«Растительный мир Азиатской России», 2010, № 2(6), 88–95

УДК 581.524(510)

CLIMATE CHANGE AND POTENTIAL EFFECTS ON VEGETATION OF BORDERLAND AMONG SHAANXI AND GANSU PROVINCES, AND NINGXIA HUI AUTONOMOUS REGION

ИЗМЕНЕНИЕ КЛИМАТА И ЕГО ВОЗМОЖНОЕ ВЛИЯНИЕ НА РАСТИТЕЛЬНОСТЬ ГРАНИЧНЫХ ТЕРРИТОРИЙ МЕЖДУ ПРОВИНЦИЯМИ ШЕНЬСИ И ГАНЬСУ, А ТАКЖЕ НИНЬСЯ-ХУЭЙСКИМ АВТОНОМНЫМ РАЙОНОМ

J.H. DAI, M.M. WANG, H.J. WANG

Institute of Geographic Sciences and Natural Resources Research, CAS, 11A Datun Road, Beijing, 100101, China
Fax: +8 610 648–72–274; e-mail: daijh@igsnrr.ac.cn

Indices of temperature, precipitation and relative evapotranspiration (*RET*) for the last 51 years in the borderland between Shaanxi and Gansu Provinces, and Ningxia Hui Autonomous Region (BSGNAR) were calculated to analyze the climate change in this area. During the past 50 years, the average temperature increased significantly, while precipitation decreased slightly with regional differences. *RET* change was not so distinct in general, but had a minor increase at the late stage of the study period. Under such circumstances, climate change had clear effects on distribution of potential vegetation in the area, with a tendency to transit to warming and drying vegetation types.
Key words: borderland between Shaanxi-Gansu-Ningxia, climate change, relationship between climate and vegetation.

Для оценки изменений климата на территории между Провинциями Шааньси и Ганьсу, а также Нинся-Хуэйским автономным районом были рассчитаны показатели температуры, количества осадков и относительной эвапотранспирации за последний 51 год. Установлено, что за последние 50 лет значительно возросла средняя температура, тогда как количество осадков немного уменьшилось, хотя и с некоторыми региональными различиями. Изменения показателей *RET* в целом не были очень четкими, но они немного возросли на последней стадии изученного периода. В общем же, при таких условиях, изменения климата оказали отчетливое воздействие на распределение потенциальной растительности исследованного района, которое выразилось в трансформации ее в более термо- и ксерофитные типы.
Ключевые слова: граница между провинциями Шааньси, Ганьсу, Нинся, изменения климата, взаимоотношения между климатом и растительностью.

INTRODUCTION

Climate changes are very different for various regions in China, especially for loess plateau region, as its warming and drying trend are very pronounced (The compiling…, 2007), which may have very significant effects on regional ecosystem. The vegetation of this part is inside a typical ecotone in China, and thus, is more sensible to climate change (Allen et al., 1998). The study area located in borderland among Shaanxi-Gansu-Ningxia of the east part in Northwest China includes the west of Weibei, Longdong and the loess plateau in the south part of Ningxia. This region is the transition zone from semi-humid to semi-arid areas in West China, and also from warm-temperate deciduous broad-leaved forests through forest steppes to dry steppes (Wu, 1980). This region belongs to the west part of north China flora region with deserts in east of Central Asia, and steppes of Inner Mongolia to the east and central China flora region to the south (Wu, Wang, 1988; Wang, 1999).

MATERIALS AND METHODS

Meteorological Data

Considering the long length of data sequence and with few absent years, the data from 14 meteorological stations were selected (Fig. 1). The study period is 1958–2008, 51 years in total. Monthly mean temperature, monthly mean maximum temperature, monthly mean minimum temperature, monthly precipitation were calculated. In addition, mean relative humidity, wind speed and sunshine duration were adopted to calculate reference evaporation (*RET*).

Data Analysis Methods

The data in this study involved both temporal and spatial data series. Methods for temporal data series analysis and primary statistics included linear trend test, moving average method were used in the study; wavelet analysis was used to analyze the cycles of each environmental factors; and Mann-Kendall test was used to test if there was abrupt climate change, and if any, it was also used to decide the turning point (Wei, 2007). Besides, the method used for spatial data series was Kriging interpolation. Some specific numerical software and programming language were also used in the course of the analysis.

FAO Penman-Monteith Methods to estimate *RET*

In calculation of reference evapotranspiration (Allen et al., 1998), the reference surface was defined in FAO Penman-Monteith method as «a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23», and *RET* was estimated as the following:

$$RET = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)},$$

where, R_n — net radiation at the crop surface (MJ m^{-2}); G — soil heat flux density (MJ m^{-2}); T — mean daily air temperature at 2 m (°C); u_2 — wind speed at 2 m (m/s); e_s — saturation vapor pressure (kPa); e_a — actual vapor pressure (kPa); Δ — slope of the saturation vapor pressure curve at air temperature T (kPa °C^{-1}); γ — psychrometric constant (kPa °C^{-1}).

