4167	151.9551	126.5616	35.5131	2765.1150	2718.6498	6140.2113

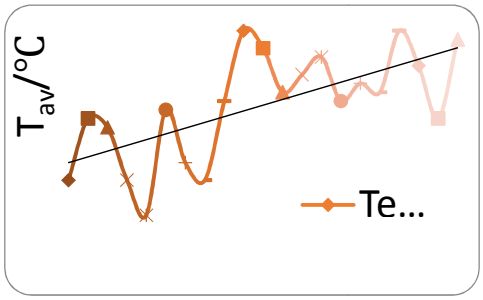
Note: Row is initial state and column is final state.

TABLE III TRANSITION MATRIX DURING 1989 AND 1909 (KM2)

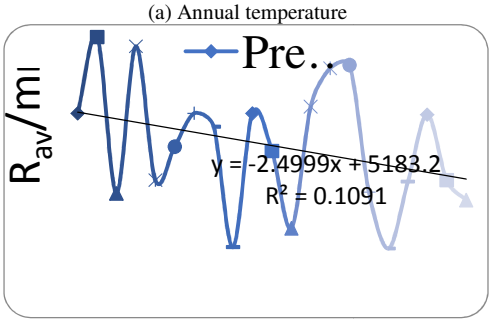
	River	Lake	Pond/Canal	Aquaculture	Agriculture	Other	Total
River	99.9945	0	0.1449	0	2.3157	7.4943	109.9494
Lake	3.5388	64.4175	13.4622	4.8879	5.5188	35.4357	127.2609
Pond/Canal	11.7855	11.7810	26.2152	2.2401	13.4523	66.7188	132.1929
Aquaculture	0	3.9366	3.6540	23.8446	2.8746	8.9676	43.2774
Agriculture	**77.8320**	**36.4878**	**37.9701**	1.5264	2242.3104	818.6274	3214.7541
Other	**149.2659**	**35.3322**	**45.1152**	3.0141	498.6432	1781.4060	2512.7766
Total	342.4167	151.9551	126.5616	35.5131	2765.1150	2718.6500	6140.2113

TABLE IV TRANSITION MATRIX DURING 1999 AND 2009 (KM2)

	River	Lake	Pond/Canal	Aquaculture	Agricultural	Other	Total
River	56.6352	0.3969	1.8504	0	**8.4330**	**30.8169**	98.1324
Lake	1.0926	35.7903	3.4407	1.6506	**17.6868**	**44.1162**	103.7772
Pond/Canal	0.7470	7.200	15.4197	1.2069	**11.9673**	**23.8050**	60.3459
Aquaculture	0.0765	**15.2100**	7.3530	27.5031	**7.9326**	**12.2265**	70.3017
Agricultural	**35.2242**	**38.4903**	55.1970	4.9662	2618.4168	799.2747	3551.5692
Other	**16.1739**	**30.1734**	48.9321	7.9506	550.3176	1602.5373	2256.0849
Total	109.9494	127.2609	132.1929	43.2774	3214.7541	2512.7766	6140.2113



(a) Annual temperature



(b) Yearly precipitation

Fig.4 Climate change of Yinchuan Plain during 20 years

In arid and semi-arid regions, the drier the climate is, the more fragile the wetlands ecosystems are. The drier climate is one of the important factors for the shrink of natural wetlands. On the other hand, Yinchuan Plain is an important commercial grain base, the increasing agriculture land need more quota of water consumption from the Yellow River and groundwater, which reduced the water supply for natural wetlands systems. As a consequence, a great deal of natural lakes have dwindled, some even dried-up.

G. The inflow change of Yellow River

Inflow of Yellow River is an important supply for wetlands sustainability. For the 20 years, there was a downturn of the inflow of Yellow River. Accompanied with over consumption of water, the cutoff situation is serious, especially in the 1990s. The inflow changes of Xiaheyan hydrological station in the study area were shown in Figure 5. It shows that the inflow of Yellow River decreased in the first decade, and it plummeted in 1990 and 1995, which lead to not only the sharp decrease of the area of Yellow River, but also reducing the water supply for lakes and canals. In the later decade, the inflow fluctuated slightly near $2.4*10^{10}$ m^3.

