Postprint: Spatial-Temporal Variation and Influencing Factors of Wind Erosion Climatic Erosivity in Xinjiang over the Past 50 Years

Authors: Wang Yaqin

Date: 2022-04-13T23:38:07+00:00

Abstract

Based on daily meteorological data from 62 weather stations in Xinjiang Uygur Autonomous Region from 1969 to 2019, this study investigates the effects of meteorological factor variations on wind erosion climate erosivity; utilizes Geographically Weighted Regression models and centroid migration models to analyze the spatiotemporal patterns of wind erosion climate erosivity centroid migration in Xinjiang; and employs effective sensitivity index, Effective Impact Area (EIA), and other indicators to quantitatively characterize the sensitivity of wind erosion climate erosivity to various meteorological factors, thereby analyzing regional-scale differences in dominant factors influencing wind erosion climate erosivity across different regions of Xinjiang. The results demonstrate that over the past 50 years, the centroid migration range of wind erosion climate erosivity has been primarily distributed at the junctions of southern Xinjiang, northern Xinjiang, and eastern Xinjiang, with both interannual and intermonthly migration directions exhibiting a reciprocating northwest-southeast-northwest pattern; the centroid migrates from northwest to southeast as spring and summer approach, and returns to the northwest as the cold season nears. The influence magnitude of climate factors on wind erosion climate erosivity follows the order: wind speed > temperature > precipitation > relative humidity. Over the past 30 years, the EIA of wind speed, average temperature, relative humidity, and precipitation on wind erosion climate erosivity has decreased by 124,598.15 km^2, 51,891.28 km^2, 11,287.12 km^2, and 18,627.12 km^2, respectively. Regionally, wind erosion climate erosivity in the Altay region of northern Xinjiang is predominantly influenced by relative humidity and precipitation; wind erosion climate erosivity in the southwestern region of southern Xinjiang is predominantly influenced by wind speed and average temperature; and wind erosion climate erosivity in eastern Xinjiang is predominantly influenced by wind speed. These findings can provide regionally differentiated theoretical guidance for the prevention and assessment of soil wind erosion disasters in Xinjiang,

while also offering a novel research perspective for large-scale driving force studies of soil wind erosion.

Full Text

Migration Characteristics of Wind Erosion Climate Erosivity and Its Influencing Factors in Xinjiang in Recent 50 Years

WANG Yaqin[1,2], YANG Haimei[1,2], FAN Wenbo[1,2], XU Zhongyu[3], QIAO Changlu[1,2]

[1]College of Water & Architecture Engineering, Shihezi University, Shihezi 832000, Xinjiang, China
[2]Key Laboratory of Modern Water-Saving Irrigation of Xinjiang Production & Construction Group, Shihezi University, Shihezi 832000, Xinjiang, China
[3]College of Science, Shihezi University, Shihezi 832000, Xinjiang, China

Abstract

Based on daily meteorological data from 62 meteorological stations in Xinjiang, China from 1969 to 2019, this study investigated the influence of meteorological factor variations on wind erosion climate erosivity. Using geographically weighted regression and gravity center migration models, we analyzed the spatiotemporal patterns of wind erosion climate erosivity centroid migration in Xinjiang. Combined with the effective sensitivity index and effective influence area (EIA) metrics, we quantitatively described the sensitivity of wind erosion climate erosivity to various meteorological factors and analyzed regional differences in dominant influencing factors across Xinjiang.

The results indicate that over the past 50 years, the centroid of wind erosion climate erosivity has primarily migrated within the border regions connecting southern, northern, and eastern Xinjiang. Both annual and monthly migration directions exhibit a recurring northwest-southeast-northwest pattern. As spring and summer approach, the centroid shifts from northwest to southeast, then returns northwestward when the cold season nears. The influence degree of climatic factors on wind erosion climate erosivity follows the order: wind speed > air temperature > relative humidity > precipitation. Over the past 30 years, the effective influence areas of wind speed, mean air temperature, relative humidity, and precipitation on wind erosion have decreased by 124,598.15 km^2, 51,891.28 km^2, 11,287.12 km^2, and 18,627.12 km^2, respectively. Regionally, wind erosion climate erosivity in the Altay region of northern Xinjiang is mainly influenced by relative humidity and precipitation; in southwestern southern Xinjiang, it is primarily affected by wind speed and mean temperature; while in eastern Xinjiang, wind speed is the dominant factor. These findings provide regionally differentiated theoretical guidance for the prevention and assessment of soil wind erosion

disasters in Xinjiang and offer new research perspectives for large-scale driver studies of soil wind erosion.