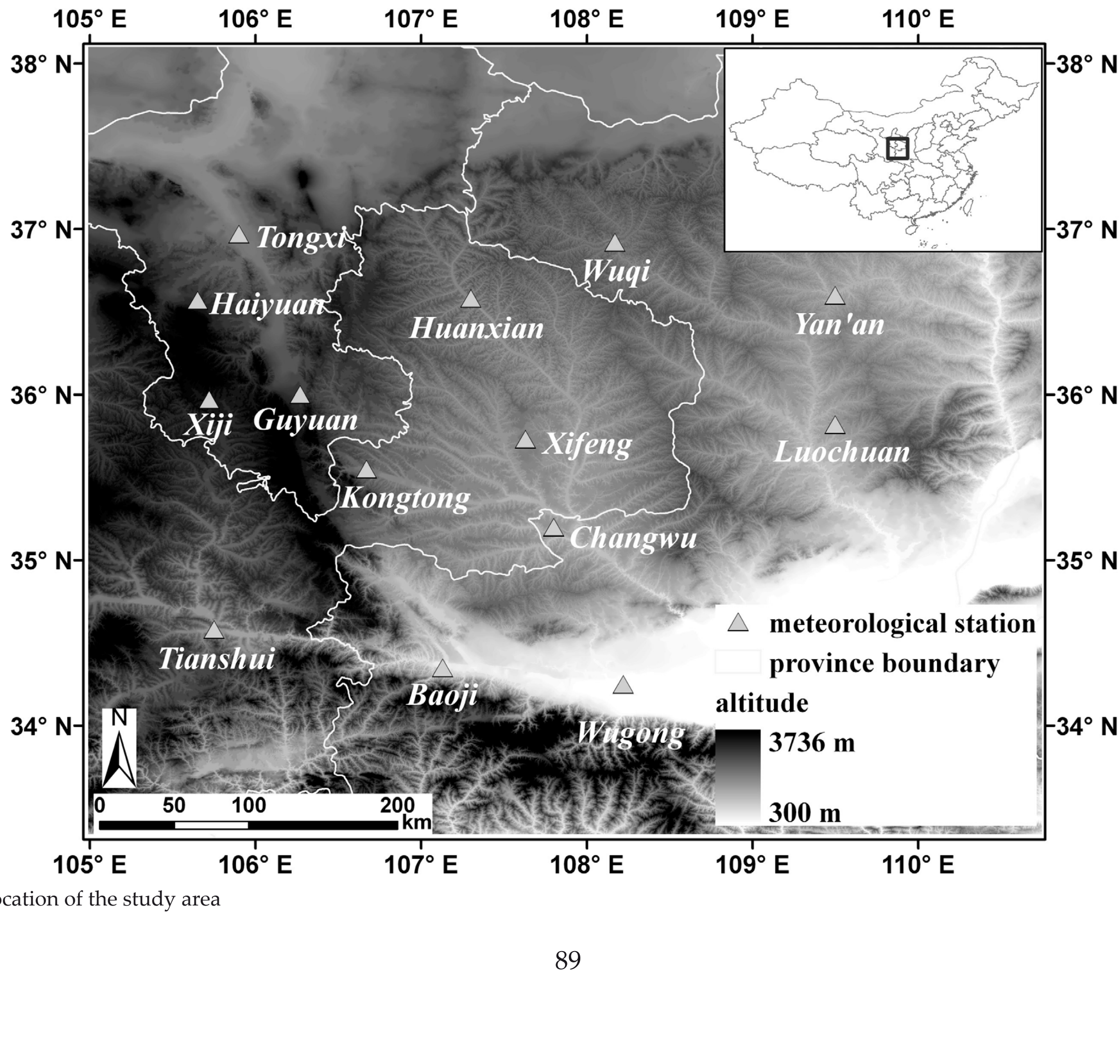

Fig. 1. Location of the study area

All the above parameter except R_n can be acquired from either the direct meteorological data or ordinary calculation (Allen et al., 1998).

The solar radiation, if not measured, can be calculated using the angstrom formula (Allen et al., 1998):

$$R_s = (a_x + b_s \frac{n}{N}) R_a,$$

where, R_s — solar or shortwave radiation (MJ m^{-2}); n — actual duration of sunshine (hour); N — maximum possible duration of sunshine or daylight hours (hour); n/N — relative sunshine duration; R_a — extraterrestrial radiation (MJ m^{-2}); a_s, b_s — regression constant.

In this study, the observations of n and R_s from seven stations were used to calibrate the Angstrom coefficients a_s and b_s. R_a and N were computed based on date and latitude (Allen et al., 1998). The regression equation was stable. Base on a_s and b_s from the seven stations, the a_s and b_s in other stations were acquired by Kriging. *RET* of each station was required based on the above calculation.