The reduced inflow of yellow river also made canals more narrow, and many smaller ditches could not be recognized in TM images. So the area of canals decreased.

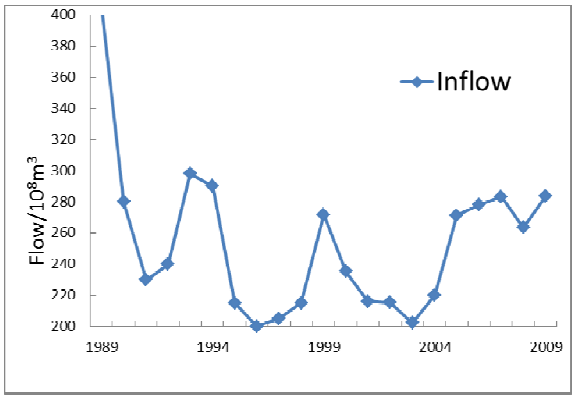


Fig.5 The inflow of Yellow River

H. Population change

In Yinchuan Plain, population increased from 1.45 to 2.35 million at its fastest pace in history[16] during 1989-1999, and it had a population of 2.9 million in 2009. The increased population results in the need for increased amounts of water, food and built-up land, and unreasonable exploitation and utilization of wetlands further to some extent. In the periods of 1989-1999 and 1999-2009, the areas of agricultural land increased 449.63 km^2 and 336.82 km^2 respectively, and the areas of natural wetlands reclaimed to agricultural land increased 114.32km^2 and 73.71 km^2, respectively. The population change influences wetlands landscape strongly.

I. economic factors

Since the 21st century, Yinchuan government has made great efforts to develop water associated economic, like aquaculture development, wetlands tourism and lakeside-villa construction. Although some natural wetlands protection projects, such as water supplement to natural wetlands, rivers and lakes dredging, lakes connection for many small lakes, ponds being turned into big lakes, have been implemented, the area of wetlands still affects by water associated economic. From 1999-2009, 15.21 km^2 lakes were used for aquiculture farm, and the tourism revenue increased steadily (Figure 6), except in 2003 when the economic was effected by SARS. Rapid tourism development and the over-exploited of natural wetlands, made the natural wetlands shrink and their functions degradation. 30.17 km^2 lakes were converted to other land use.

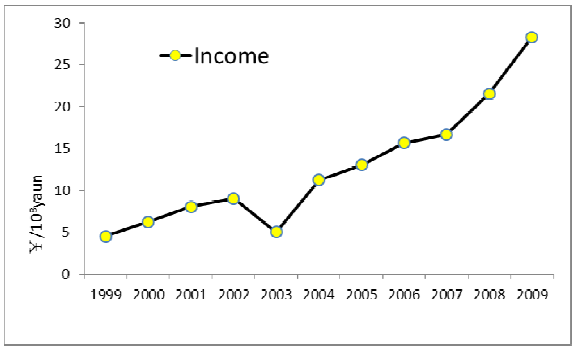


Fig.6 The tourism revenue of Yinchuan city

V. CONCLUSIONS

From the above analysis, it can be concluded as follows:

(1) During 1989 and 2009, wetlands in Yinchuan Plain declined obviously, the area in 2009 was only half of that in 1989. The natural wetlands had a dramatically decrease for the 20 years, the area in 2009 only 40.84% of that in 1989. Natural wetlands area dominated in 1989, accounting for 75%, but the percentage declined to 60.71% in 2009.

(2) For natural wetlands, the river wetland area has a sharp reduction, which decreased from 342.42 km^2 in 1989 to 98.13 km^2 in 2009. For artificial wetlands, area of aquaculture was doubled from 30.51 km^2 to 70.3 km^2 in recent 20 years. There annual change rates were very large, and fluctuated wildly during 1989-1999 and 1999-2009.

(3) During the period, the dominate land use change was from other land use to agricultural lands. But there were also many agricultural lands developed to other land use because of urbanization.

(4) The temperature rise, precipitation fall, the decrease of inflow of Yellow River, population increase, and development of water associated economic were the main factors for the wetlands dynamic over the 20 years. It should be make more efforts to protect the natural wetlands.

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