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VARIATION TREND OF DRY-WET CLIMATIC FACTORS AND CORRELATION WITH WETLANDS IN WESTERN JILIN PROVINCE, CHINA

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Abstract: The variation of climate elements and its relationship with wetland landscape in western Jilin Province (WJL) were studied to support decision-making for drought prevention and ecology protection. Mann-Kendall test and linear regression algorithm methods were used to analyze the characteristics of climate change, using a large amount of data of temperature, precipitation, evapotranspiration and dry-wet index, collected from nine monitoring stations during 1960-2014. The results showed that annual temperature and dry-wet index in WJL displayed a ascendant tendency, with the average rate of 0.34℃/10a and 0.14/10a, respectively. The annual precipitation and potential evapotranspiration showed a declining trend; decreasing by about -7.92mm/10a and -3.4mm/10a, respectively. Homogeneous trend was found for temperature and evapotranspiration in the autumn; an increasing trend observed. A sharp declining trend was found in the summer season for precipitation, which was the biggest contributor to the overall decrease of annual precipitation. The spatial distribution of annual and seasonal climate factors indicated that the WJL area is becoming drier, especially in the summer and autumn seasons. The wetland landscape indexes in most regions are significantly correclated with summer precipitation. The significance level for I, II and IV regions located in the west of WJL reached 99%. It is important to plan responding measures of water resource management, to counter the decrease of summer precipitation in western WJL, and reduce the impact of drought and wetlands degradation, which is possibly caused by the global climate change.

Keywords: climate change, western Jilin, wetlands landscape indexes, trend analysis, correlation analysis

1. INTRODUCTION

The evidence of global warming in recent decades is indisputable. Many observations have demonstrated increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level. The IPCC 2013 reports suggested that global land-surface air temperature (LSAT) had increased over the instrumental period of record, with the warming rate approximately double that reported over the oceans since 1979，but precipitation records show mixed and non-significant long-term trends in reported global mean changes. And it is also noted that precipitation and temperature changes have not been uniform around the globe. Regional variations can be much larger, and considerable spatial and temporal variations may exist between climatically different regions (Yue & Hashino, 2003). Yang et al., (2013) reviewed the spatiotemporal changes of various components for water cycle processes, including precipitation, runoff, and evapotranspiration in China in the last decades. It showed that precipitation in China has strong spatial and seasonal variability as discussed by Qian et al., (2002), Yang et al., (2010) and Wang et al., (2011). This is especially true for semi-humid and semi-arid regions exemplified in certain regions in Northeast China, which was located at middle and high latitudes in the eastern of Eurasia. Liang et al., (2011) investigated the temporal variation and spatial distribution of the precipitation in Northeast China from 1961 to 2008, by means of a linear fitted model, the Mann–Kendall test, the moving *t*-test, and the Morlet wavelet and Kriging (exponential) interpolation methods. Because air temperature data are more readily available, most previous studies in northeast China focused on the spatiotemporal variations of annual, summer and winter air temperatures (e.g., Yu et al., 2004; Dong & Wu, 2008; Wei et al., 2008; He et al., 2009). Recent researches were focused on the temperature and precipitation. Although these studies produced information, they did not undertake systematical and comprehensive analyses of multiple climate factors, and the scale of these studies were primarily inter-annual and inter-decadal.

Climate change on global scale has been studied by many researchers while regional studies are limited, especially the semi arid western Jilin province. The Western Jilin Province (WJL), located in the hinterland of Songnen Plain, is an ecological fragile region in the transition zone from semi-humid to semi-arid climate, and also is the largest and one of the most important wetland ecosystems in Songhua River Basin (Pan et al., 2006; Ren et al., 2007). Maintaining and enhancing eco-environment were restricted to a large extent by water supply. Topographically, the area was low-flat and situated mainly on an alluvial plain, making the discharge of surface water difficult. The main water source was the Tao'er River and Huolin River, but it showed sharply decrease of water level of Huolin River and Tao'er River by the influence of the climate change (rising temperatures and declining rainfall) and human activities (hydraulic engineering constructions, especially reservoirs). And wetlands had undergone functional loss as well as acreage loss (Yue et al., 2008).

