Parametric Studies on the Characteristics of Climate Change in Hulunbeir Steppe of China

Shengxing Ye1, 2, Zhirong Zheng2, Zhaoyan Diao2, Shihai Lv2, Jing He2, Guodong Ding1,*

1 College of Soil and Water Conservation, Beijing Forestry University, Beijing, 100083, China
2 State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing, 100012, China

*Corresponding author e-mail: dgd1999@163.com

Abstract. This study aims to analysis the characteristics of climate change on Hulunbeir steppe of China in the past 50 years which are from 1958 to 2007. First hand monitoring data were collected by utilizing a parametric model that is established using indicators of temperature, precipitation, and relative humidity. The Ivanov model were applied in the case study in order to calculate land evaporation and drought index for obtaining better understand on the climate changes in Hulunbeir Steppe. The modelling results indicated that the overall situation of climate change began to dry out and had a tendency towards drought according to the last 50 years, especially there was a significant increasing in average temperature, precipitation, and the evaporation. According to the monitoring date from our six meteorological stations established in Hulunbeir steppe, it has been shown that the average temperature have increased by 2.31 ℃, the maximum value of precipitation have increased by 158.56mm after 1980s, drought indexes and evaporation capacity have increased by 3.2 to 10.6 times and 4.3 to 5.4 times during 1991 to 2007, respectively. The results in present study are expected to give a theoretical support for relevant researches in the future.

1. Introduction
Climate change impacts has become the one of the most important issue in the world, especially the extreme weather events have been occurred more and more frequently in recent years. Some meteorological disasters including floods and droughts are greatly influenced the sustainable development of economy and society. Therefore, it is necessary to apply a systematic study on the characteristics of climate change at various scales for climate resources exploitation and utilization, disaster prevention, mitigation and climate prediction [1-2]. Hulunbeir is in the east of Inner Mongolia belonging to climate of continental monsoon of frigid and temperate zone. The Great Hinggan Mountains throughout the middle of Hulunbeir from northeast to southwest result in significant difference in climate of Hulunbeir. Recent years, Hulunbeir grassland have experienced a seriously degradation due to global climate change and population increasing in pasturing area, there were 90% of natural grassland has showed symptoms of degradation and desertification in this region [1]. Some
pervious researches indicated climate change was one of the crucial inducing factors lead to grassland degradation [2]. It is urgent to conduct some relevant researches on analyzing the variation and of climate, and to find out the causes of drought to reveal the natural process of environment change. In the past decades, there were some literatures were focusing on the quantitative analyses of climate characteristic. For example, Fangkui Xu et.al has made a classification of grassland in Hulun Buir by analyzing precipitation data for thirty-five years [3]. Liyin Song et.al has quantitatively identified the climate change and extraordinary weather in Hulun Buir nearly 50 years [3-4]. Yushuang Bai et.al has used 30 years climate data of Hulun Buir to confirm that the dryness trend of the surface result from precipitation decrease and temperature increase [5]. However, there are only limited researches have discussed the main cause of the drought in grassland of Hulunbeir. 

In this study, the characteristics of climate change in Hulunbeir steppe of China in the past 50 years will be analyzed based on long-term monitoring data including precipitation, temperature and the relative humidity, which were collected from our six meteorological stations established in Hulunbeir. The main reasons that lead to the drought in Hulunbeir steppe will be identified and discussed.

2. Case study and methods

Hulunbeir is located in the east of Inner Mongolia at 115°31′E~126°04′E and 47°05′N~53°20′N. The area of Hulun Buir is 0.25 million km² which amounts to 21.4% of the total area of Inner Mongolia, measuring 630 km from east to west and 700 from south to north. It is the sum of areas of the provinces of Shandong and Jiangxi. It is connected with Hinggan League in the south and Heilongjiang in the east. It is bounded by Russia in the northwest and north, and Mongolia in southwest and west. The length of border is 1723.82km, including 1048km Sino-Russian border (without undefined boundary) and 675.82km border between China and Mongolia [6].

Hulunbeir is belonging to climate of continental monsoon of frigid and temperate zone. The Great Hinggan Mountains throughout the middle of Hulunbeirfrom northeast to southwest result in significant difference in climate of Hulunbeir in the west of the Great Hinggan Mountains which belonging to semi-humid climate zone, there is four distinct seasons, mild climate and more rainfalls. While in the east, there is much colder and drier in semi-arid and semi-humid savannah climate.

Meteorological data were collected from year of 1958 to 2007 by six meteorological stations in Hulunbeir including regions of Erguna, Manzhouli City, Hailaer Area, Xiaoergou, Tulih county, and Xin Barag Right Banner. Firstly, based on the meteorological data, the departure from normal value of every month annual temperature was calculated by using statistic methods. Then land evaporation and drought index were analyzed through the available data. The following provides specific steps:

The Ivanov model was applied to calculate land evaporation:

\[ E = 0.0018(25 + t)^2 \cdot (100 - f) \]

Where, E is possible evaporation, t is the average temperature of month, f is average relative humidity of month.

