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Characteristics of regional climate change and pattern analysis on Ordos Plateau

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Abstract: The characteristics of precipitation, temperature and their combination determine the special ecological environment pattern of Ordos Plateau. Analyzing its evolutionary trend attributes to understanding the succession process of the ecological environment of Ordos Plateau and has crucial instructional significance on the ecological restoration research being conducted in this region. Four time scales, arranging from ten days, one month, one season (growing season contrasting to non-growing season) to one year were adopted to analyze the climate data which included nearly 30 years and were collected by eight weather stations on Ordos Plateau. The results indicated that the mean annual temperature and the mean monthly temperature of February, September and December, had increased significantly during the late 30 years. The annual precipitation did not show significant changes but its distribution pattern had changed obviously. The ratio of precipitation of major growing season (May-October) to annual precipitation had increased distinctively, and five counties' precipitation reached statistically significant level. And the ratio of precipitation of latter growing season (September) to one year decreased significantly while the ratio of non-growing season (November-next April) to one year changed insignificantly. The results showed that maybe the interaction of increased mean temperature and insignificant change of precipitation in non-growing season was one of the reasons why the desertification of the region was deteriorating in recent years. Using some factors closely relating to vegetation succession such as mean annual temperature, mean annual precipitation, distributive pattern of precipitation, mean temperature of the coldest month, mean temperature of the warmest month, precipitation of the warmest month, mean temperature of growing season, precipitation of growing season, potential evapotranspiration (PET) and radiative dryness index (RDI), to synthetically analyze the climate characteristics of Ordos Plateau. The regionalized Ordos Plateau to three synthetical climate types were recognized as follows: Type I, semi-humid and low evaporation (including Jungar Banner, Dongsheng City and Ejin Horo Banner), Type II, semi-arid, semi-humid and moderate evaporation (including Uxin Banner and Dalad Banner), Type III, arid and high evaporation (including Hanggin Banner, Otog Banner and Otog Qian Banner).

Keywords: climate change; climatic synthetical regionalization; restoration ecology; Ordos Plateau

Introduction

Ordos Plateau lies in the southwest of Inner Mongolia and belongs to a multi-player and complicated ecogeographical transition zone, namely, it is a transition zone of atmosphere circle, climate, geology and geography, vegetation and natural belt, biota, industry and culture. Its eco-environment is very frail and sensitive (Zhang, 1994). Ordos Plateau had ever been a fine pasture with plenty of water and grass as well as huge potential productivity. But its topographical structure is very special and the land is subject to desertification (Zeng, 1985). Over past 2000 years especially the recent 50 years, climate change, irrational cultivation of wasteland and overgrazing resulted in severe desertification, so Ordos Plateau has been one of main sources of sand dirt in northern China. At present, this region is the largest resource base of high quality dynamic coal in China (Guo, 1994) and exploitation of diggings is giving rise to more severe environmental problem. Therefore, it is urgent to combat desertification and restore its degraded ecosystem.

Desertification and degradation of ecosystem appear to be natural phenomena, but in fact, they are social economic problems. In recent 20 years, some process has been obtained in combating desertification but the condition is getting worse on the whole, for climate, natural condition and social economy had not been taken into account as a whole during the arrangement and plan. So we attempted to analyze the climate, natural condition and social economy of Ordos Plateau integrally to arrange the project of social economic development and combating desertification, sequentially to improve the sustainable management of

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combating desertification. This article is one part of the study.

According to natural condition, precipitation of Ordos Plateau has significant change from east to west but the change of temperature is small. Therefore, it is especially important to process regionalization of climate types and regionalize ecological economic function of Ordos Plateau, combining the development trend of social economy, so that synthetic combating desertification can be done in different patterns.

There is much literature about analysis of particularity of climate factors or climate regionalization (Woodward, 1978; Qiu, 1987; Box, 1995; Ci, 1994). And much literature of the effect of climate on ecosystem is available too(Brown, 1997; Inouye, 2000; Menzel, 1999). But the related literature about synthetic study of Ordos Plateau climate is rarely seen. We applied four time scales, ranging from ten days, one month, one season (growing season contrasting to non-growing season) to one year, analyzing about 30 years' climate data collected by eight weather stations on Ordos Plateau. Combining the analysis of climate data with precipitation pattern brought forward in this article, we processed the climate regionalization to provide basis of climatic change analysis for synthetic arrangement of ecological economy and restoration of degraded ecosystem on Ordos Plateau.