The climate change will control the hydrological regime, which shifts the pattern and area of wetlands. Many studies have indicated that the area and distribution of wetlands were sensitive to the response of climate change (Erwin, 2009; Withey & van Kooten, 2011; Su & Wang, 2012; Ouyang et al., 2014; Garris et al., 2015). Liu et al., (2011) predicted the potential distributions of wetlands in this area and in the Great Xing'an Mountains, northeastern China, under warming climate conditions, using the Random Forests model. The simulation results show that the potential area of wetlands is vanishing and more than 60% of the wetlands will disappear by 2100. Now there are few relative researches in China in this topic, especially in arid and semi-arid region.

The main aim of this study was to comprehensively analyze the fundamental characteristics of spatial-temporal change and trends of various dry-wet climate variables, such as annual and seasonal temperature, precipitations, potential evaporation (ET_0), and dry-wet index, using the Mann-Kendall method, based on daily climate data from 1960 to 2014 at 9 meteorological stations in Western Jilin Province. The relationships between the wetland landscape (Mean Shape Index (Msi), No. of Patches (Nump), Mean Patch Size (Mps), Mean Patch Fractal Dimension (Mpfd)) and climate factors were also approached through correlation analysis. This study will provide important reference to the countermeasures formulation of regional climate change in WJL, the ecological protection and restoration of wetlands in Western Jilin Province.

2. DATA AND METHOD

2.1 Study areas

Western Jilin Province (WJL), with an area of 55,340 km^2, located between 43°22′N - 46°18′N and 121°36′E 126°12′E, includes 9 counties (cities): Baicheng, Zhenlai, Taonan, Tongyu, Da'an, Songyuan, Qianguo, Qian'an, and Changling (Fig. 1). The climate belongs to the transitional zone from dry in the western part, to semi-humid type in the eastern part. Based on data collected from 20 meteorological stations nearby, the mean annual rainfall for the years 1975-2010 was 350-500 mm, while the multi-year mean temperature ranged from -30ºC to -2ºC in January and from 12ºC to 33ºC in July. The geomorphology is low-flat, making the discharge of surface water difficult (Li et al., 2015).

The rivers that enter into Western Jilin Province are Second Songhua River, Tao'er River, Huolin River. The rivers crossing the WJL are Nenjiang River, Second Songhua River. Taoer River (in western WJL), Huolin River (in central WJL) are tributaries of Nenjiang River (Fig.1).

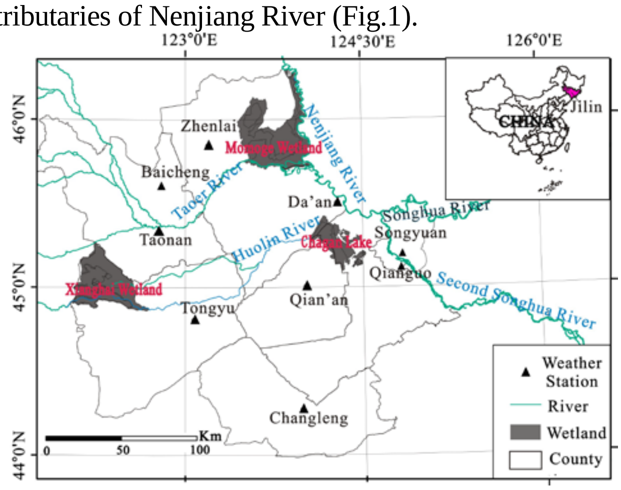

Figure 1. Western Jilin province

According to related survey data, the wetlands area reduced by 1100 km^2 from 1980 to 2002, and the area only accounted for 22% of original area (Li, 2011). Therefore, several natural reserves were established to conserve remnant semi-natural wetland habitats. Among the natural reserves, Xianghai wetlands, Momoge wetlands and Chagan Lake Wetlands are National Natural Reserves (NNR) in the study area.

2.2 Data

There are 9 surface meteorological stations in the WJL. Considering the reliability and integrality, the observed data of daily series of precipitation (P), mean air temperature (T_{mean}) from 1960 to 2014 are selected in this study. The location of the study area and the selected meteorological stations are shown in figure 1. Seasons were defined as follows: spring (Mar-May), summer (Jun-Aug), autumn (Sep- Nov), and winter (Dec- Feb).

2.3 Calculation of potential evaporation and dry-wet index

The daily potential evaporation in 9 stations is calculated by the Penman-Monteith equation (Allen et al.,1998). The dry-wet index (DWI) is defined as follows (Zheng & Liu, 2011):

$$DWI = \frac{ET_0}{P} \qquad (1)$$

where ET_0 is the calculated potential evaporation, P is the precipitation value. Hence, a higher value of DWI indicates a drier climate. The regions with DWI<1.0 are considered humid regions, whereas 1.0<DWI<1.5 indicates semi-humid regions, 1.5<DWI<4.0 semi-arid regions, and 4.0<DWI arid regions.