Drought index is depending on precipitation and temperature, which means the contribution of nature precipitation, transpiration, and evaporation to water yield. Higher values mean less water yield and drier climate [6]. Because the forest-steppe ecotone of Hulun Buir is in the half-drought cross region, selected indices were endowed with 0.5 weights in order to synthetically reflect the effects of precipitation and temperature to drought index.

The calculation model of drought index is:

\[ DI = -a \cdot \Delta R / \sigma_R + b \cdot \Delta T / \sigma_T \]

Where, DI is drought index, \( \Delta R \) is precipitation departure in a certain period, \( \Delta T \) is average temperature departure in a certain period, \( \sigma_R \) and \( \sigma_T \) are the mean square error of precipitation and
temperature in a certain period, respectively, $a$ and $b$ are the weight of precipitation and temperature, respectively.

3. Results analysis

3.1. Changes of temperature
Comparing with the temperature data from six meteorological stations in Hulunbeir during the past 50 years, results have shown that the annual average temperature departure has increased in different degree since 1958. The trend coefficient ranged from 0.0395 to 0.05 (Fig.1). This indicated that the temperature has increased significantly in the past 50 years.
Through analyzing the annual average temperature departure from the monitoring results, we have found that the changes of temperature have demonstrated in various characteristics affected by different latitudes, altitudes, terrains and human activities under impact of global warming. Based on the regression equations, the temperature of Erguna, Hailaer Area, Manzhouli City, Tulihe County, Xiaoergou, and Xin Barag Right Banner were increased by 2.05°C, 3.23°C, 2.15°C, 1.94°C, 2.37°C, and 2.31°C, respectively. However, comparing with other meteorological stations, there was wide range of the annual average temperature of Hailaer Area, rise up by 0.06°C per year for 50 years. Under effect of climate changes, it shows the temperature has increased significantly in the past 50 years affected by different latitudes, altitudes, terrains and human activities in Hulunbeir. These could
be the major reason that lead to droughts in Hulunbeir over the past years and further increase the risk of large scale in soil erosion.

3.2. Changes of precipitation
Through analyzing the annual average precipitation departure from the monitoring results, they have shown that the precipitation has increased significantly except Xin Barag Right Banner and Manzhouli City. The trend coefficient ranged from 0.7277 to 3.2359 (see Fig.2). This indicated that precipitation in Hulunbeir has increased significantly in the past 50 years. The precipitation in Xin Barag Right Banner and Manzhouli City have decreased 53.16mm and 33.39mm respectively for 50 years, while that in other stations has increased from 35.66mm to 158.56mm. Due to the geographical differences of each meteorological station, the precipitation was found not evenly distributed between western and eastern Hulunbeir. There was small quantity of precipitation in Xin Barag Right Banner, Manzhouli City and Hailaer Area but more in Erguna, Tulihe County and Xiaoergou. The reason is because of the Hulunbeir belongs to plateau landscape, which is far away from the sea and moisture circulation is inactive by blocking of Great Hinggan Mountains.

3.3. Changes of drought index
Some useful regression equations were obtained after analyzing the drought index from the monitoring results. They have shown that drought coefficient was ranged from 0.0144 to 0.0257, which indicated that the effect of temperature is greater than the effect of precipitation on the severity of drought. Therefore, climate warming is an important factor contributing to drought index increased in Hulunbeir.

Table 1. Drought index of key meteorological stations in different years in Hulunbeir

| Year     | Erguna | Hailaer | Manzhouli | Tulhe  | Xiaoergou | Xin Barag Right |
|----------|--------|---------|-----------|--------|-----------|-----------------|
| 1958~1970| -0.1245| -0.1659 | -0.2741   | -0.2226| -0.2294   | -0.3319         |
| 1971~1980| -0.1329| -0.1798 | -0.2389   | 0.0508 | -0.1275   | -0.2268         |
| 1981~1990| -0.4311| -0.3364 | -0.4921   | -0.3533| -0.2387   | -0.2679         |
| 1991~2000| 0.2186 | 0.1772  | 0.3299    | 0.1407 | 0.1745    | 0.2621          |
| 2001~2007| 0.7245 | 0.7923  | 1.0820    | 0.6446 | 0.6999    | 0.9488          |
| Average  | 0.0509 | 0.0575  | 0.0814    | 0.0520 | 0.0558    | 0.0768          |

Notes: the negative value means the dry condition of atmosphere is humid.

Changes of drought index in different years from each meteorological station in Hulunbeir is shown on table 1, which indicates the drought index has increased significantly. The average drought index in each station was showing a negative value during 1958 to 1990. The drought indexes of Erguna, Manzhouli City, Hailaer Area and Xiaoergou have been negative growth. In the periods of 1958 to 1970 and 1971 to 1980 in Tulhe County, the drought index was increased by 1.2 times from -0.2226 to 0.0508. But the drought index fell below zero in the period of 1981 to 1990 and then reminded increase after 1991. Therefore, the drought index has increased 2.8 times during 30 years in Tulhe County. In 1991 to 2007, the drought index of each station was positive value and has increased 3.2 to 10.6 times. All data from each meteorological station presented an upward trend for 50 years. The results have illustrated that the arid degree was worse year by year.