Quantitative Methods of Vegetation-Climate Relationship

Kira Vegetation-Climate Index (Kira, 1945) and Holdridgoe Life Zone (Holdridge, 1947, 1967) were used as the quantitative methods to study vegetation-climate relationship in this study. The classification indexes of Kira Tatuo were thermal index and humidity index (Kira, 1945). The thermal index contained warmth index (*WI*) and coldness index (*CI*), calculated by different temperature (*t*). The indexes were defined as follows:

$WI = \Sigma(t - 5)$, t is the average temperature above 5 °C;
$CI = -\Sigma(5 - t)$, t is the average temperature below 5 °C;
$K = P/(WI + 20)$, 0 °C ≤ WI ≤ 100 °C month;
$K = 2P/(WI + 140)$, WI > 100 °C month.

Where, *P* stands for precipitation. Besides, humidity index (*HI*) was advanced by W. Xu (1985) in his study of the relationship between vegetation and climate in China, and was well applied in the study of the grassland boundary in northeast China. It is defined as follows: $HI = P/WI$.

The Holdridge life zone classification using indicators of mean annual biotemperature (ABT), annual precipitation, and potential evapotranspiration ratio (*PER*) (Holdridge, 1947). The model is based on the three-dimensional construct with a logarithmic scale, and can show effects of evironment changes on vegetation.

In the model, *ABT* is calculated as the following: $ABT = {}^1/_{12}\Sigma t_i$, 0 °C ≤ t_i ≤ 30 °C; annual potential evapotranspiration (*APE*) is defined as $APE = 58.93\ ABT$ and potential evapotranspiration ratio (*PER*) is calculated as follows: $PER = APE/P$.

RESULTS

Regional Climate Change

Temperature change. Annual average temperature observed by the weather stations in the study area rose significantly. The obvious temperature rise began in mid-1980s, with average temperature in all 4 seasons rising at varying degrees. The temperature increased more significantly in winter and spring than in autumn and summer. The obvious temperature rise began quite earlier in winter than in the other seasons. Besides, the amplitude of temperature fluctuations in winter were significantly higher than in other seasons, indicating that temperatures in winter fluctuated very strongly.

The rise of average temperature for all the stations was 0.287 °C/10a. The annual average temperature of all the stations except Wuqi rose very significantly at 95 % confidence level. The rise of average temperature for all stations was 0.343 °C/10a in spring, 0.147 °C/10a in summer, 0.278 °C/10a in autumn, and 0.380 °C/10a in winter. The temperature rises in winter and spring were most significant. The temperature rise in autumn was less significant and only temperature rise in Wuqi and Changwu station was not statistically significant. The temperature rise in summer was the lest significant and results of temperature rise in five stations did not pass the significance test. As far as the spatial distribution of these stations are concerned, the temperature rise in northwest was more significant than southeast and there was a notable borderline to separate the two parts, namely Wuqi-Changwu-Baoji line.

The result of wavelet analysis shows that both annual and seasonal average temperature had a 16–17 years cycle. The temperature in spring was relatively stable, followed by summer and autumn. The temperature in winter was most fluctuant. Besides, there were also obvious 6–8 and 2–3 years cycles.

The result of mutation analysis shows that there were obvious upward trends of annual average temperature, temperature in winter and autumn after late 1980s. The temperature in spring and summer began to rise obviously later, almost in late 1990s. All the trends are statistically significant. The mutational points were the year 1994 for annual average temperature, the year 2000 for spring average temperature, the year 1997 for summer average temperature, the year 1989 for autumn and winter average temperature. Therefore, the sudden changes of temperature occurred the earliest in winter and autumn, followed by summer, and the latest was in spring.

Precipitation change. Precipitation did not change so significantly as temperature. However the annual precipitation decreased slightly in general. The precipitation changes in spring and autumn were relatively more significant than in winter and summer. The trend for annual precipitation decrease for all stations was 17.769 mm/10a, and the trends of precipitation change in spring, in summer, in autumn and in winter were –5.662, –3.912, –10.566 and 1.020 mm/10a respectively. The result of wavelet analysis shows that the annual precipitation had obvious 16–17, 6–7 and 2–3 years cycles. The cycles for precipitation changes in the four seasons of a year were different from each other during the study period, but three kind of cycles in all season were very clear, namely around 15 year, around 6 years, and 2–3 years cycles.

The result of time series analysis showed that the annual precipitation decreased in the past 51 years, but the trend was not statistically significant. Both precipitations in spring and summer did not pass the 0.05 significance test either, but statistically significant decreases of precipitation in autumn and winter were very clear. The abrupt change in winter occurred mid-1970s, and occured in autumn around 2000.

RET change. Seen from the spatial distribution of the *RET* trends, the *RET* increased significantly in Guyuan (12.345 mm/10a), in Yanan (10.747 mm/10a), in Kongtong (11.329 mm/10a), in Xifeng (13.281 mm/10a) and in Baoji (12.868 mm/10a). Only the *RET* in Wugong decreased with a –21.347 mm/10a trend. In general, the *RET* in the north of Changwu had relatively significant increasing trends, while the *RET* in the south of Changwu including Changwu did not have this trends or even with a decreasing trend. If *RET* increase while the precipitation decrease, the region will be drier, on the contrary, it will be more humid.