Keywords: wind erosion climate erosivity; climate change; center of gravity migration; geographically weighted regression; Xinjiang

1. Data and Methods

1.1 Study Area Overview

Xinjiang covers an area of 1.66$\times10^{6}$ km^2 and features a typical continental arid climate characterized by dryness, low precipitation, strong winds, and extreme seasonal temperature variations. The complex topography creates an alternating landscape pattern of mountains, oases, and basins. Influenced by unique geomorphic features and atmospheric circulation, both the number of gale days and precipitation distribution follow a pattern of being higher in northern Xinjiang than in southern Xinjiang. This distinctive terrain creates complex and diverse ecological types. The combination of arid conditions with limited rainfall and widespread wind zones renders the regional ecological environment fragile, with prominent issues of soil wind erosion and desertification. Wind-eroded desertified land is widely distributed across Xinjiang' s two major basins and surrounding plain areas, accounting for 75.86% of the total desertified area in the region.

1.2 Data Sources and Processing

Meteorological data for this study were obtained from the "China Surface Climate Data Daily Dataset (V3.0)" provided by the National Meteorological Science Data Sharing Service Platform (http://data.cma.cn/). Stations with severely discontinuous data, such as Tazhong Station and Urumqi Pastoral Experiment Station, were eliminated. Missing single values were filled using adjacent station data, resulting in the selection of 62 meteorological stations with complete temperature, precipitation, relative humidity, and wind speed indicators as initial calculation values. Data were resampled using a 0.3°$\times$0.3° grid, yielding 2,654 grid cells for analysis.

1.3 Methodology

1.3.1 Wind Erosion Climate Erosivity This study employed the United Nations Food and Agriculture Organization (FAO) method to calculate wind erosion climate erosivity (C-value), using the formula provided in the "Guidelines for Delineating Ecological Protection Red Lines" (Environmental Office Ecology [2017] No. 48). The power law method was used to correct wind speed data to a standard height. Monthly potential evapotranspiration (ETP) was calculated using the revised formula: $ETP = 0.19(20 + T) \times d$, where T is the monthly mean temperature (°C) and d is the number of days in the month. The wind erosion climate erosivity (C) was then computed considering monthly mean wind speed at a reference height, monthly precipitation (p), and monthly mean relative humidity (r).

1.3.2 Gravity Center Migration Model The gravity center was calculated using the population distribution centroid principle from population geography. The formulas are:

$$X = \frac{\sum_{i=1}^{n} C_i x_i}{\sum_{i=1}^{n} C_i}, \quad Y = \frac{\sum_{i=1}^{n} C_i y_i}{\sum_{i=1}^{n} C_i}$$

where X and Y are the geographic coordinates of the wind erosion climate erosivity centroid; n is the number of meteorological stations in the study area; C is the wind erosion climate erosivity index value at station i; and (x , y) are the geographic coordinates of station i.

The migration direction and distance between years α and β are calculated as:

$$\theta = \arctan\left(\frac{Y_\alpha - Y_\beta}{X_\alpha - X_\beta}\right), \quad d = k\sqrt{(X_\alpha - X_\beta)^2 + (Y_\alpha - Y_\beta)^2}$$

where is the migration direction (counterclockwise positive, -180° ≤ ≤ 180°), d is the migration distance, (X , Y) and (X , Y) are the centroid coordinates for years α and β, respectively, and k is a constant conversion factor.

1.3.3 Geographically Weighted Regression Model (GWR) Geographically Weighted Regression [22] incorporates spatial differentiation characteristics of independent variables, representing an extension of global regression models. The model is specified as:

$$y_i = \beta_0(u_i, v_i) + \sum_{j=1}^{k} \beta_j(u_i, v_i) x_{ij} + \varepsilon_i$$

where y is the dependent variable at sample point i; β_0 is the intercept term; (u , v) are the coordinates of sample point i; β (u , v) is the regression parameter for variable j at point i; x is the value of independent variable j in region i; and is the error term following an independent normal distribution with zero mean.