1 Physical geography and ecological characteristics

Ordos Plateau in 37°35′24″N—40°51′40″N, 106°42′40″E- 111°27′40″E, extends from east to west, about 400 km long, from south to north about 340 km. Its terrain shows a belt geomorphological structure, which presents an extension from east to west and alternation from south to north. There are four geomorphological belts from south to north, MUS plain covered sand→Jungar, Dongsheng hills and high plain→Hobq sandy belt (desert and sandy land)→plain along the Yellow River, and eight geographical belts from east to west, the Yellow River canyon→Jungar loess hills→Dongsheng and Jungar hills covered sand→Dongsheng eroded hills→Hanggin high plain→low hills in front of Zhuozi Mountain→eroded middle and low Zhuozi Mountain→low hills in front of Zhuozi Mountain→sloped plain in front of Zhuozi Mountain →alluvial and diluvial plain geomorphological belt along the Yellow River (the sub-team of Yikezhao League of applied remote research team of Inner Mongolia rangeland resource, 1990). More detailed natural condition can be obtained from related literature (Zhang, 1994).

2 Study methods

We applied about 30 years' climate data of eight weather stations to analyze temperature, precipitation and the related indices: mean temperature change of ten days, one month, one season (growing season contrasting non-growing season) and one year, precipitation change of ten days, one month, one season (growing season contrasting non-growing season) and one year and the ratio of precipitation of each time scale to annual precipitation (defined as distributive pattern of precipitation in this article).

According to experiential equation, we applied biological temperature (BT) and annual precipitation (P) to count potential evapotranspiration (PER), and radiative dryness index (RDI).

And we applied the related indices close to plant growth to process synthetically climate regionalization in tree clustering analysis method provided by STATISTIC software, these indices include annual precipitation, mean annual temperature, mean temperature of warmest month, mean temperature of coldest month, precipitation of warmest month, variance coefficient of annual precipitation, mean temperature of growing season, distributive pattern of precipitation, PER and RDI.

3 Result analysis

Using methods above, we analyzed the data, from 1971—1998, of weather stations in seven banners and one city on Ordos Plateau.

3.1 Change of the temperature

3.1.1 Changes of each ten-day period(Table 1)

In Table 1, only the mean temperature of each ten-day period of Jungar Banner(the first ten-day period of August), Uxin Banner (the second ten-day period of August), Dalad Banner(the second ten-day period of January)and Hanggin Banner(the first and third ten-day period of August)showed significantly decreased trends and others showed significantly increased trends or no significant changes. Each ten-day period of August is the period when plants grow most actively on Ordos Plateau, from which we can conclude that the low temperature of this period is disadvantageous for growth and restoration of vegetation. The higher temperature of each ten-day period from October to March of next year was, moreover, aggravating the dryness of winter and spring of Ordos Plateau, which was also adverse to vegetation restoration and should be paid more attention to.

Table 1 List of each ten-day period with significant changes of mean temperature of eight weather stations

Station	Dongsheng	Jungar	Ejin Horo	Uxin	Dalad	Hanggin	Otog	Otog Qian
M of Jan.					↘**			
L of Jan.					↗*		↗*	
F of Feb.				↗*	↗*			
M of Feb.				↗*	↗*			
M of Mar.			↗*					
L of Jun.								↗*
F of Jul.	↗*		↗*				↗*	
F of Aug.		↘*		↘*		↘*		
L of Aug.	↗*		↗*			↘*		
F of Sep.								↗*
M of Oct.							↗*	
M of Dec.				↗*			↗*	
L of Dec.			↗*	↗*	↗*		↗*	

Note: F = former, M = middle, L = latter. The arrow "↗" represents the ascending trend of mean temperature and the arrow "↘" represents the down trend of mean temperature . The asterisk(*)stands for the significant level of the changes of the mean temperature(* $P < 0.05$, ** $P < 0.01$). And the unmarked show that the mean temperature changes of the period of the weather station had not reached the regressive significance

