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Study on spatio-temporal evolution and driving factors of soil wind erosion in Ordos City

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Abstract

Soil wind erosion is one of the main causes of soil loss / degradation. Studying its spatial and temporal distribution characteristics and influencing factors plays a key role in effectively inhibiting regional soil wind erosion, and provides scientific basis for regional windbreak and sand fixation and soil wind erosion prevention and control measures. This study takes Ordos City as the research object, and uses RWEQ model, Slope trend analysis method, Pearson correlation analysis and spearman correlation coefficient analysis method to quantitatively evaluate the spatial and temporal evolution and influencing factors of soil wind erosion modulus from 2000 to 2021. Research findings: 1) The soil wind erosion modulus showed a downward trend from 2000 to 2021, from 45.42 t/km²·a in 2000 to 14 t/km²·a in 2021. The soil wind erosion is mainly slight and mild erosion, which is distributed in the south and east of the study area, and the severe and extremely strong areas are distributed in the northwest of Hangjin Banner. 2) Precipitation, temperature and relative humidity had a negative correlation with soil wind erosion. Evaporation and sunshine hours had a positive correlation with soil wind erosion. Wind speed and soil wind erosion showed negative and positive correlations in the north and south of the study area, respectively. 3) The influence of socio-economic factors on soil wind erosion is ranked as follows: industrial waste gas emissions > tertiary industry > population density, coal mining > nighttime light index > primary industry, secondary industry > industrial waste generation > urbanization rate. The results showed that improving land use patterns and optimizing climatic conditions can effectively reduce soil wind erosion intensity and promote the improvement of ecological environment.

Keywords

Soil drifting; vegetation coverage; climatic factor; land utilization; driving factors.

1. Introduction

Wind erosion is a natural geomorphological process of separation, transport, and accumulation of surface materials under the action of wind [1], and is one of the main causes of land desertification in arid and semi-arid areas [2]. The harm of soil erosion lies in the destruction of land resources, the decline of soil fertility and quality, and the deterioration of the ecological environment [3], which poses a threat to human survival, economy, and ecological sustainable development, and is one of the key problems that seriously restricts the sustainable use of resources and environment in the world today [4].

With the application and development of remote sensing and geographic information technology, the wind erosion model has been gradually applied, and the wind erosion equation (WEQ), wind erosion prediction system (WEPS) and modified wind erosion model (RWEQ) have been proposed. Gong Guoli et al. [5] used the RWEQ model to analyze the spatiotemporal variation trend of the windbreak and sand fixation service function in Xilin Gol League, and Xing Lizhu et al. [6] studied the impact of climate change on soil wind erosion in Bayannur City based on the RWEQ model, and the results showed a downward trend. Jiang Ling et al. [7] estimated the soil wind erosion modulus in Qinghai Province based on the RWEQ model, and the results showed that mild erosion was the main problem. Chi Wenfeng et al. [8] studied soil wind erosion in the Inner Mongolia Plateau based on the RWEQ model, and the results showed that soil wind erosion was effectively suppressed. At the same time, the RWEQ model was used to simulate the wind erosion and the 137CS tracer method was used to verify the soil wind erosion modulus, and the fitting results were good. The model has been widely used in the calculation and evaluation of soil wind erosion and windbreak and sand fixation functions in China, such as the Hunshandak Sandy Land and the Hulunbuir Forest-Grassland Ecological Symtone, which shows that the RWEQ model has high feasibility in wind erosion simulation in China.