In this study, the C-value served as the dependent variable, with meteorological factors (temperature, precipitation, wind speed, relative humidity) as explanatory variables. Normality and multicollinearity tests were conducted using the Kolmogorov-Smirnov test and variance inflation factor analysis, respectively, confirming the suitability of these variables for GWR analysis.

1.3.4 Effective Influence Area of Explanatory Variables The magnitude of regression coefficients reflects the influence degree of each explanatory variable on wind erosion climate erosivity. Regression coefficients at each grid point were classified into five levels using the natural breaks method. The absolute value of the highest-level regression coefficient was taken as the effective sensitivity index (ESI) to reflect the sensitivity degree of each explanatory variable' s influence on wind erosion climate erosivity. The effective influence area (EIA) was then defined to quantitatively describe the extent of meteorological factor impacts:

$$\text{EIA} = \sum_{i=1}^{n} \text{ESI}_i \times A_i$$

where EIA is the effective influence area; A is the area of grid cell i; ESI is the effective sensitivity index for explanatory variable i; and n is the number of explanatory variables.

---

2. Results

2.1 Gravity Center Migration Characteristics of Wind Erosion Climate Erosivity

The gravity center of wind erosion climate erosivity in Xinjiang primarily migrated within the border regions connecting southern, northern, and eastern Xinjiang. The migration trajectory revealed a distinct pattern: from 1969 to 1979, the centroid moved northwestward by 191.34 km at an average rate of 7.36 $\text{km} \cdot \text{a}^{-1}$; from 1979 to 1989, it shifted southeastward by 191.15 km at 21.69 $\text{km} \cdot \text{a}^{-1}$; and after 1989, the centroid showed a trend of returning northwestward, though the overall movement remained southeastward. This pattern indicates that over the past 50 years, wind erosion climate erosivity in Xinjiang has followed a northwest-southeast-northwest migration cycle, ultimately tending toward higher latitude regions.

Monthly centroid migration exhibited similar characteristics. From January to May, the monthly centroid moved significantly northward, accumulating a northwestward displacement of 81.96 km. From May to August, the change amplitude decreased with a relatively concentrated position range. However, from August to December, the centroid moved substantially southeastward at a rate of 21.69 $\text{km} \cdot \text{month}^{-1}$. This pattern demonstrates that as spring and summer approach, the wind erosion climate erosivity centroid migrates from south to north and west to east, then returns to the southwestern Tianshan region when the cold season approaches. The substantial monthly centroid changes occur precisely when temperatures drop sharply across Xinjiang, and precipitation plus snow cover in areas north of the Tianshan Mountains exceeds that in southern regions, causing the winter wind erosion climate erosivity centroid to shift significantly southward.

Table 1. Characteristics of Annual Gravity Center Migration of Wind Erosion Climate Erosivity

Period	Centroid Coordinates	Migration Direction	Migration Distance (km)
1969-1979	88°31 14 E, 42°27 28 N	144° (NW)	191.34
1979-1989	87°08 59 E, 43°28 17 N	321° (SE)	191.15
1989-1999	88°23 02 E, 42°44 51 N	132° (NW)	87.36
1999-2009	87°25 51 E, 43°18 38 N	323° (SE)	81.96
2009-2019	87°39 25 E, 43°15 30 N	112° (NW)	21.69

Note: Directions are measured counterclockwise from east. NW = northwest, SE = southeast.

2.2 Spatial Non-Stationarity and Sensitivity Analysis

2.2.1 Spatial Non-Stationarity of Single Factor Effects Spatial visualization of regression coefficients revealed distinct spatial heterogeneity in how each factor influences wind erosion climate erosivity. Regression coefficients for wind speed, air temperature, precipitation, and relative humidity showed both positive and negative values, with alternating regions of correlation, indicating spatially heterogeneous effects.