3.1.2 Changes of mean monthly temperature

The results regarding month as a time scale can be available from Table 2. Except in Otog Banner, the mean monthly temperature of February, September and December in most other banners significantly increased but other months' had no significant changes. Since September is the late growing period on Ordos Plateau and February and December are in winter, the ascending of temperature of these three months may aggravate the dryness of soil and air in early spring and be disadvantageous for vegetation restoration of spring. It may be one of the reasons that desertification had been aggravating in recent years.

Table 2 List of each month that the changes of monthly mean temperature had reached significant level in eight weather stations

Station	Dongsheng	Jungar	Ejin Horo	Uxin	Dalad	Hanggin	Otog	Otog Qian
Feb.	↗*	↗*	↗*	↗*	↗*	↗*	↗*	
Sep.	↗*		↗*	↗*			↗*	
Dec.	↗**		↗*	↗**	↗**	↗**	↗**	

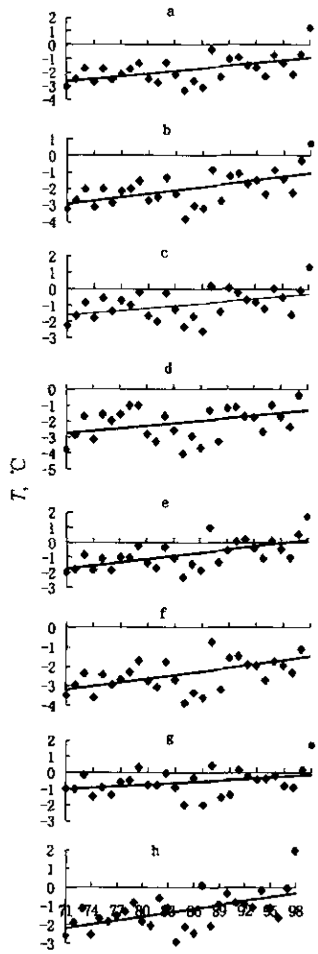
Notes: The arrow "↗" represents the ascending trend of the changes of monthly mean temperature. The asterisk stands for the significant level of the changes of monthly mean temperature(* $P < 0.05$, ** $P < 0.01$). The unmarked show that the changes of the monthly mean temperature of the station had not reached the regressive significance

3.1.3 Changes of mean seasonal temperature

Mean temperature of growing season(May—September)in eight weather stations showed a more or less increased trend. However, most of them, except Otog and Ejin Horo banner, did not reach the significant level, which indicated that the mean temperature of growing season had no significant change(Table 3). But the mean temperature of non-growing season contrasting growing season (October—next April) had increased significantly(Fig. 1).

Table 3 Trend of mean temperature of major growing season in eight weather stations

Station	Dongsheng	Jungar	Ejin Horo	Dalad	Uxin	Hanggin	Otog	Otog Qian
P	0.16	0.466	0.05	0.098	0.758	0.094	0.031	0.07



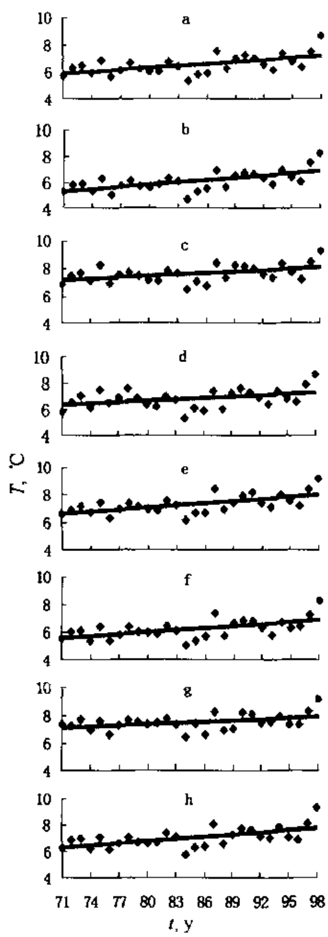


Fig.1 Fig. 1 The mean temperature of ungrowing season
a. Ejin Horo Banner, $P = 0.004$; b. Dongsheng City, $P = 0.002$; c. Zhunge'er Banner, $P = 0.019$; d. Dalad Banner, $P = 0.036$; e. Wushen Banner, $P = 0.001$, f. Hanggin Banner, $P = 0.003$; g. Otog Qian Banner, $P = 0.066$; h. Otog Banner, $P = 0.001$