M-K test shows that there was no significant sudden change of *RET* in the study area during the recent 50 years.

Annual average temperature, precipitation and RET changes can be seen in Fig. 2.

Vegetation-Climate Relationship

According to the methods in 2.4, the Kira vegetation-climate index including *WI*, *CI*, *K* and *HI* for the 14 stations during the period 1971–2000 in the study area were acquired and interpolated spatially. The results were overlaid by vegetation zones (Fig. 3, 4). As far as distribution of *WI* is concerned, characteristics of environment in the study area is from warm temperate (*WI* is 85–180) in the southeast to cold temperate (*WI*

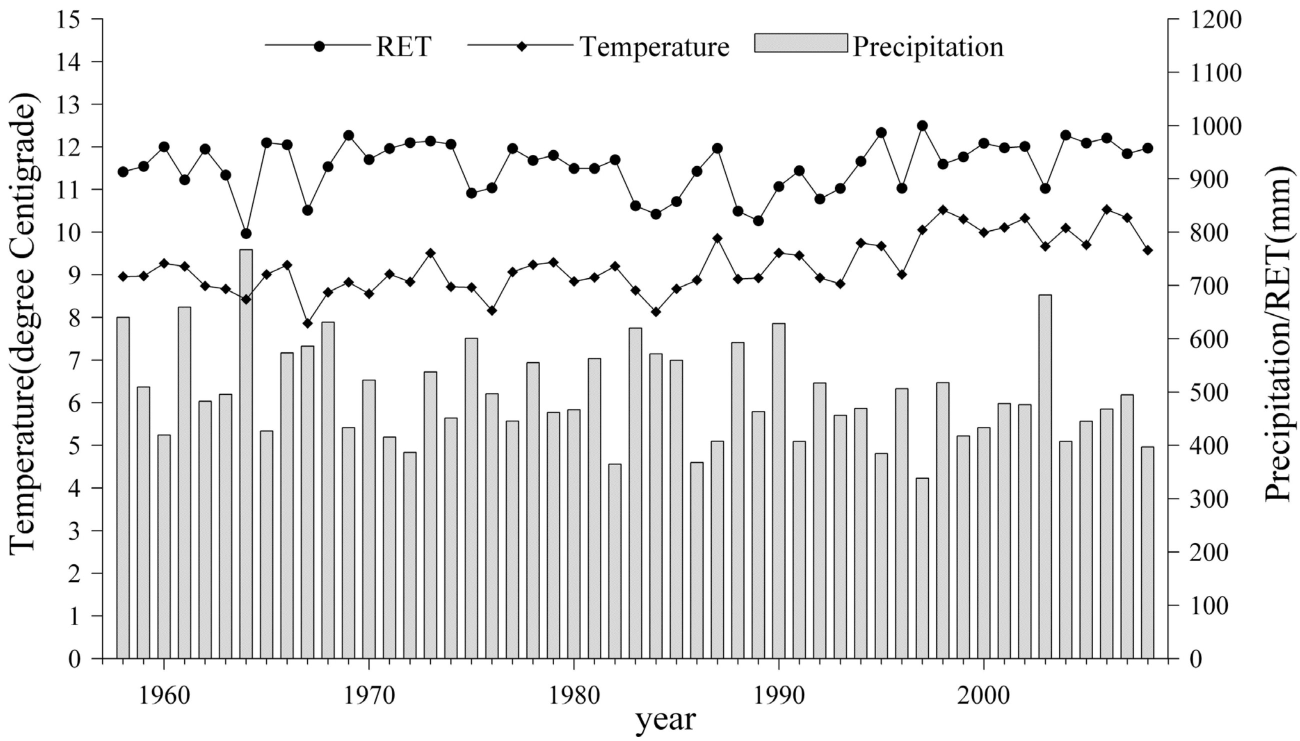

Fig. 2. Temperature, precipitation and RET changes in the study area

is 45–85) in the northwest (Wu et al., 2004). Similarly seen from the distribution of *K* value, the study area is form forest steppe (*K* is 5–7) in the southeast to typical steppe (*K* is 3–5) in the northwest (Wu et al., 2004). *WI* and *CI* were very suitable to divide deciduous oak forest in northern warm temperate and deciduous oak forest in southern warm temperate, *WI* value for the boundary of both types is at about 150 and 100 °C · month respectively. But in terms of classification of various steppe types, consideration of *WI* value is not so suitable, but adoption of *K* and *HI* was very effective (Fig. 3). It is noteworthy that located in south of Ningxia, affected by orographic uplifting, the region including Liupan Mountain, Jingyuan and Xiji is call «humid island» of loess plateau with high annual precipitation of 655.9, 599.4 and 414.4 mm respectively (Shi et al., 2005; Wang et al., 2005). *WI*, *CI*, *HI* and *K* value in this area had large differences from the nearby region at loess plateau. *K* value was at about 4.75 and *HI* at about 6.07 as for the boundary between deciduous oak forest in northern warm temperate and forest steppe in southern temperate, and *K* was about 4.60 and *HI* is about 5.85 as for the boundary between forest steppe in southern temperate and typical steppe in southern temperate. By comparison of the two variables, it is clear that *HI* was more sensitive to stand for the above two boundaries. Thus, as for the vegetation zones limited by temperature, *WI* and *CI* were more sensitive; while as for the vegetation zones limited by precipitation or both temperature and precipitation, *K* and *HI* are better to be used to classify different vegetation types. Particularly, *HI* is more applicable when analyze the relationship between vegetation and climate in the study area.

