Evolution of Dry-Wet Environment in Inner Mongolia and Analysis of Advantageous Climatic Background for Regional Ecological Construction: Postprint

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Abstract

Through analysis of the trend rates and difference changes in precipitation, potential evapotranspiration, and humidity over the recent 46 years in Inner Mongolia before and after the abrupt temperature change, the spatiotemporal variation characteristics of dry-wet environment evolution for the main vegetation types in this region were obtained. The research results indicate that precipitation exhibited an "increase in the east and decrease in the west" pattern before the abrupt temperature change, while showing an opposite trend after the change. Areas with increased precipitation trend rates over the 46 years were mainly concentrated in the eastern part of Hulunbuir City and most areas west of Ulanqab City. Potential evapotranspiration showed a decreasing trend before the abrupt temperature change and an increasing trend after the change, with post-change potential evapotranspiration being significantly lower than pre-change values. The 46-year potential evapotranspiration trend rates in Inner Mongolia were relatively low in most areas, with higher values only existing in the north-central regions. After the abrupt temperature change, an obvious "evaporation paradox" existed in most areas of the entire region. Humidity increased significantly after the abrupt change in the western foothills of the Greater Khingan Mountains and areas west of Ulanqab City, and the warm-humid climate environment is conducive to local vegetation construction and ecological restoration, while southeastern Inner Mongolia, the Hulunbuir Grassland, and the Xilingol League grassland area show a warm-drying trend, with the aforementioned grassland areas facing potential degradation risks.

Full Text

Preamble

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1. Study Area

Inner Mongolia Autonomous Region extends from 126°04 –97°12 E and 37°24 – 53°23 N, covering a total length of approximately 2400 km from east to west. The region features complex topography with elevations mostly above 1000 m.

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2. Data and Methods

2.1 Data Sources

Meteorological data from 107 stations across Inner Mongolia were collected for the period 1971–2016, including monthly observations of temperature, precipitation, sunshine duration, relative humidity, wind speed, and atmospheric pressure. The dataset was quality-controlled and processed into annual values.

2.2 Data Processing

Data processing and analysis were conducted using Excel 2013 and SPSS statistical software. The Penman-Monteith method recommended by the Food and Agriculture Organization (FAO) was employed to calculate potential evapotranspiration (ET) [**?**].

2.4 Mann-Kendall Mutation Test

The Mann-Kendall (M-K) mutation test was used to detect abrupt changes in climatic time series. The test identifies significant trend breakpoints in the data [**?**].

2.5 Analysis Methods

Spatial and temporal variation characteristics were analyzed using statistical methods. The moisture index was calculated to assess dry-wet conditions.

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3. Results

3.1 Temperature Variation

From 1971 to 2016, the annual average temperature in Inner Mongolia showed a significant increasing trend at a rate of 0.039°C per decade ($r = 0.799$, $p < 0.01$). The M-K test identified an abrupt temperature change in 1988 [Figure 2a: see original paper]. Following this mutation point, the temperature trend accelerated, with the post-1988 period showing significantly higher temperatures than the pre-1988 period [Figure 2b: see original paper].

3.2 Precipitation Variation

Before the temperature mutation (1971–1988), precipitation exhibited an increasing trend in eastern Inner Mongolia but a decreasing trend in the western regions. After the temperature mutation (1988–2016), this pattern reversed: precipitation decreased in the east while increasing in the west. Over the entire 46-year period, areas with significant precipitation trends were concentrated in eastern Hulunbuir League and most areas of western Ulanqab League [Figure 3a: see original paper].

The spatial distribution of precipitation trends showed complex patterns. The post-mutation period exhibited increased precipitation variability, with the western desert and steppe regions showing more pronounced changes [Figure 3b: see original paper]. The rate of precipitation change reached up to 30 mm per decade in some areas [Figure 3c: see original paper].

3.3 Potential Evapotranspiration Variation

Potential evapotranspiration (ET) showed a decreasing trend before the temperature mutation but an increasing trend afterward. The rate of change was relatively small across most areas during the 46-year period, except in north-central Inner Mongolia where more significant changes occurred [Figure 4: see original paper]. An "evaporation paradox" phenomenon was evident in most parts of the region.

3.4 Moisture Index Variation

The moisture index, calculated as the ratio of precipitation to ET , revealed distinct spatial patterns. Before the temperature mutation, the index showed a decreasing trend in the east and increasing trend in the west. After the mutation, this pattern intensified, with the western regions becoming more humid and eastern regions becoming more arid [Figure 5: see original paper].