Wind Speed: Wind speed exhibited positive correlations with C-values across most regions, with regression coefficients showing a gradual eastward increasing trend. The distribution was symmetrically polarized, with both high and low values appearing in northern Xinjiang. The northwestern part of northern Xinjiang showed the weakest wind speed influence, while eastern Xinjiang demonstrated the highest sensitivity to wind speed variations.

Precipitation: Precipitation effects showed clear north-south differences. Since northern Xinjiang receives higher average precipitation than southern Xinjiang, precipitation' s inhibitory effect on C-values was significantly stronger in the north. Regionally, the northeastern part of northern Xinjiang showed the greatest precipitation influence, with the Altay region being most sensitive to precipitation changes. Conversely, precipitation had minimal inhibitory effects on wind erosion along the southeastern margin of the Tarim Basin and in Bortala and Tacheng areas of northern Xinjiang.

Temperature: Temperature effects displayed a latitudinal layered distribution with significant north-south differences. In northern Xinjiang, temperature showed positive correlations with C-values, with correlation strength increasing with latitude. The Altay region exhibited the most significant temperature enhancement of wind erosion climate erosivity. In contrast, southern Xinjiang showed negative correlations, with sensitivity decreasing at higher latitudes. The southeastern corner of the Bayingolin region was most sensitive to temperature changes.

Relative Humidity: Relative humidity generally showed negative correlations with C-values, with its influence concentrated in northern Xinjiang, particularly in the Altay region and areas east of Urumqi.

2.2.2 Phased Differences in Climate Change Driving Mechanisms

Based on effective sensitivity indices, the spatial and temporal evolution of meteorological factor influence zones was analyzed quantitatively through effective influence areas.

During 1969-1989, relative humidity sensitive zones spanned the Altay region, areas east of Urumqi, and northern Hami, covering 275,305.63 km^2. Precipitation sensitive zones were located in southern Altay and eastern Changji, covering 13,784.86 km^2. Wind speed sensitive zones included northwestern Hami, the western margin of the Tarim Basin, and central-southern Bayingolin, covering 26,790.43 km^2. Temperature sensitive zones were situated between Altay and northern Tacheng, covering 40,898.3 km^2. Overlapping influence zones where multiple factors jointly affected wind erosion climate erosivity covered 187,549.95 km^2, primarily in Altay where temperature, relative humidity, and precipitation all played significant roles.

During 1990-1999, wind speed sensitive areas expanded northward to 65,942.40 km^2. Precipitation sensitive areas increased to 29,387.97 km^2, while relative humidity sensitive areas expanded by 817.80 km^2, extending to the southern margin of the Taklamakan Desert. Temperature and precipitation sensitive zones overlapped in northwestern northern Xinjiang, covering 56,185.85 km^2.

During 2000-2009, wind speed sensitive zones continued moving northward, reaching 161,944.63 km^2. Temperature sensitive zones shifted southward to the southeastern corner of the Taklamakan Desert, decreasing to 15,596.83 km^2. Precipitation sensitive zones expanded northward to cover the entire Altay region, reaching 28,376.56 km^2. Relative humidity sensitive zones remained stable in position but decreased in area by 7,088.80 km^2. The joint influence zone of temperature, precipitation, and relative humidity covered 200,366.85 km^2.

During 2010-2019, wind speed sensitive zones moved southwestward, covering 154,418.60 km^2. Temperature sensitive zones were distributed in northern Xinjiang, decreasing to 3,096.80 km^2. Precipitation sensitive zones were confined to southern Altay, covering 3,646.44 km^2. Relative humidity sensitive zones showed minimal change, with an area of 12,077.92 km^2. The southeastern

Altun-昆仑 mountain region developed into a relative humidity sensitive zone covering 4,448.67 km^2.

Overall, the effective influence areas of all explanatory variables showed a decreasing trend from 1969-2019, with wind speed decreasing by 124,598.15 km^2, temperature by 51,891.28 km^2, relative humidity by 11,287.12 km^2, and precipitation by 18,627.12 km^2. This decline suggests an overall weakening of wind erosion climate erosivity, likely related to weakening westerly circulation and winter monsoon, as well as reduced intensity and frequency of cold air activity in the Northern Hemisphere.