The trends for *WI*, *CI*, *K* and *HI* in the past 50 years were calculated (Fig. 4, 5). There was an obvious boundary line between eastern Gansu and the southwest. To the northwest of this line there was a clear increase of *WI*, but there were decreases of *CI*, *K* and *HI*. *WI* in the study area was increasing while *CI*, *K* and *HI* were decreasing from the whole aspect. It was inferred that the boundary between deciduous oak forest in northern warm temperate and deciduous oak forest in southern warm temperate has a northward trend while the boundaries between deciduous oak forest in northern warm temperate and forest steppe in southern temperate and between forest steppe in southern temperate and typical steppe in southern temperate have a westward and northward trend, and the latter will be more significantly.

According to the methods in 2.4, the Holdridge life zone index including *ABT*, *APE*, *P* and *PER* for the 14 stations were acquired and interpolated spatially. The results were overlaid by vegetation zones (Fig. 6). As for the boundary between forest and steppe (is deciduous oak forest in warm temperate and forest/typical steppe in southern temperate in the study area), *ABT* was 9–10 °C, *APE* was 550–600 mm, *P* was 425–450 mm and *PER* was 1.35–1.40. As for the boundary between deciduous oak forest in northern warm temperate and deciduous oak forest in southern warm temperate (was considered as humid forests and arid forests in Holdridge life zone), *ABT* was 10.5–11.0 °C, *APE* was 625–650 mm, and values for *P* and *PER* were hard to decide near this boundary. According to the theory of Holdridge life zone, the *PER* value for steppe and arid forests had the common interval, and *PER* was the indicator to distinguish them from humid forests, while the *P* value for humid forests and arid forests had the common interval, and *P* was the indicator to distinguish them from steppe. Taken into consideration of above analysis, the actual Holdridge life zones and vegetation zones in the study area, the above two boundaries were determined at 1.2–1.3 (*PER*) and 425–450 mm (*P*), showing difference from the ordinary boundaries in Holdridge life zone, and based on which, Holdridge life zone was modified regionally.

CONCLUSIONS AND DISCUSSION

Based on analysis of meteorological data from 14 stations in the past 51 years in the study area, the average temperature rise of all the stations was 0.287 °C/10a. The average temperature rise in winter (0.380 °C/10a) and spring (0.343 °C/10a) are the most obviously. The significant warming began in 1980s. From the spatial distribution, the temperature rise in northwest of the study area was more significant than southeast and there was a notable borderline, namely Wuqi-Changwu-Baoji line. The temperature in winter has high annual variability and is more unstable. Both annual and seasonal average temperature had a 16–17 years cycle. The temperature in spring was relatively stable, followed by summer and autumn. The temperature in winter was most fluctuant. Besides 16–17 years cycle, there were also obvious 6–8 and 2–3 years cycles for temperature change. The turning point were the year 1994 for average annual temperature, the year 2000 for average spring temperature, the year 1997 for average summer temperature, the year 1989 for average autumn and winter temperature respectively.