Fig.2 The mean annual temperature
a. Ejin Horo Banner, $P = 0.002$; b. Dongsheng City, $P = 0.001$; c. Jungar Banner, $P = 0.022$; d. Dalad Banner, $P = 0.046$; e. Wushen Banner, $P = 0.001$, f. Hanggin banner, $P = 0.005$; g. Otog Qian Banner, $P = 0.03$; h. Otog Banner, $P = 0.001$

3.1.4 Changes of mean annual temperature

The changes of mean annual temperature were significant and the mean annual temperature of eight stations all showed significant increased trend. The mean annual temperature increased significantly but the mean temperature of growing season had no significant change and the mean temperature of non-growing season had increased significantly, which was coincident with the result that Ci Longjun(Ci, 1994) had obtained in the study of climate change of Chinese arid region. That is to say, mean annual temperature had increased especially in winter but increased inapparently in summer(Fig. 2).

3.2 Changes of precipitation

3.2.1 Changes of each ten-day period precipitation

The changes of most each ten-day period precipitation were not significant but the mean precipitation of some ten-day periods in January and September of most stations decreased significantly, which showed that precipitation of each ten-day period in the late growing season and winter decreased, so it was very difficult to maintain soil moisture of the next year(Table 4).

Table 4 List of each ten-day period with significant changes in mean precipitation, of eight stations

Station	Dongsheng	Jungar	Ejin Horo	Uxin	Dalad	Hanggin	Otog	Otog Qian
M of Jan.						↘*		
L of Jan.			↘*	↘*	↘*	↘*	↘*	
F of Mar.						↘*		
F of Apr.						↘*	↘*	
L of Jun.								↘*
M of Jul.				↘*			↘*	
F of Sep.								↘*
M of Sep.	↘*	↘*		↘*			↘*	
L of Sep.				↘*				
F of Dec.						↘*		

Notes: F = former, M = middle, L = latter. The arrow of "↘" represents the downtrend of the changes of each ten-day period precipitation. The asterisk stands for the significant level of the changes of each ten-day period precipitation(* $P < 0.05$). The unmarked show that the changes of each ten-day period precipitation of the station had not reached the regressive significance

3.2.2 Changes of monthly precipitation

The changes of precipitation of September were most significant, with significant decrease in seven stations, while precipitation of January decreased significantly in four weather stations(Table 5).

Table 5 List of each month, with significant changes of monthly precipitation of eight weather stations

Station	Dongsheng	Jungar	Ejin Horo	Dalad	Uxin	Hanggin	Otog	Otog Qian
Jan.	↘*		↘*			↘**		
Sep.	↘*	↘*	↘**		↘*	↘	↘**	↘*

Notes: The arrow of "↘" for the downtrend of the changes of monthly precipitation. The asterisk stands for the significant level of the changes of monthly precipitation(* $P < 0.05$, ** $P < 0.01$). The unmarked show that the changes of the monthly precipitation of the station had not reached the regressive significance

3.2.3 Change of seasonal precipitation

Through our analysis result, it could be known that the changes of precipitation of growing and non-growing season showed increase or decrease on trend line, but their changes had not reached the statistically significant level. The result showed that, adopting growing and non-growing season as the time scale, precipitation of this region increased or decreased indistinctively with time going.

3.2.4 Changes of annual precipitation

Annual precipitation of all eight stations had no significant changes. Considering the condition that total precipitation of one year had no significant changes but precipitation of specific months had, our results showed distributive pattern of precipitation changed. It was necessary to discuss the distributive pattern of precipitation because changes of distributive pattern of precipitation had an important effect on ecosystem, especially in arid and semi-arid region.