3.4. Changes of evaporation
By utilizing the Ivanov model to calculate land evaporation and departure, the results indicated that the trend coefficients of evaporation ranged from 3.9444 to 13.858 which were 4.3~5.4 times for precipitation. There was an increasing trend in evaporation of each meteorological station. Due to the maximum of evaporation appeared nearly 10 years, it might be related to global warming.
Figure 2. The departure changes of annual average precipitation and amount of evaporation of different stations in Hulun Buir from 1958 to 2007

Fig. 2 shows the trend lines of precipitation departure in each station were higher than those of evaporation from 1958 to 1983. This result has illustrated that precipitation amount was higher than the evaporation since the climate was relative humid in this period. However, trend lines of precipitation departure in each station were lower than those of evaporation from 1983 to 2007. It has shown that climate was relative arid in this period. Xin Barag Right Banner was the largest evaporation area with the trend coefficient was 13.858. The reason of high evaporation is because Xin
Barag Right Banner is located in west of Hulunbeir where belong to arid grassland and related to vegetation pattern and vegetation cover. Tulihe County which located in the forestry of the Great Hinggan Mountains was the smallest evaporation area. In this region, the forestry has the ability of water conservation. The increasing evaporation for 50 years has destroyed the water balance, which leads to the extent of drought and more serious soil erosion in HunlunBuir.

3.5. Changes of wind speed
According to the results of 6 monitoring station by comparing to the average value of wind speed in year of 1995, some regions with weakness and strongly wind speed have been found (Fig. 3). The wind speed in 1990s was obvious slower than that in 1980s in the regions as Xin Barag Right Banner, Manzhouli City and Hailaer Area. But after 2000, there was a small increase in average wind speed. The wind speed has gradually deceased from 1980s to 1990s in Erguna, Tulihe County and Xiaoergou. However, the wind speed has been obviously enhanced after 2000.

![Figure 3. Changes of annual average wind speed of different stations in Hulun Buir](image)

Wind force as the driving force to soil erosion is related to the intensity of wind erosion. The wind became much stronger, the more serious of wind erosion. The values of actual quantity of wind erosion in 1995, 2000, and 2005 were consistent with the changes of wind speed. Xin Barag Right Banner, Manzhouli City and Hailaer Area were in the scope of wind erosion. From 1995 to 2000, the
intensity of wind erosion has decreased, while that has increased from 2000 to 2005. Therefore, the intensity of wind is the basic reason lead to severe wind erosion in Hulunbeir.

4. Conclusion remarks
This paper discussed variation of temperature, precipitation, drought indexes and coefficients of evaporation by collecting first hand data from our monitoring station in Hulunbeir in 50 years. Some interesting results are found as follows:

(1) This study shows that the annual average temperature of Hulunbeir are increased by 2.3 °C from 1958 to 2007. Among the six monitoring stations, we found Hailaer Area has the biggest rise in annual average temperature by 3.23°C. During the past fifty years, annual average temperature has increased by 0.06°C each year since it might be also related to urbanization effect in strength over the years. Due to the impact of global warming, the annual average temperature increased obviously in each meteorological station after 1980s.

(2) The amount of precipitation in Barag Right Banner and Manzhouli City have decreased by 53.16mm and 33.39mm respectively during 50 years, while that in other stations has increased with the maximum in 158.56mm. Based on the increasing trend of precipitation in Hunlun Buir during 50 years, there was a greater difference from the conclusions made by Xie Anand Bai Yushuang that precipitation has decreased in the same region [7-10]. The reason for declining precipitation in Xin Barag Right Banner and Manzhouli City might be related to the geographic location of that area, since this region was located in the west of Hulunbeir. which belongs to plateau landscape and was affected by cold air from Siberia and Mongolia.

(3) The drought indexes from the six meteorological stations have been found were increased significantly. From 1958 to 1990, the average drought index in each station was negative. The drought indexes of Erguna, Manzhouli City, Hailaer Area and Xiaoergou have been negative growth, therefore the climate was humid in this period. In 1991 to 2007, the drought index of each station was positive value and has increased by 3.2 to 10.6 times. All data from each meteorological station presented an upward trend for 50 years. The results have illustrated that the arid degree was worse year by year. It is identified that effects caused by temperature rising were larger than those caused by precipitation during climate changes. Therefore, climate warming is the important factor contributing to drought index increased in Hulunbeir, and such conclusion is similar with Xie[11-13] and Wang Z[14-16] results.

(4) It is also shown that the trend coefficients of evaporation ranged from 3.9444 to 13.858 which were 4.3~5.4 times for precipitation. All trend lines of precipitation departure in each station were higher than those of evaporation from 1958 to 1983. This result has illustrated that precipitation was more than evaporation and climate were relative humid in this period. However, trend lines of precipitation departure in each station were lower than those of evaporation from 1983 to 2007. It indicates that climate was relative arid in this period. Due to the upward trend in temperatures, the evaporation capacity was larger than precipitation, thus accelerated progress of the soil drought in Hulunbeir.

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