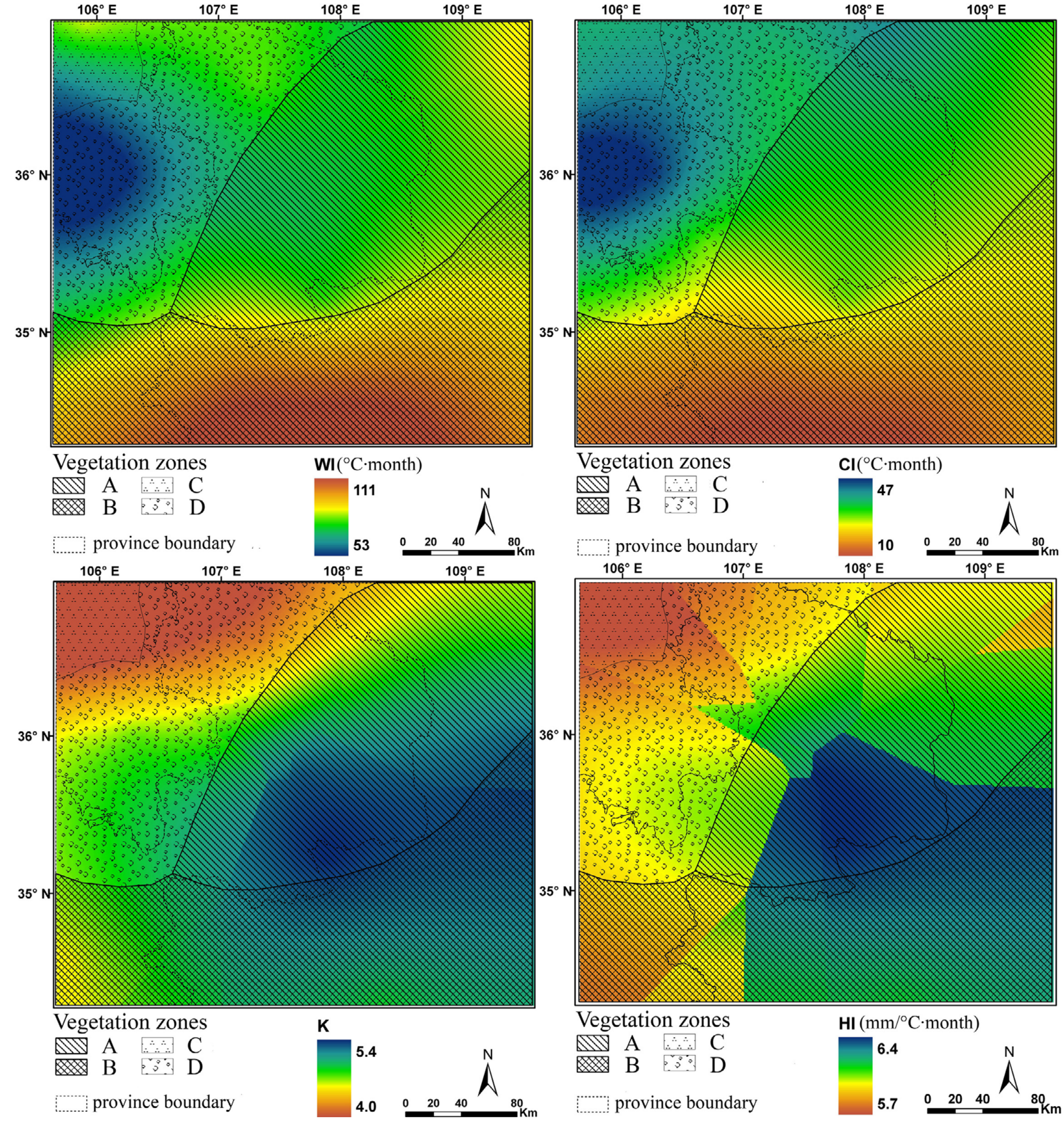

Fig. 3. *WI* , *CI*, *K*, *HI* and vegetation zones in 1971–2000 in the study area (A: deciduous oak forest in northern warm temperate; B: deciduous oak forest in southern warm temperate; C: typical steppe in southern temperate; D: forest steppe in southern temperate)

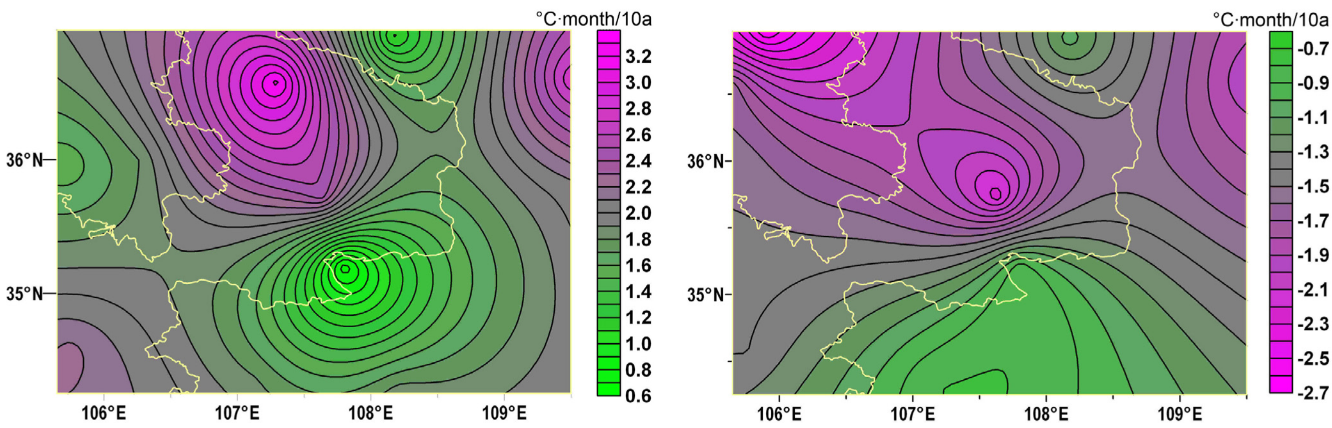

Fig. 4. The trend of *WI* (left) and *CI* (right) in the past 50 years in the study area

