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Original Research Paper

Climate Change Impacts on Wetlands of the Yellow River Headwaters

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ABSTRACT

The impacts of climate change and human activities have modified the structure and the distribution pattern of wetlands of the Yellow River headwaters. We studied ETM and TM satellite images data using GIS from 1990, 2000 and 2010 to analyse changes in the spatial distribution and patterns of the wetland area that supplies water to the Yellow River. We propose stable conditions for the different types of wetlands and mutual transition probabilities. Time series data on temperature, precipitation and evaporation at the Jimai and Maduo hydrological and meteorological stations were analysed. Characteristics and trends of meteorological factors were studied. The relational grades of different wetlands and meteorological factors were calculated using Grey System Theory. Major factors determining wetland evolution in the Yellow River headwaters were proposed and the impacts of climate change on wetland evolution were analysed. Wetland evolution in the Yellow River headwaters is closely related to climate change. Precipitation is the dominant meteorological determinant for the wetland pattern evolution and transformation of the other wetland types. Presence of wetland areas is positively correlated with precipitation and temperature and negatively correlated with evaporation. Wetlands are important for maintaining the "cold and wet" effect on regional climates; when precipitation increases, the "cold and wet" effect of the wetland increases.

INTRODUCTION

Wetlands are important for flood and drought control, precipitation runoff, climate modulation, soil erosion control, and maintenance of biological diversity. Wetlands also play an important role in the improvement of the regional environment, economic development and ecological security (Sun 2000). With these ecological, economic and social benefits, wetlands have become a major topic and a focal point with regard to human sustainable development. The climate of wetland regions drives their structural and functional evolution. Climate change may alter the wetland's material cycle, energy flow, productivity, hydrology, biogeochemistry processes, plant and animal composition, and ecological function (Li & Chen 2005, Burris et al. 2013, Mitsch et al. 2008). At the same time, the effect of climate change on wetland structure and function will modify its existing ecology which will, in turn, affect the rate of environmental change. The relationship between climate change and regional water resources, wetlands and the evolution of lakes has been previously investigated (Chang et al. 2007, Lan et al. 2005, Herrera et al. 2012). The results of these studies indicate that in many areas, the climate is becoming warmer and drier, while the utilization of all water resources, and wetland resources in particular, is becoming more intense (Zhang et al. 2011, Armandine et al. 2014). These factors can lead to structural changes, and even destruction of wetlands.

The Yellow River headwaters are one of the most important wetland areas in the Qinghai-Tibet Plateau of China. It plays an important role in the protection of regional biodiversity, maintenance of ecological balance, conservation of water sources, and the formation and maintenance of the plateau's climate (Li et al. 2009). The wetland in this area is sensitive to disturbance. A combination of high altitude, harsh climate, frozen soil, and melt-water inputs contribute to the natural conditions present. The formation, development and evolution of the wetland are closely related to these unique natural conditions. Climate change and human activities, in recent decades, have changed the distribution pattern and other characteristics of this wetland area and the ecological environmental problems have increased in severity. These problems include shrinking water surface area, grassland degeneration, land desertification, and reduced biodiversity (Li et al. 2009, Wang et al. 2002, Li et al. 2012). These problems affect environmental changes and ecological security of the Qinghai-Tibet Plateau and upper Yellow River. This paper analyses the causal factors involved with wetland evolution and climate change, and reveals the evolution mechanism of the wetland area and its distribution pattern affected by climate change (Brogaard & Zhang 2002, Willard et al. 2011). This study is conducted to provide insight into strategies that can provide sustainable resource utilization and environmental protection of the Yellow River wetlands.

OVERVIEW OF THE STUDY AREA

For the purpose of this study, the upper catchments of the Dari (Jimai) hydrological station in the Qinghai province