3.5 Combined Analysis

[Figure 6: see original paper] shows the integrated changes in precipitation, potential evapotranspiration, and moisture index from 1971 to 2016. The results indicate that climate warming has significantly altered the regional water balance, with the temperature mutation in 1988 serving as a critical turning point.

3.6 Dry-Wet Environment Evolution

The evolution of dry-wet conditions was analyzed using the moisture index. The formula for potential evapotranspiration is:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

where R_n is net radiation, G is soil heat flux, T is mean air temperature, U_2 is wind speed at 2 m height, e_s is saturation vapor pressure, e_a is actual vapor pressure, Δ is the slope of the vapor pressure curve, and γ is the psychrometric constant.

The analysis revealed that the desert, steppe desert, and desert steppe in western Inner Mongolia experienced humid climate conditions, which were beneficial for vegetation construction and ecological restoration. In contrast, southeastern Inner Mongolia and the grasslands of Hulunbuir and Xilingol leagues showed a warming-drying trend, posing potential degradation risks.

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4. Discussion and Conclusions

4.1 Conclusions

(1) From 1961 to 2016, the annual average temperature in Inner Mongolia increased significantly at a rate of 0.365°C per decade, with an abrupt change detected in 1988.

(2) Precipitation patterns reversed after the temperature mutation: the pre-mutation period (1971-1988) showed increasing precipitation in the east and decreasing in the west, while the post-mutation period (1988-2016) exhibited the opposite pattern.

(3) Potential evapotranspiration decreased before the temperature mutation but increased afterward. The moisture index showed corresponding changes, with most areas experiencing relatively small trend rates over the 46-year period, except for north-central Inner Mongolia.

(4) An "evaporation paradox" was observed across most of the region, where increasing temperatures did not lead to consistently higher evapotranspiration rates due to complex feedback mechanisms.

4.2 Discussion

The relationship between precipitation, ET , and moisture index requires further investigation [**?**, **?**, **?**]. The spatial heterogeneity of climate change impacts across Inner Mongolia' s 2400 km span necessitates region-specific adaptation strategies. The warming-drying trend in southeastern grasslands requires strengthened natural grazing management and ecological protection, while large-scale artificial vegetation construction should be prohibited in vulnerable areas [**?**].

The findings provide scientific basis for regional ecological construction, vegetation protection, and rational utilization of climate resources. Future research should focus on the mechanisms driving the evaporation paradox and the long-term sustainability of vegetation restoration efforts in the context of ongoing climate change.

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Abstract: The temperature in Inner Mongolia, China keeps increasing from 1971 to 2016. According to the result of MK mutation test, there was a sudden change of the annual average temperature in 1988. The temporal and spatial variation characteristics about the dry and wet environment of the main vegetation types in the region was derived based on the analysis of the change and the tendency rate of the precipitation, potential evapotranspiration and moisture index before and after the sudden change of the air temperature in the course of the late 46 years. The results showed that the precipitation had the pattern of an increasing trend in the east area but a decreasing trend in the west area before the sudden change of the temperature, and it turned to an opposite pattern after the sudden change of the temperature which meant a decrease trend in the east area but an increase trend in the west area. The areas with a precipitation trend rate in the past 46 years were mainly concentrated in the east of Hulunbuir League and most area of the western Ulanqab League. The evapotranspiration showed a decreasing trend before the sudden change of the temperature, but an increase trend after that change, and the latent evapotranspiration was significantly smaller after the sudden change of the temperature. The potential evaporation tendency was relatively small in most areas in the past 46 years with the exception only in the north-central part of Inner Mongolia. There was an obvious "evaporation paradox" in most parts of the region. The desert, steppe desert and desert steppe in the west region of Inner Mongolia were in the humid climate background, which was beneficial to the local vegetation construction and ecological recover. In southeastern Inner Mongolia, and the grasslands of Hulunbuir and Xilingol League there was a warming and drying tendency, which poses a potential degradation risk in the above steppe areas. It is required to strengthen the maintenance of natural fending and ecological stability of the grassland areas, to reduce human disturbance, and large-scale artificial vegetation construction should be prohibited at present. The conclusion can provide scientific basis for regional ecological construction, vegetation protection, reasonable utilization of regional climate resources and climate change solutions.

Keywords: Inner Mongolia; climate change; precipitation; potential evaporation; dry and humid change

Note: Figure translations are in progress. See original paper for figures.