3.3 Change of distributive pattern of precipitation

Although the effect of precipitation on specific ecosystems is important, the effect of distribution of precipitation in different period on structures and functions of ecosystems is more important. Distribution of precipitation may change the effect of ecosystems on environment and affect the rhyme of change in ecosystems. So, to discuss the distributive law of precipitation had more important ecological significance under condition that total annual precipitation did not change. In this article, distributive pattern of precipitation was defined as: in specific interval, the ratio of precipitation of different period to annual precipitation, namely, distributive pattern of total precipitation in different period.

3.3.1 Distributive pattern of each ten-day period precipitation

Its law was similar to the law of change of precipitation in most ten-day periods. But distribution of precipitation of some ten-day periods of February and September in most stations decreased significantly, which showed both absolute precipitation of each ten-day period and ratio of each ten-day precipitation to annual precipitation of the two months decreased significantly (Table 6).

Table 6 List of each ten-day period, during which significant changes of its precipitation ratio to annual precipitation appeared of eight weather stations

Station	Dongsheng	Jungar	Ejin Horo	Dalad	Uxin	Hanggin	Otog	Otog Qian
F of Jan.						↘*		
L of Jan.			↘*	↘*	↘*	↘*	↘*	
F of Mar.								
F of Apr.						↘*	↗**	
L of Jun.								↘*
M of Jul.			↘*				↗*	
F of Sep.					↘*			↘*
M of Sep.	↘*	↘**	↘**	↘**		↘*		
L of Sep.			↘*					
F of Dec.						↘*		
L of Dec.					↘*			

Notes: F = former, M = middle, L = latter. The arrow "↗" represents the increasing trend and the arrow "↘" represents the downtrend of the changes of ratio of each ten-day precipitation to annual precipitation. The asterisk stands for the significant level that the changes had reached(* $P < 0.05$, ** $P < 0.01$). The unmarked show that the ratio changes of the period of the station had not reached the regressive significance

3.3.2 Distribution of monthly precipitation

The ratio of precipitation of September to annual precipitation of each station had significant downtrend. And the ratio of February to one year at Hanggin Banner, Dongsheng City, Ejin Horo Banner and Uxin Banner had also showed significant downtrend. But distribution of precipitation of other months did not change significantly(Table 7).

Table 7 List of the trend of changes, which is the precipitation ratio of January and September to one year

Station	Dongsheng	Jungar	Ejin Horo	Uxin	Dalad	Hanggin	Otog	Otog Qian
Jan.	↘*		↘*	↘*		↘*		
Sep.	↘**	↘**	↘**	↘**	↘*	↘*	↘**	↘**

Notes: The arrow "↘" represents the downtrend of the changes of the ratio of monthly precipitation to annual precipitation. The asterisk stands for the significant level of the changes(* $P < 0.05$, ** $P < 0.01$). The unmarked show that the changes of the ratio of monthly precipitation to annual precipitation had not reached the regressive significance

3.3.3 Distribution of seasonal precipitation

The ratio of growing season(May—September)precipitation to annual precipitation can be discussed in two parts. The first part is the one whose ratio of precipitation in major growing season (May—August)to annual precipitation had not reached the significant level but most of them showed increased on trend line. The second part is the one whose ratio of precipitation in September to annual precipitation had decreased significantly. See Fig. 3 and Table 7. The ratio of non-growing season(October—next April)precipitation to annual precipitation had no significant change.

3.4 Change of potential evapotranspiration(PET), potential evapotranspiration rate(*PER*) and radiative dryness(*RDI*)

Because *PET*, *PER* and RDI are the synthetic reflects of ecosystem to total environmental factors, they can present integral effect of climatic factors. And we analyzed their changes of present 30 years.

For many indices are needed to count the three indices and some of them cannot be obtained easily, we applied experimental equation (Zhou, 1994) to count these indices.

$RDI = (0.629 + 0.237PER - 0.00313PER^2)^2$.

Where, *RDI* is the radiative dryness and *PER* is the annual potential evapotranspiration rate.

$PER = PET/r = BT \times 58.93/r$.