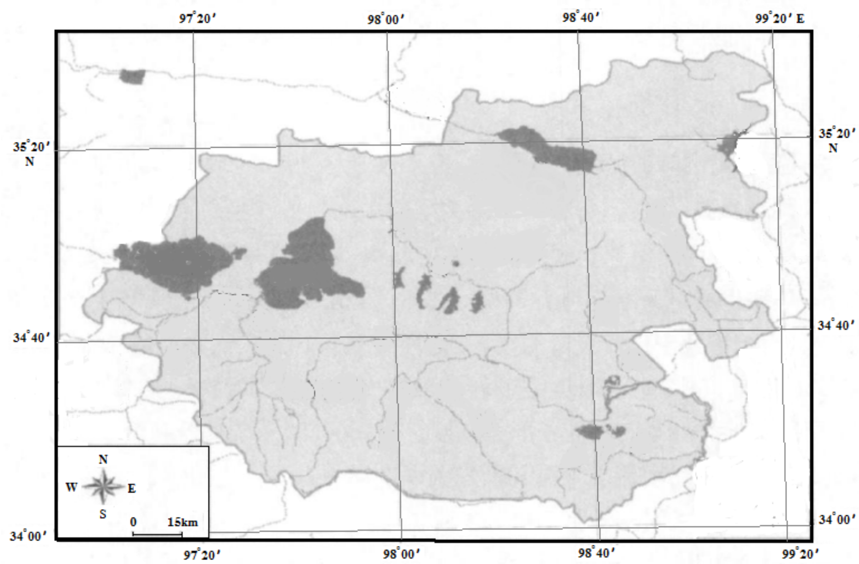

Fig. 1: Figure of the location of the Yellow River headwater.

are regarded as the headwaters of the Yellow River. The region includes Ma duo in the northeast of the Qumalai County of the Yushu Autonomous Prefecture, Qinghai Province, Maduo County, Dari County, Gande County and Maqin Xian County west of the Tibetan Autonomous Prefecture of Goluo. The area is 6.6×10^4 km^2, the average altitude is 4200 m and the elevation ranges from 500m-1000m (Fig. 1).

The Yellow River headwaters are a natural pond of the Yellow River known as "the water tower of the Yellow River". The landform of the headwaters belongs to the plateau-mountain area of the Bayanhar mountains with the northwest terrain being high while the southeast terrain is low. The region consists of low mountains, broad valleys, lakes and swamps. The mountains are steep; the mountain top has strip irregularities, concave-convex, and has continuous or island permafrost and seasonally frozen soil. Glaciers are no longer growing and the runoff supplying the headwaters is mainly from precipitation. The region is located in the center of Eurasia. It has an alpine semi-humid climate with cold and warm seasons. During the long cold season, winds are strong and snowfall is heavy. The short warm season is characterized by relatively higher humidity than that which occurs in the cold season. In the warm season, precipitation is affected by the southwest monsoon as the moisture from the Bay of Bengal moves into the Tibetan Plateau with a southwest airflow. Simultaneously, the Tibetan Plateau, often creates a vortex and wind shear. The terrain in the northwest is high contrasted to the low southeast terrain and this creates airflow uplift. Regional precipitation decreases from southeast to northwest.

EVOLUTION CHARACTERISTICS OF THE WETLAND

Three general factors influence the evolution of wetland spatial patterns. These are abiotic, biotic and anthropogenic (human related) (Arias et al. 2014, Acreman et al. 2009). The wetland of the Yellow River headwaters has spatial variation caused by the abiotic and biotic succession processes and by impacts from the continuous human activity. Among the abiotic factors, climate directly affects the scope, structure and spatial distribution of the wetland. Factors such as orography, soil and landform are relatively stable anthropogenic factors, which can directly or indirectly change the scope of the wetland and its internal ecological characteristics. There are few data related to the effects of biotic factors on this region so these are not considered in this study. In the past 20 years, obvious climate changes have occurred in the Yellow River headwaters. During the same period, the area and composition structure of the wetland has also significantly changed.

Remote sensing technology can be used to obtain objective and reliable data as it has a wide ranging, multitem-poral dynamic detection functions. Geographic information system technology can evaluate wetland sources and analyse wetland changes by use of a spatial information processing function (Ouyang et al. 2014, Macalister & Mahaxay 2009). The combination of the two technologies is a powerful tool for analysis of spatial variation and study of wetland pattern changes. The spatial distribution and the patterns of wetlands in the Yellow River headwaters are

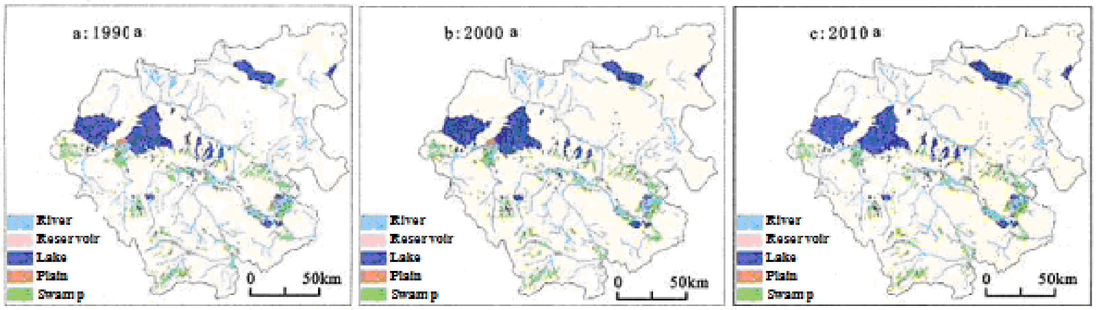

Fig. 2: Remote sensing images of the wetlands in the Yellow River headwaters.