2. Overview of the study area

The Ordos section of the Yellow River Basin is located in the semi-arid area of Northwest China, the average temperature of the coldest month in this area is lower than-3 °C or below 0 °C, and the annual precipitation distribution is relatively uniform, and the precipitation in the driest month in summer is less than 1/3 of the precipitation in the wettest month in winter, it belongs to the typical north temperate continental weather. Which belongs to the typical northern temperate continental weather. With a total area of 87,000 km^2, the Ordos section of the Yellow River Basin is a city. with seven banners and two districts. This is neighboring Shaanxi, Ningxia Hui Autonomous Region and Shaanxi in the east, west and south, and Bayannur and Baotou in the north across the Yellow River. Drought is a common climate problem in the Yellow River Basin. The average annual precipitation is between 190 mm and 300 mm. The lack of precipitation leads to the lack of soil moisture, which limits the growth metabolism and photosynthesis of vegetation, and then reduces the soil wind erosion [8]. The average annual temperature is between 6 °C and 8 °C, and the extreme temperature ranges from -35 °C to 40 °C, with the lowest temperature in January and the highest temperature in July. Persistent high temperature may lead to extreme weather events such as drought, aggravate the negative impact on vegetation soil wind erosion, accelerate soil moisture evaporation, and restrict vegetation growth. The frequency and intensity of extreme climate events caused by climate change are increasing, which brings greater survival pressure to vegetation [9] and puts vegetation soil wind erosion at greater risk. see Figure 1.

3. Data Sources and Research Methods

3.1. Data Sources

The data of 9 meteorological stations in the second district of 7 counties in Ordos City were downloaded from the China Meteorological Network, and the interpolation analysis of the station data was carried out by using the kriging interpolation method in ArcGIS 10.8 to obtain raster images of meteorological data, and the downloaded soil type data attributes included soil sand content, soil silt content, soil clay content, organic matter content, calcium carbonate content, and the spatial resolution of soil wind erosion data was 250m. For the data with different spatial resolutions, the spatial resolution of the data is adjusted to 250m by the resampling tool in GIS. see Table 1.