2.4 Trend analysis methods

The Mann–Kendall test (Mann, 1945; Kendall 1955), linear regression algorithm methods were applied to detect and analyze the trend of climate factors in the time series. Because these methods have been used widely in the study of trends in hydrometeorological time series, the details are not described here.

2.5 Correlation analysis

The wetland landscape indexes Mean Shape Index (Msi), No. of Patches (Nump), Mean Patch Size (Mps), Mean Patch Fractal Dimension (Mpfd) were calculated by Spatch Analyst tool in Arcgis. And the coorelation between these indexes and climate factors (annual and seasonal P, T, ET_0, DWI) was identified by correlation analysis method in SPSS software.

3. RESULTS AND DISCUSSION

3.1 Annual trends

Annual trends of P, T_{mean}, ET_0 and DWI obtained by the Mann–Kendall test and the linear regression are given in table 1 and table 2.

The average temperature in WJL increased from north regions (Zhenlai, Baicheng, Da'an) to south regions (Tongyu, Taonan, Changling) and the annual rate of increase reached 0.034ºC. All stations had statistically significant increasing trends in annual mean temperature with 99% confidence level. The magnitude of the decreasing slopes ranged from 0.27 to 0.40ºC/10a for all the stations. The range of increase was larger in east than that in west.

The spatial distribution of precipitation was inhomogeneous, and it was more in east than that of west. Most of the stations (6 out 9) showed a decreasing trend for precipitation and among them only Changling was statistically significant which the magnitude of the slope was -20.53mm/10a. The other three stations which located in the north, showed a rising trend, but not significant. Using the Thiessen polygon method, the areal of the annual precipitation of WJL was analyzed, and it also showed insignificant trend.

The annual average ET_0 was high in east, but low in west, which was contrary to precipitation. Six stations exhibited a decreasing trend in annual potential evaporation, and only Qian'an and Da'an were significant, at 95% was -0.79 mm/a and 0.78 mm/a.

The spatial change of annual average DWI was the same as ET_0. All but Changling, of the stations experienced no significant trends in DWI. The annual increase rate of Changling was 0.17. The above analysis revealed that the climate had been becoming warmer and drier in the south of WJL, with Changling being the most arid region in WJL.

3.2 Seasonal trends

The spatial distribution of values of slope b of the linear regression analysis, values of statistics Z and β of the Mann-Kendall test for seasonal T_{mean}, P, ET_0 and DWI (1960–2014) were shown in figures 2, 3, 4, 5.

Most stations showed spatial consistency in the seasonal trends and annual trends of T_{mean}, P, ET_0, DWI.

For T_{mean} (Fig. 2), all the stations showed significant increasing trends for spring, summer and autumn. In winter, except that two stations (Tongyu and Zhenlai) had non-significant increasing trends, the other stations all had significant increasing trends. The slope b of T_{mean} in spring had the largest increase and the temperature in summer has the smallest rate. And the average change rate of T_{mean} in south was bigger than that of north. Taonan, Tongyu, Changling, Baicheng station showed significant trends in all seasons.

For P (Fig. 3), all stations showed increasing trends in spring, and decreasing trends in summer and autumn. Three stations (Da'an, Taonan, Zhenlai), had significant increasing trends in spring and winter. Changling station presented decreasing trends both in summer and autumn. The slope of summer was the biggest, which contributed the most to the decrease of annual P. So it will result in less precipitation in western WJL, especially Changling.

For ET_0 (Fig. 4), all the stations showed downward trend in spring and summer, and most of stations located in the east of WJL had significant trends, also with bigger negative slope. Two stations (Tongyu, Zhenlai) had significant increasing trends in autumn. The upward trend of ET_0 and downward of precipitation in autumn may lead to drier climate in autumn. The spatial distribution of P and ET_0 indicate that warm desiccation's tendency was more obvious in west than east.

For DWI (Fig. 5), there was not consistent trend in seasons. Da'an, Taonan, Zhenlai, Songyaun showed significant decreasing trends in winter and spring, with seasonal average negative slope from 0.04 to 0.21 in winter and 0.22 to 0.37 in spring. Baicheng and Changling stations showed significant increasing trends in autumn and spring. Only Tongyu station showed significant increasing trend in summer. So it is indicated that a significant drier trend occurred in west WJL except Taonan station.