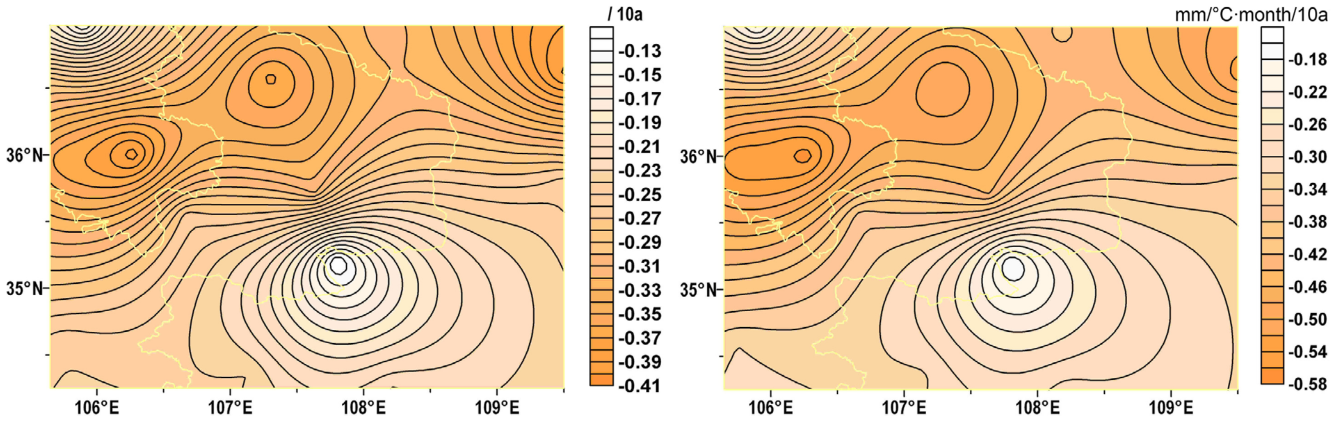

Fig. 5. The trend of K (left) and HI (right) in the past 50 years in the study area