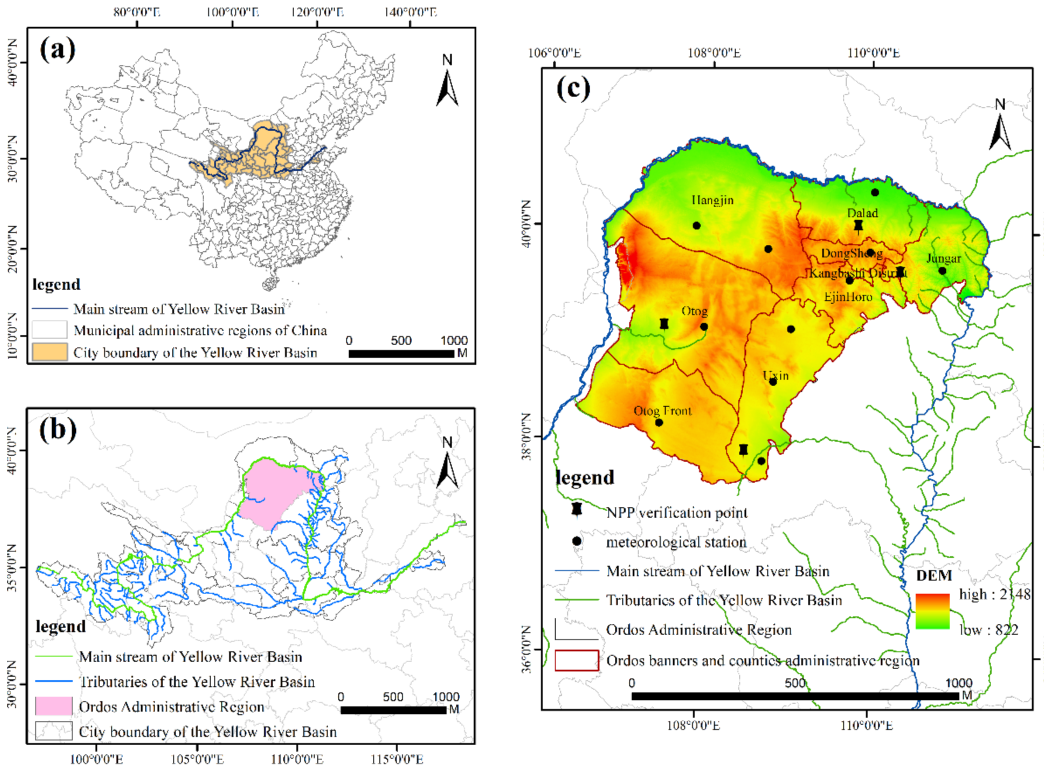

Figure 1. Overview of the study area

Table 1 Data source

data type	data sources
meteorological data	China Meteorological Data Network of National Meteorological Data Center
Topography, soil type	Institute of Geographical Science and Resources, Chinese Academy of Sciences and Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences
normalized difference vegetation index	Application for Scientific Data Center in Cold and Arid Areas was obtained
digital elevation model	geographical spatial data cloud
Soil moisture, snow cover factor	National Glacier Frozen Desert Science Data Center

3.2. Research Methodology

3.2.1. Soil Wind Erosion Model (RWEQ)

In this study, the modified soil wind erosion model (RWEQ) was used to calculate the soil wind erosion rate in Ordos City from 2000 to 2021 by fully considering the climatic conditions, vegetation conditions, surface soil roughness, soil erodibility, and soil crust factors [9].

$$SL = \frac{2z}{S^2} Q_{max} e^{-(z/s)^2} \tag{1}$$

$$S = 150.71(WF \times EF \times SCF \times K' \times COG)^{-0.3711} \tag{2}$$

$$Q_{max} = 109.8 (WF \times EF \times SCF \times K' \times COG) \tag{3}$$

where: SL is the wind erosion modulus; Q_max is the maximum transfer of potential wind erosion; z actual plot length; S was the length of the plot with 0.6321 times the maximum soil transfer, WF was the meteorological factor, EF was the soil erodibility factor (dimensionless), SCF was the soil crust factor (dimensionless), and K′ was the surface roughness factor (dimensionless). COG is a comprehensive vegetation factor. The correction and calculation formula of each factor are as follows:

(1)Weather Factor (WF)

The meteorological factor WF comprehensively considers the comprehensive effects of wind speed, temperature, rainfall, solar radiation and snowfall on wind erosion, and the calculation formula is as follows:

$$WF = \frac{\sum_{i=1}^{N} WS_2 (WS_2 - WS_t)^2 N_d \rho}{N \times g} \times SW \times SD \tag{4}$$

where: the WS_2 is the wind speed at the height of 2m, m/s; The WS_t is a critical wind speed of 2m, and according to the wind tunnel test study, when the water content is about 0.8%, the sand wind speed is 4.5~5m/s, so the critical sand wind speed in Ordos City is 5m/s; N is the number of observations of wind speed, and 500 times were taken in this study; N_d is the number of days of experimentation; ρ is the air density, kg/m^3, calculated based on altitude and absolute temperature. g is the acceleration due to gravity, m/s^2, and the value in this paper is 9.8 m/s^2; SW is the soil moisture factor; SD is the snow cover factor.

(2) Soil Erodibility Factor (EF)

$$EF = \frac{29.09 + 0.31S_a + 0.17S_i + 0.33\frac{S_a}{CL} - 2.59OM - 0.95C_aCO_3}{100} \tag{5}$$

where: S_a is the content of soil sand, S_i is the content of soil silt, CL is the content of soil clay, OM is the content of organic matter, and C_a CO_3 is the content of calcium carbonate.

(3) Soil Crust Factors

$$SCF = \frac{1}{1 + 0.0066(CL)^2 + 0.021(OM)^2} \tag{6}$$

Where: CL the soil clay content and OM is the organic matter content.

(4) Surface Roughness Factor (K′)

$$K = \cos(slope \times \Pi/180) \tag{7}$$

Where: Sope is the slope, which is extracted by ArcGIS according to the DEM data.

(5) Comprehensive Vegetation Factors

$$COG = e^{-0.0438(SC)} \tag{8}$$

$$SC = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \tag{9}$$

Where: SC is the vegetation coverage, the NDVI _max is the maximum NDVI, and the NDVI _min is the minimum.