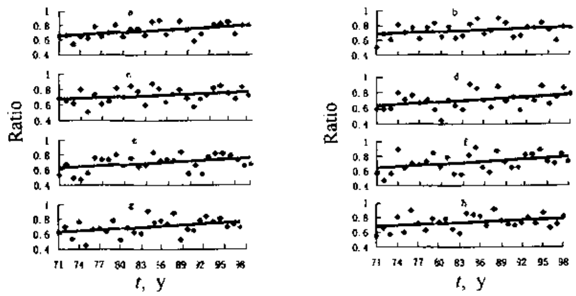


Fig.3 The ratio of precipitation of major growing season to annual precipitation

a. Ejin Horo Banner, $p = 0.006$, b. Dongsheng City, $p = 0.134$; c. Jungar Banner, $p = 0.114$; d. Dalad Banner, $p = 0.039$; e. Uxin Banner, $p = 0.038$; f. Hanggin Banner, $p = 0.042$; g. Otog Qian Banner, $p = 0.032$; h. Otog Banner, $p = 0.079$

Where, *PET* is the potential evapotranspiration(mm), *BT* is the mean annual biological temperature (℃) and *r* is the annual precipitation(mm).

$$BT = \sum t/365 = \sum T/12.$$

Where, *t* is the mean daily temperature($0℃ < t < 30℃$) and *T* is the mean monthly temperature($0℃ < T < 30℃$).

PET showed significantly increased trend in all stations except Dalad and Jungar Banner(Table 8), which showed that climate had some dry trend under condition that annual precipitation had no significant increase.

The changes of *PER* and *RDI* of eight stations had not reached significant level but all showed increased trend.

Table 8 Trend of potential evapotranspiration of eight stations

Station	Dongsheng	Jungar	Ejin Horo	Uxin	Dalad	Hanggin	Otog	Otog Qian
P	0.002	0.122	0.006	0.01	0.065	0.007	0.009	0.046

4 Synthetic climate regionalization of Ordos Plateau

We applied many indices, closely relating to plants growth, to process climatic regionalization on Ordos Plateau synthetically. The factors were annual precipitation, mean annual temperature, mean temperature of the warmest month, mean temperature of the coldest month, precipitation of the warmest month, coefficient of variation of annual precipitation, mean temperature of growing season, precipitation of growing season, distribution of precipitation, potential evapotranspiration and radiative dryness.

Fig. 4 indicated that the eight counties can be divided into three climatic types. Type I is the semi-humid and the low evaporation type including Jungar Banner, Dongsheng City and Ejin Horo Banner. Type II is the semi-arid, semi-humid and moderate evaporation including Uxin and Dalad Banner. Type III is the arider and high evaporation including Hanggin, Otog and Otog Qian Banner.

Although, Dongsheng City is the semi-humid and the low evaporation type, it is the capital of Ih ju League. It suits to develop industry and commerce and to reinforce political and cultural function. Dongsheng City should be the center of politics, culture, industry, commerce and protected agriculture of whole league.

The condition in Jungar Banner is relatively better, but it lies in transition region between Loess Plateau and sandy land. Loess hills with severe erosion of water and soil is the major terrain of this banner. So the banner should develop into loess hills agro-pastoral base that combines agriculture with animal husbandry.

Ejin Horo Banner's climatic condition is better, but it ought to be sandy land agro-pastoral base combining agriculture with animal husbandry, for its location is in MUS sandy land.

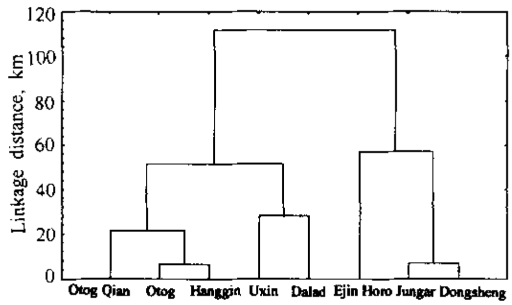


Fig.4 Tree diagram for synthetical climate division of the Ihju League

Dalad Banner has special condition to develop agriculture because its climatic condition is moderate and it lies near the Yellow River. And it is also an important line of communications and should be the base of special agriculture and the information base of commerce and communication service.