Table 1. Mean values with standard deviation, values of slope b of the linear regression analysis, values of statistics Z and β of the Mann-Kendall test for annual P, T_{mean} (1960–2014).

Station	P				T_{mean}			
	P(mm)	Z	β	b(mm/10a)	T_{mean}(℃)	Z	β	b(℃/10a)
Baicheng	395.5±124.6	-1.65	-1.43	-13.79	5.0±0.9	5.97**	0.03	0.34
Da'an	417.8±94.4	0.37	0.29	3.28	4.9±0.8	4.08**	0.03	0.29
Qianguo	438.2±93.7	-1.47	-1.25	-8.07	5.3±1.0	5.61**	0.04	0.38
Qian'an	414.8±106.9	-1.11	-1.05	-4.37	5.4±0.9.	5.17**	0.04	0.36
Songyuan	424.6±94.2	0.12	0.17	0.76	5.3±1.0	5.11**	0.04	0.40
Taonan	379.4±105.1	-0.71	-0.63	-8.47	5.6±0.9	4.99**	0.04	0.38
Tongyu	387.8±99.0	-1.87	-1.52	-15.55	5.7±0.9	4.10**	0.03	0.27
Changling	443.7±110.3	-2.93**	-2.17	-20.53	5.5±0.9	5.60**	0.03	0.36
Zhenlai	389.5±110.5	0.21	0.27	-0.42	5.0±0.8	5.60**	0.03	0.28
WJL	400.4±83.9	-1.07	-0.83	-7.92	5.37±0.9	4.43**	0.03	0.34

*Trends statistically significant at the 95% confidence level. **Trends statistically significant at the 99% confidence level.

Table 2. Mean values with standard deviation, values of slope b of the linear regression analysis, values of statistics Z and β of the Mann-Kendall test for annual ET_0 and DWI (1960–2014).

Station	ET_0				DWI			
	ET_0(mm)	Z	β	b(mm/a)	DWI	Z	β	b(1/10a)
Baicheng	956.0±48.5	-0.16	-0.07	-0.08	2.58±1.46	0.96	0.009	0.14
Da'an	996.0±47.5	-1.97	-0.86	-0.78	2.29±0.7	-0.54	-0.003	-0.02
Qianguo	1022.4±38.1	-0.94	-0.37	-0.23	1.96±0.7	-0.01	0.000	-0.01
Qian'an	1134.9±43.3	-2.22*	-0.97	-0.79	2.48±0.8	0.35	0.002	0.06
Songyuan	1046.0±40.3	-0.42	-0.19	-0.21	2.23±0.7	-0.38	-0.003	-0.02
Taonan	859.4±48.3	-1.70	-0.73	-0.75	2.99±1.2	0.42	0.004	0.08
Tongyu	1029.1±47.2	0.52	0.27	0.22	2.70±1.0	1.19	0.010	0.15
Changling	896.3±48.5	0.13	0.08	0.07	2.02±0.7	1.97	0.012	0.17
Zhenlai	948.5±44.3	0.19	0.10	0.18	2.56±1.3	-0.22	-0.002	-0.02
WJL	987.6±37.2	-1.63	-0.68	-0.34	2.42±0.8	0.97	0.009	0.14

*Trends statistically significant at the 95% confidence level. **Trends statistically significant at the 99% confidence level.