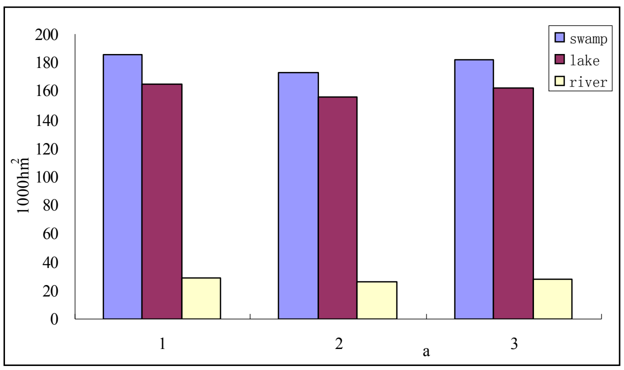

Fig. 3: Distribution patterns of swamp, lake and river in 1990a, 2000a and 2010a.

analysed using ETM and TM data from the USA Landsite. Images of the wetland area of the Yellow River headwaters in the years 1990, 2000 and 2010 are shown in Fig. 2.

Spatial pattern of the wetland: Through processing, interpretation, and data extraction of the remote sensing information, the area of the different wetlands can be obtained in the Yellow River headwaters in the years 1990, 2000, and 2010. The results are given in Table 1. The table shows that the two main types of wetlands in the Yellow River headwaters are swamps and lakes. The percentage of swamp area was 49.0%, 48.7% and 48.8% in 1990, 2000 and 2010 respectively. The percentage of the lake area was 43.5%, 43.9% and 43.7% in 1990, 2000 and 2010 respectively. The swamp and lake areas account for 92.5%, 92.6% and 92.6% of the total wetlands area for the three years respectively, whereas the proportion of the river area account for 7.5%, 7.4% and 7.4%.

The dynamic changes of the wetlands area in different periods can be seen in Table 1. The results are depicted in Table 2 and Fig. 3, which show that between 1990 and 2010, the wetland area in the Yellow River headwaters shrank at first and then expanded. During these 20 years, the wetland area decrease by 4271 hm^2. The average rate of decrease is 214 hm^2/a. The area decreased by 12659 hm^2 during the first 10 years, but then it increased by 8388 hm^2 during the second 10 years. The average rate of decrease is 1266 hm^2/a, whereas the average rate of increase is 839 hm^2/a. Overall, the different types of wetlands, swamp, lake and river are declining. Comparing 2010 to 1990, the areas of swamp, lake and river declined by 2.30%, 1.28% and 2.82% respectively.

Evolution characteristics of the wetland: From 1990 to 2000, the wetlands of the Yellow River headwaters decreased rapidly due to climate change and human activities, with the average rate of decrease as 1266 hm^2/a. Since 2000, the Chinese government has implemented ecological reconstruction efforts and thus helps to protect the ecological environment of the Yellow River headwaters. The area of wetland in the headwaters of the Yellow River has increased at a rate of 839 hm^2/a. A spatial overlay of the wetland landscape type maps in the headwaters of the Yellow River in the years 1990, 2000 and 2010 was analysed using ARC/INFO software. The 20-year time period is divided into two different stages; the first stage from 1990 to 2000, and the second stage from 2000 to 2010. The mark off transfer matrix is employed to represent the transformation between the various landscape components. Using the transfer matrix, the transformation and conversion rate between various wetland types can be analysed, as can the stability of the different wetland types. The mutual transfer between various wetlands from 1990 to 2000 in the source region of the Yellow River is given in Table 3.

Table 3 shows that from 1990 to 2000 the swamp and rivers are in unstable states; the transfer probability of the swamp and river is 40.19% and 46.25% respectively. The main transfer types of the swamp are grassland, the transition zone from shrub to grassland, barren wasteland and wasteland. The greatest transfer probability from swamp to grassland is 30.88%, while the second greatest transfer probability (3.49%) is from the swamp to transition zone. The main transfer types of the river are river rapids, grassland, swamp and barren wasteland. The transfer probability from river to river rapids, river to grassland, and river to swamp is 17.30%, 14.92% and 10.22% respectively.