Uxin Banner's climatic condition is moderate and it lies in the middle of MUS sandy land. It is suit for becoming sandy land agro-pastoral base .

The natural condition of the third type(including Hanggin, Otog and Otog Qian Banner) is severe and water resource is limited. So they suit to make full use of advantage of sandy land and grassland to establish the animal husbandry base and become the base of stock production of whole league.

5 Discussion

Desertification was resulted from the interaction of human activities and climatic factors. We only provided the base of climatic change trend for ecological restoration and combating desertification on Ordos Plateau in this article.

On the effect of global warming, the climate of Ordos Plateau, locating the sensitive zone of Chinese land ecosystem that responds to global change, had a warmer trend. The increase of mean annual temperature and mean non-growing season temperature had reached statistically significant level. And the mean temperature increased more significantly in winter than in summer, especially in February, September and December.

Annual precipitation on Ordos Plateau had no significant change but the distributive pattern of precipitation had changed significantly. The precipitation in September decreased significantly and precipitation in January showed a decreased trend. The total precipitation of major growing season(from May to August) showed increase and five counties' had reached statistically significant level. Although precipitation of non-growing season showed decrease, it did not reach the significant level. The effect of change of distributive pattern of precipitation on ecosystem is huge. Although increased precipitation of growing season is advantageous for vegetation restoration and increase of biological production, the interaction between no significant change of precipitation during non-growing season and increased temperature had imposed a grievous effect on severely degraded ecosystem of Ordos Plateau. To decide the final result of interaction of both, further study is needed.

Distributive pattern of precipitation proposed in this article is an important idea. From our analysis, the change of distributive pattern of precipitation can have huge effect on ecosystem even though total precipitation had not changed significantly. We were not able to discuss the distributive pattern of precipitation in small time scale and precipitation form because of lacking of more detailed data. Precipitation is limited in arid and semi-arid region, so precipitation forms become the important factor for vegetation growth. Both different precipitation forms, such as heavy rain, moderate rain, slight rain or drizzle, and the weather process after rain will have different effect on efficiency of rain. It is more important to analyze such distributive pattern of precipitation than to analyze total precipitation only. So it is significantly important to discuss the form and distributive pattern of precipitation.

The analysis of *PET* of this region showed that *PET* of the region had increased significantly. But it is the actual evapotranspiration that affects the water need in a region. The actual evapotranspiration has close relation to precipitation of each time, the lasting time of rain, soil water content and vegetation etc. To know the actual evapotranspiration exactly, both detailed data and further research are needed. *RDI* may affect the plant climatic production of this region and affect plant biomass sequentially. Then, biomass can affect the change of biodiversity (Naeem, 1994). The increase or decrease of biomass can reflect the vegetation change of this region directly or indirectly. Although *RDI* had no significant change, it showed an increasing trend. Through the analysis above, we can know that mean annual temperature increased and annual precipitation had no significant change while the climate became drier, at least in non-growing season. So, this trend must be paid more attention to and we should not analyze the data from total annual quantity only.

The eight weather stations lie in different administrative areas and these areas were regarded as unit to collect climate data, thus we had to analyze the data according to the fact and we were not able to analyze data according to natural region. In fact, the project of vegetation restoration will be processed in different administrative areas. Although the result regarding the administrative area as unit was not fine, it can be done practically. The result of climatic regionalization in this article was coarse, however, we considered not only climatic factors, but also the factual geology, geomorphology and vegetation of different areas when we processed the regionalization. Its aim was, combining the analysis of developing trend of social economy, to conduct functional division of ecological economy and propose orientation and division of regional economy of Ih Ju League in the future, so that the advantage of resource and conditions of each county can be taken of completely, which is advantageous to restore and reestablish the regional eco-environment. On the basis of rational division and orientation of social economy, according to the characteristics of different types, we can adopt different measures to accelerate the restoration process (Dobson, 1997) through restoring vegetation and ecology, and decide different types of vegetation cover and ecological landscape that should be restored and maintained finally (Swetnam, 1999). Only after these have been done that can the sustainable goal be obtained.

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