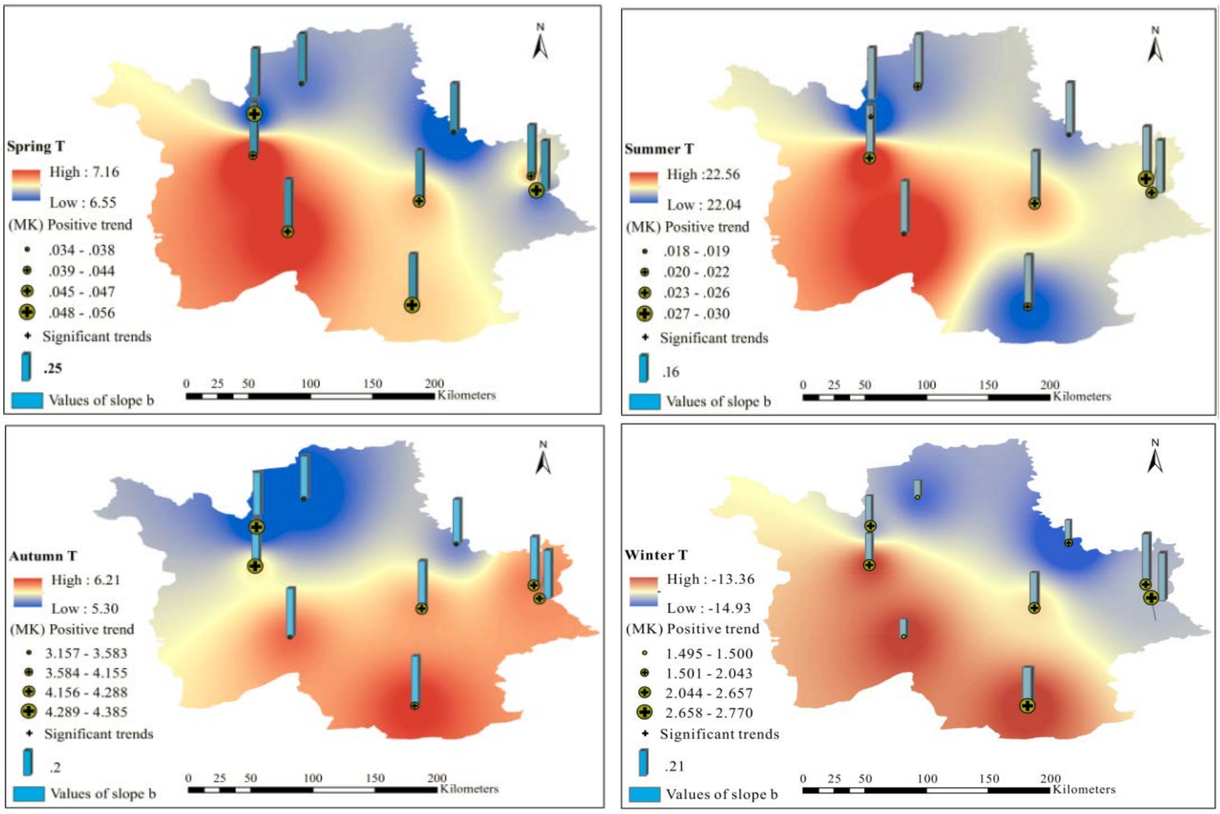

Figure 2. Spatial variation characteristics of seasonal temperature in WJL

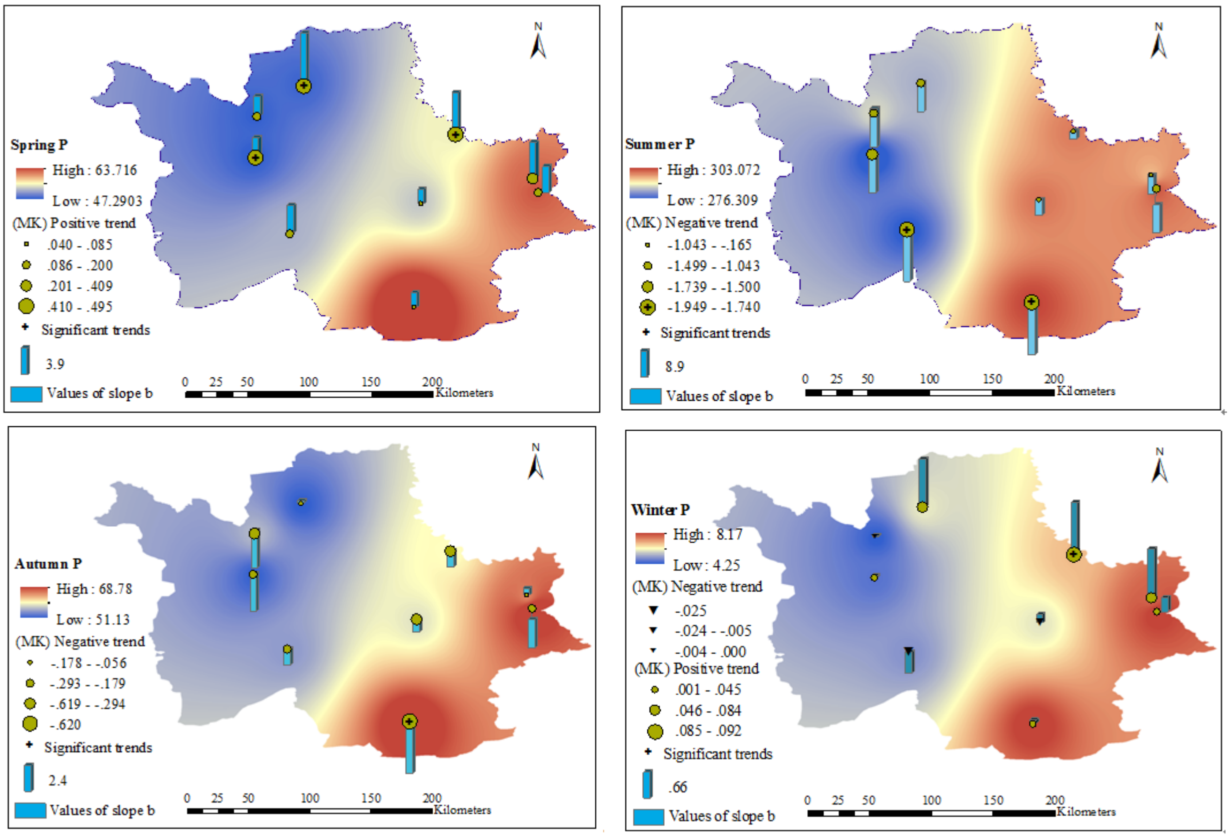

Figure 3. Spatial variation characteristics of seasonal precipitation in WJL

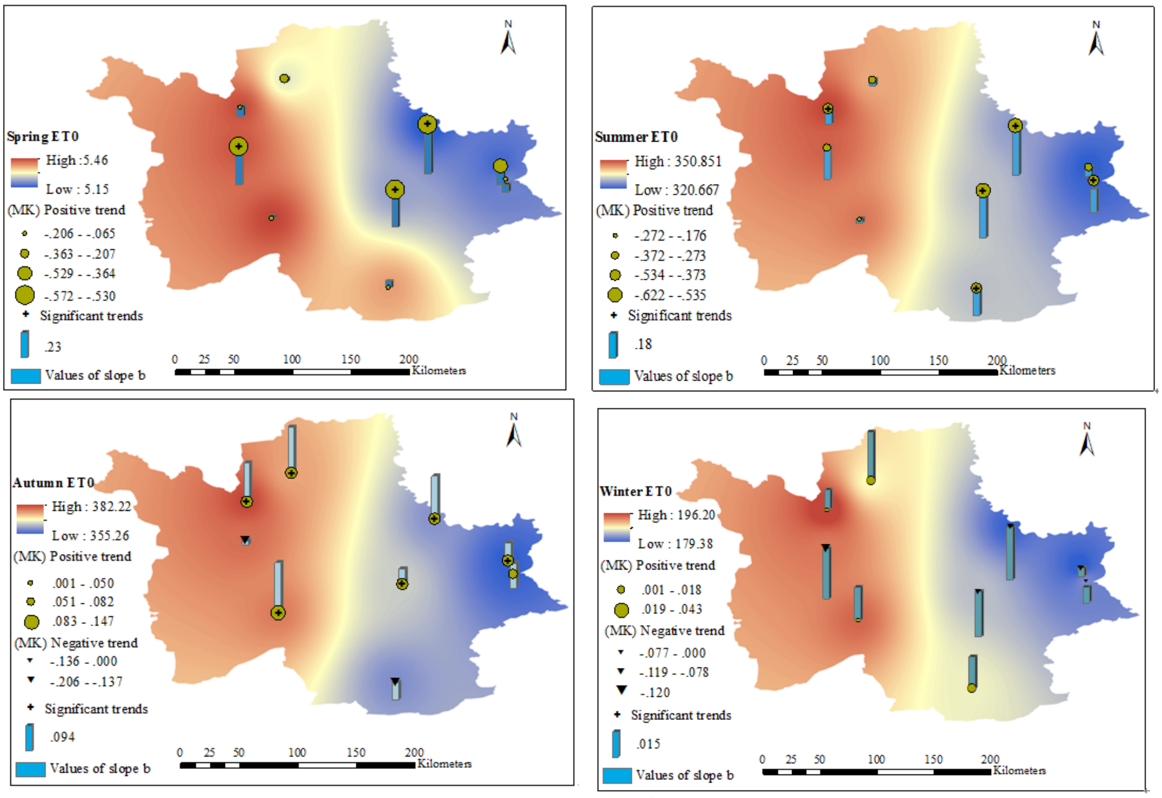

Figure 4. Spatial variation characteristics of seasonal evaporation in WJL

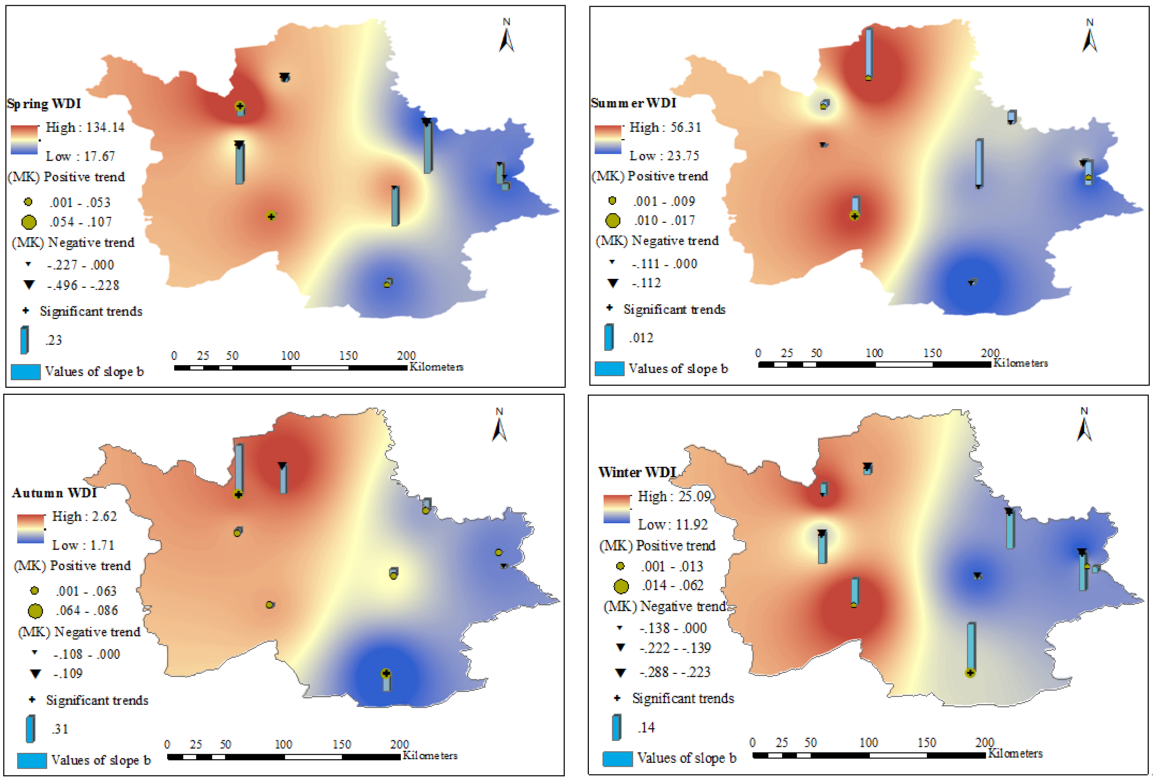

Figure 5. Spatial variation characteristics of seasonal wet-dry index in WJL

3.3 Relationships of wetland landscape with climate change

3.3.1 Sub-watersheds delineation