The mutual transfer between the various wetlands from 2000 to 2010 in the Yellow River headwaters is given in Table 4. From 1990 to 2000, the swamp, lake and river are in a stable state, and the transfer probability of the swamp, lake, and river is 7.54%, 2.72%, and 7.62% respectively. Among the various wetlands, the areas of swamp and river have increased. The transfer types of the swamp are mainly grassland, transition zone from shrub to grassland, wasteland and barren wasteland. The transfer probability from grassland to swamp is 13.02%; the transfer probability from the transition zone to swamp, barren wasteland and wasteland is 3.65%, 1.42% and 2.03% respectively. The river is transferred mainly from river rapids, wasteland, and the transition zone from shrub to grassland, grassland, barren wasteland and swamp. The transfer probability from river rapids to river is 17.10%; the wasteland is 4.41%; the transition zone is 3.96%; the grassland is 4.36%; the barren wasteland is 1.32%; and the swamp is 1.26%. The lake is in a relatively stable state in the two periods as the transfer probability of the lake is from 2.72% to 5.96%. The main transfer types of the lake are swamp and grassland and the transfer probability from the lake to swamp and grassland is less than 4%.

Table 1: Area changes of different wetland type in different periods.

Wetland	1990a		2000a		2010a	
	Patch number	hm^2	Patch number	hm^2	Patch number	hm^2
Swamp	577	185838	407	173179	641	181567
Lake	172	164663	149	156178	163	162559
River	61	28380	83	26272	69	27580
Total		378881		355629		371706

Table 2: Dynamic changes of different wetland area in different periods.

Wetland	1990-2000a		2000-2010a		1990-2010a	
	Patch number	hm^2	Patch number	hm^2	Patch number	hm^2
Swamp	-171	-12659	234	8388	64	-4271
Lake	-24	-8485	14	6380	-10	-2104
River	23	-2108	-15	1308	8	-799
Total		-23251		16077		-7175

LAWS OF CLIMATIC CHANGE

There are 10 hydrological stations in the Yellow River headwaters, which are directly subordinate to the Yellow River Conservancy Commission, the Ministry of Water Resources. There are 6 hydrological stations in the Yellow River: Huangheyuan, Jimai, Mentang, Maqu, Jungong and Tang naihai. There are 4 hydrological stations in the tributary area; Requ hydrological station on the Yellow River, Jiuzhi hydrological station on the Shakequ River, Tanggor hydrological station on Baihe River and Dashui hydrological station on the Heihe River. There are 5 rainfall stations commissioned by Yellow River Conservancy Commission of the Ministry of Water Resources: Awancang, Longriba, Waqie, Maiwa and Dongqinggou rainfall stations. The hydrological, meteorological and rainfall stations all provide useful data for analysis of climate change such as temperature, precipitation and evaporation in the Yellow River headwaters.

Temperature: Temperature is an important thermal index and it influences wetland changes in the Yellow River headwaters in the following ways: (1) It affects regional gross evapo-transpiration; (2) It changes the temperature difference between the underlying surface and the air near the soil surface so as to form a regional climate; it affects change in the spatial pattern of the wetland; (3) It affects the melting rate of the glacier and snow cover; (4) It affects the precipitation form of the alpine region; and (5) It affects the biological distribution and biodiversity of the wetland. In the past 100 years, the global climate has become warmer, with the mean temperature rising 0.3-0.4°C. In the past 40 years the mean temperature has risen 0.2-0.3°C. In China, the annual average temperature has risen by 0.3°C from 1951 to 1990 and by 0.42°C from 1900 to 2010.

Details of annual temperature variation in the Yellow River headwaters can be obtained from statistical analysis of data from the Jimai and Maduo meteorological stations. Before 1990, the temperature was relatively low, but after 1990, mean temperature shows a rapid increase (Figs. 4 and 5). In the last 50 years, there has been an oscillatory uptrend in the annual average temperature in the Yellow River headwaters. In the past 10 years, the uptrend has increased; the increased rate of the Jimai meteorological station is $0.33°C\cdot(10\ a)^{-1}$ and that of the Maduo station is $0.39°C\cdot(10\ a)^{-1}$. This exceeds the rising rates of Chinese and global average temperatures.

Precipitation: The surface runoff supply is mainly derived from precipitation. Generally, the dry and the conditions of the runoff directly depend on the size of the precipitation. Compared with air temperature, precipitation is more variable and complex; the trend lines of annual precipitation (Figs. 6 and 7) show that the tendency rate of the annual precipitation variation of the Jimai meteorological station is $3.80\ mm\cdot(10\ a)^{-1}$ and that of the Maduo station is $16.02\ mm\cdot(10\ a)^{-1}$. In the past 50 years, there has been a slight uptrend in annual precipitation in the Yellow River headwaters.

Table 3: The transfer matrix of various wetland types from 1990a to 2000a.