Regionally, the Altay area in northern Xinjiang is primarily influenced by relative humidity and precipitation. In southwestern southern Xinjiang, wind speed and mean temperature are the dominant factors, though their influence areas have been shrinking annually. Eastern Xinjiang' s wind erosion climate erosivity is mainly affected by wind speed.

3. Discussion

Previous research has extensively examined the spatiotemporal variation characteristics of wind erosion climate erosivity. This study extends that work by analyzing the spatial variation of its gravity center. The finding that the centroid migrated primarily within border regions connecting southern, northern, and eastern Xinjiang identifies these areas as high-risk zones for wind erosion, consistent with results from Yang et al. [25]. Daoran and Jiapayi [29] reported that the meridional circulation in Asia has weakened while zonal circulation has strengthened since the 1990s, with a transition from predominantly meridional to zonal circulation patterns. Our study similarly found that the inter-decadal centroid of wind erosion climate erosivity exhibited latitudinal-longitudinal migration trends, ultimately tending toward higher latitudes, suggesting a possible link between centroid migration and atmospheric circulation patterns.

The migration characteristics also correlate with changes in high wind frequency zones. Gao et al. [31] noted that before 2000, the Alashankou area in northwestern Xinjiang was a high-frequency wind region, while more recent research [32] indicates the center has shifted to the central-eastern Tianshan region. Our findings of east-west centroid migration align with these shifts in wind patterns.

Our results confirm previous findings that wind erosion climate erosivity correlates positively with wind speed and temperature, and negatively with precipitation and relative humidity, with wind speed as the dominant factor [9,11,28]. This study further quantifies the influence degree of each meteorological factor on Xinjiang' s wind erosion climate erosivity. The decreasing effective influence areas of all factors over the past 30 years indicate weakening wind erosion climate erosivity, consistent with research showing reduced westerly circulation and decreased cold air activity intensity [30,32].

References

[1] Ashkenazy Y, Yizhaq H, Tsoar H. Sand dune mobility under climate change in the Kalahari and Australian deserts[J]. Climatic Change, 2011, 112(3/4): 901-923.

[2] Kuhn N J, Oost K V, Cammeraat E. Soil erosion, sedimentation and the carbon cycle[J]. Catena, 2012, 94: 1-2.

[3] Xiao Shengchun, Zheng Haijin, Yang Jie, et al. Coupling relationships of soil erosion/soil and water conservation and climate change[J]. Science of Soil and Water Conservation, 2011, 9(6): 106-113.

[4] Jiang Lin, Xiao Yi, Rao Enming, et al. Effects of land use and cover change (LUCC) on ecosystem sand fixing service in Inner Mongolia[J]. Acta Ecologica Sinica, 2016, 36(12): 3734-3747.

[5] Zhang Yin, Tuerxunbai Gulixian, Su Litan, et al. Spatial and temporal characteristics of climate change at different altitudes in Xinjiang in the past 60 years[J]. Arid Land Geography, 2019, 42(4): 822-829.

[6] Li Chune. Spatial and temporal variation of land desertification in Xinjiang[J]. Science of Surveying and Mapping, 2018, 43(9): 33-39.

[7] Dong Yuxiang, Kang Guoding. Study on the wind erosion climatic erosivity in arid and semi-arid areas[J]. Journal of Soil and Water Conservation, 1994, 8(3): 1-7.

[8] FAO. A provisional methodology for soil degradation assessment[A]. Rome, 1979: 61-63.

[9] Ministry of Environmental Protection. Guidelines for the delineation of ecological protection red line (Environmental Office Ecology[2017] No. 48)[R]. 2017-5-27.

[10] Wei Fengying. Modern climate statistical diagnosis and prediction technology[M]. Beijing: Meteorological Press, 1999.

[11] Shi Nana, Xiao Nengwen, Wang Qi, et al. Ecological security evaluation and ecological regulation approach in Xilin Gol League[J]. Transactions of the CSAE, 2019, 35(18): 228-236.

[12] Liu Qing, Yang Yongchun, Liu Haiyang. Spatiotemporal evolution characteristics of air pollution degree in 366 cities of China[J]. Arid Land Geography, 2020, 43(3): 820-830.