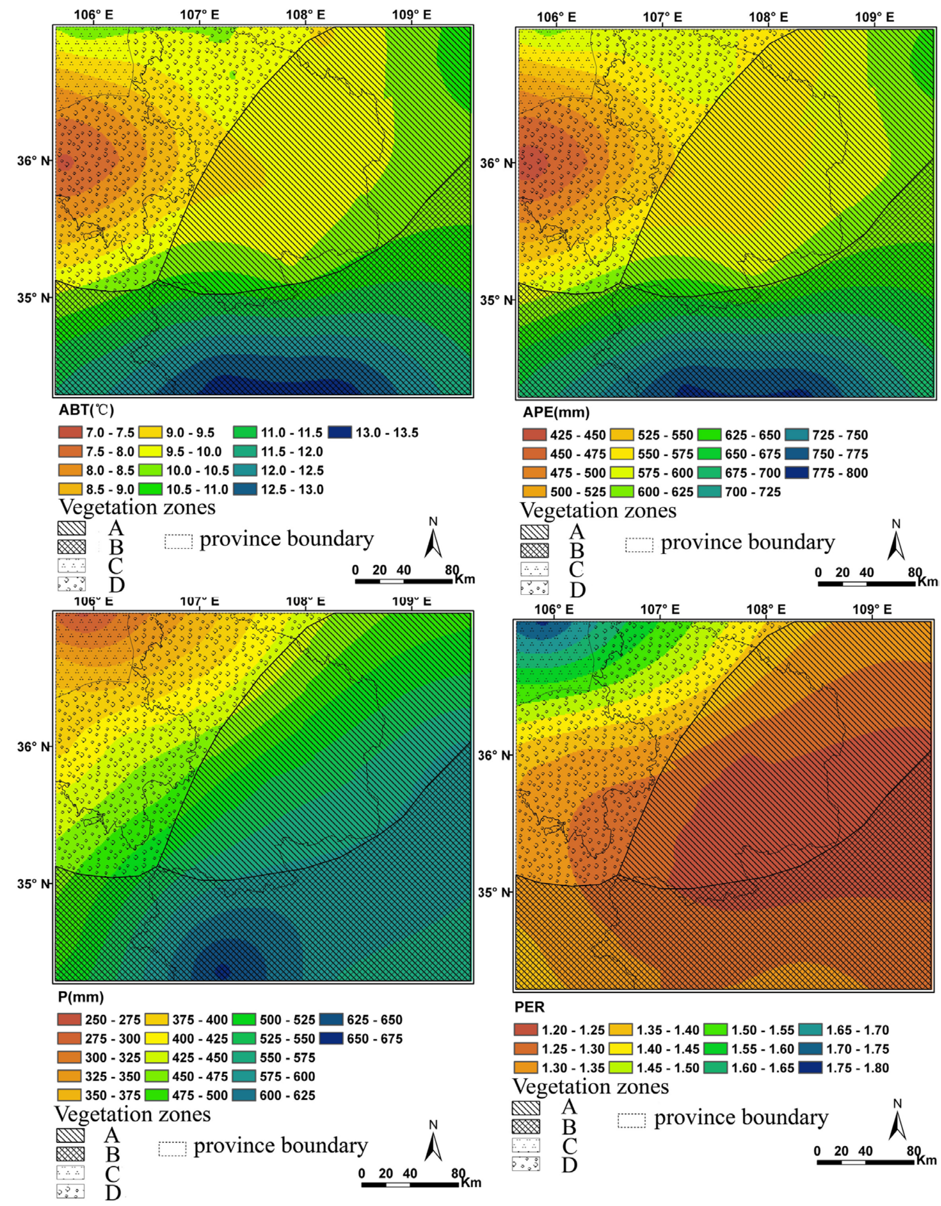

Fig. 6. *ABT, APE, P, PER* and vegetation zones

Precipitation did not change so significantly as temperature. However the annual precipitation decreased in general. The trend for the decrease was great in autumn (–10.566 mm/10a). Annual precipitation had obvious 16–17, 6–7 and 2–3 years cycles. The precipitation in the four seasons of a year differed from each other more or less. The turning point for precipitation change in autumn and winter occurred in mid-1970s and near 2000 respectively.

RET in this region varied from 840mm to 1200mm with a «high in the northwest and low in the southeast» pattern in general. The RET in the north of Changwu increased slightly, while in the south of Changwu including Changwu did not show such increasing trends, or even decreased during the study period. The precipitation in most part of northern Changwu decreased in the past 50 years. Therefore during this period, the climatic aridity kept increasing. M-K test shows that there was no significant abrupt change of *RET* in the study area.

According to analysis on vegetation-climate relations though Kira index in the study area, as for the vegetation zones limited by temperature, the adoption of *WI* and *CI* were suitable for the vegetation classification, while as for the vegetation zones limited by precipitation or both temperature and precipitation, *K* and *HI* are better, and *HI* is more applicable in the study area. *WI* increased during the study period while *CI*, *K* and *HI* decreased at the same period of time. From eastern Gansu to the southwest, there was an obvious boundary line, to the northwest of the boundary, *WI* increased very significantly, while *CI*, *K* and *HI* decreased more or less. It was inferred from above that the boundary between deciduous oak forest in northern warm temperate and deciduous oak forest in southern warm temperate tended to move northward while the boundaries between deciduous oak forest in northern warm temperate and forest steppe in southern temperate and between forest steppe in southern temperate and typical steppe in southern temperate tended to move westward and northward, and the latter tendency would be more significantly.

Based on Holdridge life zone, the boundary between forest and steppe (is deciduous oak forest in warm temperate and forest/typical steppe in southern temperate in the study area) and the boundary between deciduous oak forest in northern warm temperate and deciduous oak forest in southern warm temperate (is considered as humid forests and arid forests in Holdridge life zone) were determined at 1.2–1.3 (*PER*) and 425–450 mm (*P*) respectively. Affecting by global climate change, especially by regional warming and drying, the potential vegetation in the region will change significantly, transiting to warming and drying vegetation types.

Acknowledgements. This study was financially supported by the Natural Science Foundation of China (Grant № 40871033 40471047 and 41030101).

REFERENCES

Allen R.G., Pereira L.S., Raes D., Smith M. Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements // FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations. Rome, 1998. P. 5.

Holdridge L.R. Determination of world plant formation from simple climatic data // Science. 1947. Vol. 105. № 2727. P. 367–368.

Holdridge L.R. Life zone ecology. Tropical Science Center. San Jose, Costa Rica, 1967.

Kira T. A new classification of climate in eastern Asia as the basis for agricultural geography. Kyoto, 1945. P. 1–23.

Shi Z.Z., Wang Y.H., Yu P.T. et al. Study on different forestry vegetation's eco-hydrological function in Liupan Mountain of Ningxia China // Journal of Soil and Water Conservation. 2005. Vol. 19. № 3. P. 134–138.

The compiling Committee of National Assessment Report of Climate Change // National Assessment Report of Climate Change. Beijing, 2007. P. 23–30.

Wang H.S. The evolution and sources of North China's flora // Geography Journal. 1999. Vol. 54. № 3. P. 213–223.

Wang L.X., Min Q.W., Li F.X. et al. Microclimatic characteristics of different underlying surfaces in South Ningxia Mountains // Resources Science. 2005. Vol. 27. № 4. P. 18–21.

Wei F.Y. The statistical diagnostics and prediction technology in modern climate. Beijing, 2007. P. 104.

Wu J.H., Zhang S., Jiang Y. et al. Plant Geography. Higher Education Press. 2004. P. 328–329.

Wu Z.Y., Wang, H.S. Physical geography in China—plant geography. Beijing. 1988. P. 55–66.

Wu Z.Y. Vegetation in China. Beijing, 1980. P. 82–120, 917–955.

Xu W.D. Kira's temperature indices and their application in the study of vegetation // Chinese Journal of Ecology. 1985. Vol. 4. № 3. P. 35–39.