1990-2000	Swamp	Lake	River	Grassland	Transition zone from shrub to grassland	Wasteland	Barren wasteland	River rapids	Tidal flat
Swamp	59.81	0.40	0.61	30.38	3.49	2.57	2.74	0	0
Lake	3.81	94.04	0.10	0.88	0	0	0.46	0.71	0
River	10.22	0	53.75	14.92	0	0	3.81	17.3	0
Grassland	3.82	0.07	0.5	95.61	0	0	0	0	0
Transition zone from shrub to grassland	5.40	0	0	0	94.6	0	0	0	0
Wasteland	0	0	0	0	0.50	99.50	0	0	0
Barren wasteland	2.02	0.08	0.44	0	0	0	97.46	0	0
River rapids	0	0	17.36	0	0	0	0	82.44	0.2
Tidal flat	0	0.72	0	0	0	0	0	0	99.28

Table 4: The transfer matrix of various wetland types from 2000a to 2010a.

2010-2000	Swamp	Lake	River	Grassland	Transition zone from shrub to grassland	Wasteland	Barren wasteland	River rapids	Tidal flat
Swamp	92.46	0.96	1.26	2.94	1.26	0.72	0.4	0	0
Lake	1.09	97.28	0	0.87	0	0	0	0	0.76
River	1.25	0	92.38	1.7	0	0	0.71	3.96	0
Grassland	13.02	3.04	4.36	79.58	0	0	0	0	0
Transition zone from shrub to grassland	3.65	3.84	3.96	4.32	84.23	0	0	0	0
Wasteland	2.03	3.52	4.41	2.43	3.73	83.88	0	0	0
Barren wasteland	1.42	2.17	1.32	0	2.47	12.50	80.12	0	0
River rapids	0	0.36	17.1	0	0	0	0	82.54	0
Tidal flat	0	0	0	0	0.24	0	0	0	99.76

Evaporation: For the Yellow River headwaters, evaporation is an important factor for the wetland spatial change. Since the 1960s, there has been a slight increase in the measured values of average annual evaporation at the Jimai and Maduo hydrological stations (Figs. 8 and 9). The tendency rate of annual evaporation variation at Jimai is 4.55 mm·(10 a)$^{-1}$ and at Maduo it is 2.44 mm·(10 a)$^{-1}$. Compared with the measured air temperature data at this station during the same period, it can be seen that evaporation increases as temperature increases.

THE RELATIONSHIP BETWEEN WETLAND EVOLUTION AND CLIMATE CHANGE

Data processing: Wetland evolution is influenced by climate change occurring over time (Pittock & Finlayson 2013, Schneider et al. 2011). Thus, it is cumulative, and to calculate the average meteorological data for 10 years the data needs to be standardized. To distinguish between the time sequence and present data, “x” is added to the time sequence data to show the difference. To standardize these data, the areas of different types of wetland are divided by the average values of the time sequence data and the results are given in Table 5.

The calculation of the relationship degree: The relational analysis in Grey System Theory, advocated by Professor Deng Julong, is a direct factor optimal method, which measures the near grade according to the similar or dissimilar grade of the changing tendency between the factors. In the optimization of programs, through calculating the relational grade between the index and the reference series of various programs, a relational sequence is made in accordance with the priority. Consequently, it is possible to obtain an overall optimal program. This method converts mutually incomparable indices into a unified comparable one. It is highly suitable for the optimization of a program related to a multifactor or multi-object system.

***The determination of the number series*:** Let Y denote the reference number series, and $Y(k)$ the value of the k^{th} point, then the reference number series may be represented as follows:

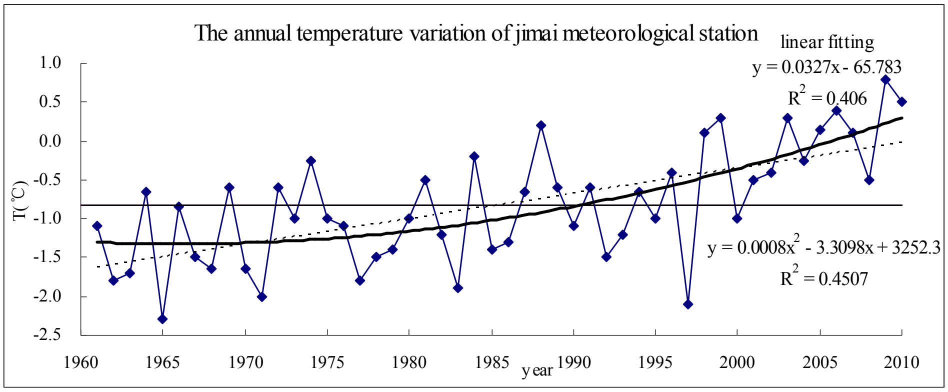

Fig. 4: The annual temperature variation at the Jimai meteorological station from 1960a to 2010a.