[13] Zhao Chaonan, Zhang Hanbing, Wang Man, et al. Impacts of climate change on wind erosion in southern Africa between 1991 and 2015[J]. Land Degradation & Development, 2021, 32(6): 2169-2182.

[14] Yang F B, Lu C H. Assessing changes in wind erosion climatic erosivity in China' s dryland region during 1961–2012[J]. Journal of Geographical Sciences, 2016, 26(9): 1263-1276.

[15] Wu Chengyong, Chen Kelong, Cao Guangchao, et al. The spatial and temporal differences and driving forces of wind erosion climatic erosivity in Qinghai Province from 1984 to 2013[J]. Geographical Research, 2018, 37(4): 717-730.

[16] Han Liu. Temporal and spatial variation characteristics of wind speed and its influence on wind erosion climatic erosivity in the wind erosion region of northern China[D]. Yantai: Ludong University, 2019.

[17] Yang Xinghua, He Qing, Li Hongjun, et al. Calculation and analysis on wind erosion climatic erosivity in the Tarim Basin[J]. Journal of Desert Research, 2012, 32(4): 990-995.

[18] Ma Qianqian, Xiao Jianhua, Yao Zhengyi, et al. Spatio-temporal evolution of wind erosion climatic erosivity in the Alxa Plateau during 1960–2017[J]. Scientia Geographica Sinica, 2021, 41(6): 1096-1104.

[19] Qi Donglin, Han Tingfang, Zhao Quanning, et al. Characteristics of regional variation of wind erosion climatic erosivity and number of wind days in winter and spring in Qinghai Province[J]. Research of Soil and Water Conservation, 2019, 26(2): 23-30, 36.

[20] Sun Yunfeng, Qiu Wei, Fan Jingyun. Spatial selection of ecological compensation in key ecological function area of Xinjiang[J]. Arid Land Geography, 2021, 44(2): 565-573.

[21] Yang Guanghua, Bao Anming, Chen Xi, et al. Wind erosion hazard assessment in Xinjiang based on RBFN model[J]. Journal of Desert Research, 2010, 30(5): 1137-1145.

[22] Fotheringham A S, Charlton M E, Brunsdon C. Geographically weighted regression: A natural evolution of the expansion method for spatial data analysis[J]. Environment & Planning A, 2016, 30(11): 1905-1927.

[23] Li Hanting. Spatial heterogeneity of vegetation change and driving factors in resource-based cities in arid area[D]. Beijing: China University of Geosciences (Beijing), 2020.

[24] Zhang Biao, Li Qingxu, Wang Shuang, et al. Spatial and temporal changes and regional differences of the sand fixing service in the Beijing-Tianjin sandstorm source region[J]. Journal of Natural Resources, 2019, 34(5): 1041-1053.

[25] Lou J P, Wang X M, Cai D W. Spatial and temporal variation of wind erosion climatic erosivity and its response to ENSO in the Otindag Desert, China[J]. Atmosphere, 2019, 10(10): 614-629.

[26] He Yi, Yang Taibao, Chen Jie, et al. Wind speed change in north and south Xinjiang from 1960 to 2013[J]. Arid Land Geography, 2015, 38(2): 249-259.

[27] Gao Jing. Research on the temporal and spatial distribution characteristics of strong wind and circulation feature of windy weather in Xinjiang[D]. Lanzhou: Lanzhou University, 2010.

[28] Gao Jing, Cui Caixia, Jing Lijun, et al. Spatial and temporal distribution characteristics and circulation background analysis of gale in Xinjiang in recent 49 years[C]//Chinese Meteorological Society. Climate Change and Its Impact in Typical Arid and Semi-arid Regions of the World. Beijing: Chinese Meteorological Society, 2012: 15.

[29] Jiapayi Daoran, Che Gang. Inter-decadal variation of wind speed in east Xinjiang[J]. Journal of Arid Meteorology, 2008, 26(3): 14-21.

[30] Li Yaohui, Zhang Cunjie, Gao Xuejie. Temporal and spatial distribution of gale weather over northwest China[J]. Journal of Desert Research, 2004, 24(6): 55-63.

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