Considering the different water sources of wetlands, the wetland change analysis was based on hydrological units. A 1:50000 scale DEM of WJL was used for watershed delineation. Then the sub-watersheds were merged according to different water supply resources. So the different hydrological connectivity regions were determined (Fig. 6).

Table 3. Correlations of wetland landscape indexes and climate factors

Region	Index	P	T	ET_0	DWI
I	Msi	-0.944**(summer)	0.870*(annual)	-	0.872*(autumn)
	Mpfd	-0.819*(summer)	0.870*(annual)	-	0.837*(winter)
	Mps	-	-0.920**(spring)	-	-
	Nump	-	0.954**(spring)	0.832*(spring)	-
II	Msi	-0.964**(summer) -0.864*(autumn)	-	0.902*(winter)	0.988**(autumn)
	Mpfd	-0.895*(summer) -0.950**(autumn)	-	-	-
	Mps	0.880*(summer)	-	-	-
III	Msi	-0.882*(summer)	-	-	-
	Mpfd	-0.888*(summer)	-	-	-
	Mps	-	-	-	-0.838*(summer)
	Nump	-	-	-	0.824*(summer)
IV	Msi	-0.947**(summer)	-	0.870*(summer)	-
	Mpfd	-0.860*(spring)	-	-	-
	Nump		-	-	0.834*(annual)
V	Mps	0.879*(summer)	-	-	-
	Nump	-0.947*(summer)	-	-	-
VI	Msi	-	-	0.930**(summer)	0.937**(autumn)
	Mpfd	-	-	0.888*(summer)	-
	Mps	-0.852*(spring)	-	-0.850*	-
	Nump	-	-	0.866*	-
VII	Mps	0.883*(summer) 0.814*(autumn)	-	-0.814*(winter) -0.834*(autumn)	-0.812*(spring) -0.827*(winter)