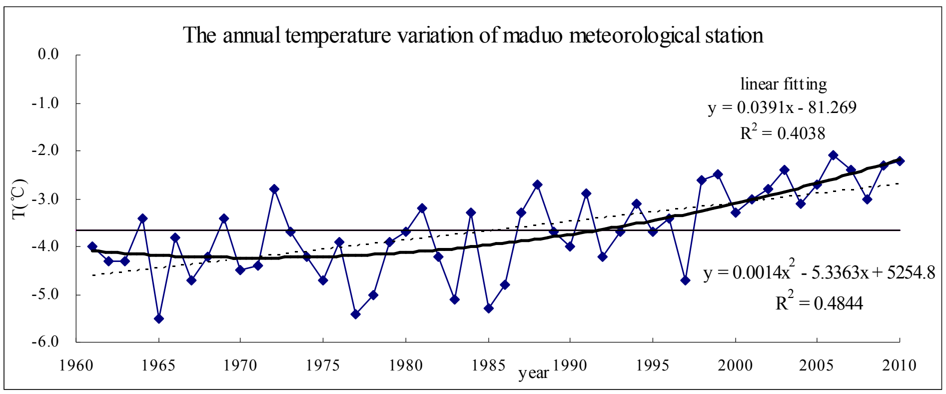

Fig.5: The annual temperature variation at the Maduo meteorological station from 1960a to 2010a.

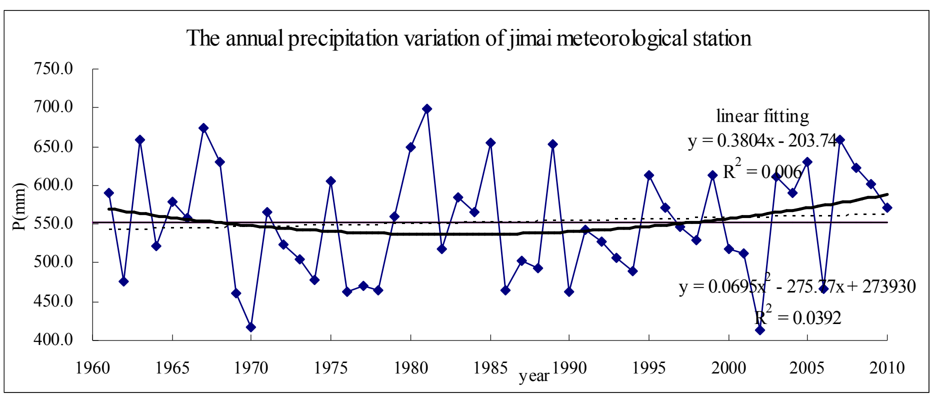

Fig.6: The annual precipitation variation of Jimai meteorological station from 1960a to 2010a.

$$Y = \{Y(k)|k = 1,2,\cdots,n\} \quad ...(1)$$

The compared number series is indicated by $X_1, X_2, \ldots X_m$, that is:

$$X_i = \{X_i(k)|k = 1,2,\cdots,n\},\ i = 1,2,\cdots,m \quad ...(2)$$

***The non-dimensionalization of variables*:** If the unit of all indices is different, it is necessary to carry out a nondimensional treatment so that it can be easily compared. A general method is to divide by the first number or mean number.

$$x_i(k) = \frac{X_i(k)}{X_i(l)}, k = 1,2,\cdots,n; i = 1,2,\cdots,m \qquad ...(3)$$

***The calculation of the coefficient of relationship*:** The difference between every comparative number series and the reference one at every point is formulated as follows:

$$\xi_i(k) = \frac{\min_i \min_k |y(k) - x_i(k)| + \rho \max_i \max_k |y(k) - x_i(k)|}{|y(k) - x_i(k)| + \rho \max_i \max_k |y(k) - x_i(k)|} \qquad ...(4)$$

Where: $|y(k) - x_i(k)| = \Delta_i(k)$ is the absolute difference between Y and X_i of the k^{th} point; $\min_i \min_k |y(k) - x_i(k)|$ is the two-stage minimum difference. Of it: $\min_i |y(k) - x_i(k)|$ is the first stage minimum difference, which implies the minimum difference between various points at $x_i(k)$ th curve andth curve and Y; $\min_i \min_k |y(k) - x_i(k)|$ is the second stage minimum difference, which implies the minimum difference of all the curve X_i according to i = 1, 2,..., m, based on the minimum difference curve; $\max_i \max_k |y(k) - x_i(k)|$ is the two-stage maximum difference; its meaning is similar to that of the minimum difference; ρ is a distinguished coefficient, $\rho \in (0,1)$. The relational coefficient increases along with ρ increasing so that the relational grade increases along with it. In a general way, $\rho = 0.5$.

***The calculation of the relational grade*:** If there are too much data and the information is too dispersed to compare, the calculation of its mean value, relational grade, is formulated as follows:

$$r_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k), k = 1,2,\cdots,n \qquad ...(5)$$

The bigger the relational grade is, the nearer the comparative number series and the reference one are. The relational grades of the wetland area and meteorological factors can be calculated by using the relational analysis in Grey System Theory. The results are given in Table 6.

Comprehensive analysis: The results of the above calculations indicate that the relational grades of different types of wetlands and meteorological factors differ. The relational grades of the swamp, lake and river with precipitation as the greatest, are 0.99, 0.983 and 0.999 respectively. Precipitation has a great impact on the types and spatial distribution of wetland and precipitation is the main meteorological factor affecting wetland evolution. The wetland area is positively correlated with precipitation, and therefore, the area increases with an increase of precipitation and decreases with a decrease. The relational grades of the swamp, lake and river with temperature as the smallest, are 0.139, 0.235, and 0.092 respectively. Temperature has a small impact on the types and spatial distribution of wetland and a relatively small impact on the wetland evolution and changes to the wetland area. Therefore, it does not play a leading role. The relational grades of the swamp, lake and river with evaporation as negative, are -0.429, -0.339 and -0.472 respectively. Evaporation also has a relatively large impact on wetland evolution and changes in wetland area. Wetland area increases with a decrease of evaporation, and decreases with an increase.

In the Yellow River headwaters the relational grade of temperature with evaporation is 0.835; the relational grade of evaporation with precipitation is 0.504; and the relational grade of temperature with precipitation is 0.055. In this region, evaporation increases as temperature increases. Although temperature does not directly affect changes, it affects precipitation indirectly through evaporation.

When the wetland area decreases, there will be reduced evaporation and precipitation. In turn, a decrease of evaporation and precipitation will cause the decrease of the wetland area. Wetland evolution mainly illustrates the "wet" effect. That is, when the regional temperature increases, the wetland area decreases, and the "cold" effect of wetland becomes weak. In contrast, when the wetland area increases, the regional temperature decreases, and the "cold" effect of wetland becomes more important.

CONCLUSIONS

In the past 50 years, the annual average temperature in the Yellow River headwaters has increased. In the past 10 years, the rate of temperature increase has accelerated. The climate tendency rate of the Jimai meteorological station is $0.33°\cdot(10\ a)^{-1}$ and that of the Maduo station is $0.39°\cdot(10\ a)^{-1}$. These exceed the rising rates of mean temperatures both in China and globally. The tendency rate of the annual precipitation variation of the Jimai meteorological station is $3.80mm\cdot(10\ a)^{-1}$ and that of the Maduo station is 16.02 $mm\cdot(10\ a)^{-1}$. In the past 50 years, there has been a slight increase in the annual precipitation of the entire Yellow River headwaters. The tendency rate of the annual evaporation variation of Jimai meteorological station is 4.55 $mm\cdot(10\ a)^{-1}$ and that of the Maduo station is 2.44 $mm\cdot(10\ a)^{-1}$. When compared with the measured air temperature data of this station in the same period, evaporation increases as temperature increases.

From 1990 to 2000, the swamp and river are in unstable

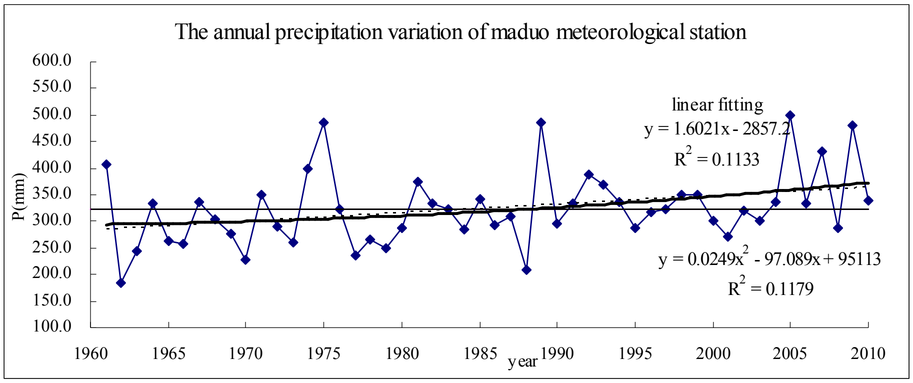

Fig. 7: The annual precipitation variation of Maduo meteorological station from 1960a to 2010a.