7 sub-watersheds were delineated in WJ. The main water sources were Taoer River (II, III), Huolin River (IV), Nenjiang River (I, VI, V), Songhua River (VII). The wetland landscape indexes were calculated in each region, and the value of climate parameters were determined by the adjacent weather stations.

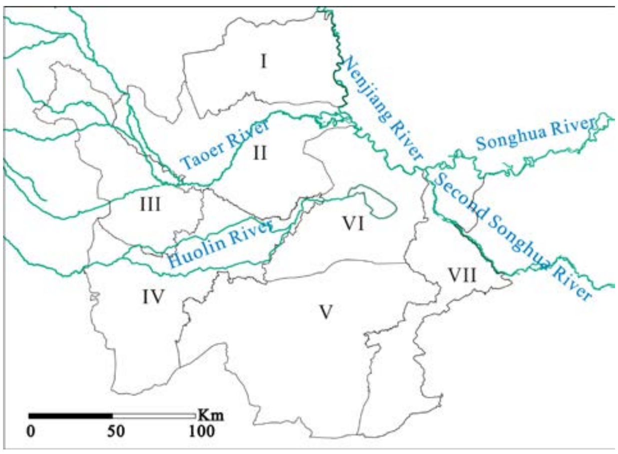

Figure 6. Hydrological connected regions in WJ

3.3.2 Correlation analysis of wetland landscape and climate change

The correlation analysis results of wetland landscape indexes Mean Shape Index (Msi), No. of Patches (Nump), Mean Patch Size (Mps), Mean Patch Fractal Dimension (Mpfd) and climate factors (annual and seasonal P, T, ET_0, DWI) in different regions were listed in table 3.

From table 3, Msi and Mpfd in all regions except V, VI and VII were significantly associated with summer precipitation. And the significance level of Msi and summer P in I, II and IV located in the west of WJL reached 99%. This indicated that the average patch fragment degree of western wetlands was significantly influence by summer precipitation. According to the temporal and spatial trend analysis results of climate factors, the western regions of WJL became drier and warmer with decrease of precipitation, increase of ET_0 and T, which resulted in shortage of water resources and the fragment of wetlands. So How to deal with the reduced summer precipitation had significance for the protection of wetlands. The Mps of V and VI also had significant relation with summer P, which indicated that the decreased summer precipitation also leaded to smaller average patch area of wetlands.

It was also indicated that wetland landscape indexes in most regions were influenced by multiple climate factors. The Msi in region II was significantly associated with summer and autumn precipitation, autumn WDI and winter ET_0. Mps of VII was significantly influenced by spring DWI, summer P, autumn P, autumn ET_0, winter ET_0, winter DWI. However, the wetland indexes in III, IV, V region were only related to one or two climate factors, and the significant level was mainly at 95%, which illustrated that variation ofwetlands in these regions was complex, not just of climate change.

4. CONCLUSION

In the recent 54 years, the annual mean of the temperature and dry-wet index in WJL showed an upward trend at an average rate of 0.34℃/10a and 0.14 /10a, respectively. The annual precipitation and potential evapotranspiration showed a declining trend, at a rate of -7.92 mm/10a and -3.4 mm/10a, respectively. But only the annual mean of the temperature showed significant trend at 99% significance level for all stations.

For seasonal variation of climate elements, the average temperature in the four seasons appeared a rising trend. The average temperature in spring had the largest increase and in summer has the smallest increase. The average of the seasonal precipitation showed an increasing trend in spring, and a downward trend in summer and autumn. The average precipitation in summer decreased most rapidly. The average evapotranspiration in spring and summer had a decreasing trend, and an increasing trend in autumn. There was not consistent trend for seasonal DWI.

The spatial distribution of annual and seasonal climate factors indicated that a significant drier trend occurred in west WJL, especially in the summer and autumn.

The wetland landscape indexes in most regions were significantly related to summer precipitation. Especially in I, II and IV regions located in the west of WJL. It needs greater attention and more drastic measures from the government to counter the decline of summer precipitation in western WJL.

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