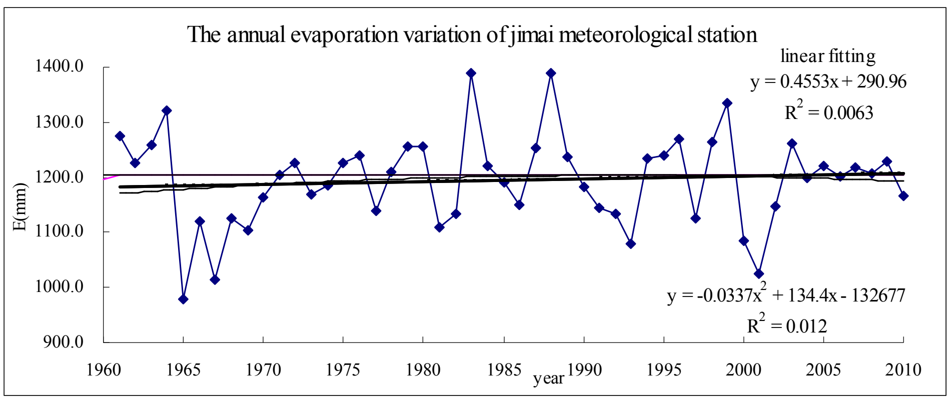

Fig. 8: Annual evaporation variation at Jimai meteorological station from 1960a to 2010a.

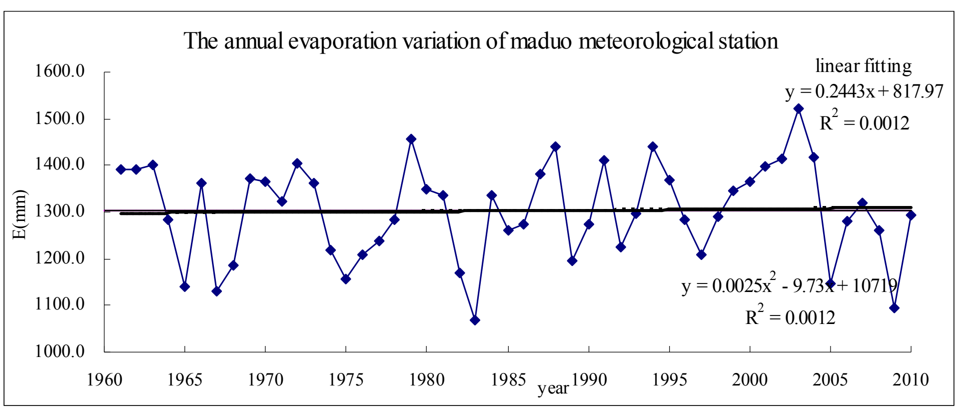

Fig. 9: Annual evaporation variation at Maduo meteorological station from 1960a to 2010a.

states; the transfer probability of the swamp is 40.19%, whilst that of the river is 46.25%. The transfer probability from wetland to non-wetland is relatively high. The main transfer type of the swamp is grassland, whereas the main transfer types of the river are river rapids, grassland and swamp. From 1990 to 2000, the swamp, lake and river are in a more stable state; the transfer probability of the swamp is 7.54%, whilst that of the lake and river is 2.72% and 7.62% respectively. Among the various wetlands, the area of the swamp and river increase. Lake is in a relatively stable state in the two periods; the transfer probability of the lake changes from 2.72% to 5.96%. The main transfer type of the lake is swamp and grassland.

Wetland evolution in the Yellow River headwaters is

Table 5: Comparison table of wetlands with climate change.

	Swamp	Lake	River	Temperature	Precipitation	Evaporation
1990x	1.031	1.022	1.035	0.466	0.579	0.617
2000x	0.961	0.969	0.958	0.479	0.445	0.540
2010x	1.008	1.009	1.006	0.713	0.524	0.486

Table 6: The relational grades of wetland area and meteorological factors.

Item		Wetland area	Temperature	Precipitation	Evaporation
Swamp	Wetland area	1.000	0.139	0.996	-0.429
	Temperature	0.139	1.000	0.055	0.835
	Precipitation	0.996	0.055	1.000	0.504
	Evaporation	-0.429	0.835	0.504	1.000
Lake	Wetland area	1.000	0.235	0.983	-0.339
	Temperature	0.235	1.000	0.055	0.835
	Precipitation	0.983	0.055	1.000	0.504
	Evaporation	-0.339	0.835	0.504	1.000
River	Wetland area	1.000	0.092	0.999	-0.472
	Temperature	0.092	1.000	0.055	0.835
	Precipitation	0.999	0.055	1.000	0.504
	Evaporation	-0.472	0.835	0.504	1.000

greatly affected by climate change. The extent of wetland area is positively correlated with precipitation and temperature and negatively correlated with evaporation. Precipitation is the most powerful meteorological driving factor for wetland evolution, while temperature has the least impact on the wetland evolution. Wetland areas play a prominent role in maintaining the "cold and wet" effect on the regional climate; when wetland area decreases, the regional temperature increases, evaporation increases, precipitation decreases, and the "cold and wet" effect of the wetland diminishes.

Relatively sparse observational data associated with the wetland climate limited analysis of mutual influences, influence mechanisms, and the effects of climate change on wetland evolution.

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