3.2.2. Trend Analysis

The interannual trend of soil wind erosion is represented by the slope of the univariate linear regression equation of continuous raster data, and the regression equation is obtained by the least squares method, and the specific formula is as follows:

$$RWEQ_{slope} = \frac{n\sum_{i=1}^{n}(i \cdot RWEQ_i) - \sum_{i=1}^{n} RWEQ_i \sum_{i=1}^{n} i}{n \cdot \sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2} \tag{10}$$

where: n denotes the number of years of study; soil wind erosion _i represents the soil wind erosion value in the ith year; slope represents the interannual trend of soil wind erosion; slope>0 indicates an increasing trend during the study period, while vice versa decreases; In this paper, the natural breakpoint method was used to divide slope into three grades: significant decrease (slope≤0), no significant change (0<slope<0.01), and significant increase (slope≥0.01).

3.2.3. Correlation Analysis

In this paper, six meteorological factors, including evaporation, relative humidity, air temperature, sunshine hours, surface air temperature and precipitation, were selected to calculate the spearman correlation coefficient between meteorological factors and soil wind erosion. The correlation coefficient is calculated as follows:

$$R_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \tag{11}$$

where: R_xy is the correlation coefficient between soil wind erosion and various climatic factors; x_i is the soil wind erosion modulus of vegetation in the ith year. y_i is the value of meteorological factors in the ith year; x¯ and y¯ represent the mean of each factor, and n is the number of samples.

3.2.4. Geodetector model

Geographical detector is a statistical method proposed by Wang Jinfeng et al. This method can evaluate whether the explanatory power of various ecosystem service functions is enhanced or weakened when social and economic factors play a role in various ecosystem service functions. The spatial differentiation is measured by the geographical detector q value, and the value range is [0, 1]. The larger the q value, the stronger the explanatory power of this factor to various ecosystem service functions, and vice versa.

4. Results and Analysis

4.1. Spatiotemporal Evolution of Soil Wind Erosion

According to Fig. 3, the wind erosion simulation results based on the RWEQ model show that the soil wind erosion modulus in Ordos City has undergone significant changes from 2000 to 2021. The wind erosion modulus was the highest in 2000 at 45.42 t/km²·a, and the lowest in 2008 was 4.77 t/km²·a. Since 2000, the soil wind erosion modulus has shown a decreasing trend year by year. Specifically, from 2000 to 2009, the wind erosion modulus decreased sharply, from 45.42 t/km²·a to 11.07 t/km²·a. From 2010 to 2021, the rate of decline slowed down, from 22.18 t/km²·a to 14 t/km²·a, with an average annual decrease of 1.49 t/km²·a. see Figure 2.

According to Table 2, according to the Soil Erosion Classification and Grading Standard (SL190-2007), soil erosion intensity is divided into six grades. The wind erosion simulation based on the RWEQ model and the application of ArcGIS raster calculator reveal the spatial and temporal distribution characteristics of soil wind erosion in Ordos City from 2000 to 2021. The main manifestations are slight erosion and moderate erosion, accounting for 56.42% and 12.36% of the wind erosion area, respectively, and the rest of the wind erosion intensity accounts for about 15% of the wind erosion area. In general, the intensity of soil wind erosion in Ordos showed obvious spatial differences. According to Fig. 4, the soil wind erosion in the study area decreased significantly from 2000 to 2005, and increased significantly in the Kubuqi Desert area in the northwest of Hangjinqi from 2005 to 2010, while there was no significant change in the rest of the area. From 2010 to 2015, the wind erosion modulus in the western and northern parts of the Jungar Banner, Ejin Horo Banner and Hangjin Banner decreased significantly, while there was no significant change in the rest of the region. From 2015 to 2021, the soil wind erosion modulus decreased significantly in the northern part of the study area, increased significantly in the northwest of Hangjinqi, and did not change significantly in other areas. Overall, the wind erosion of soil in the city has been significantly reduced. This is closely related to factors such as vegetation coverage and moderate rainfall in the region. These factors work together to inhibit the development of soil wind erosion. see Figure 3. Table 2.

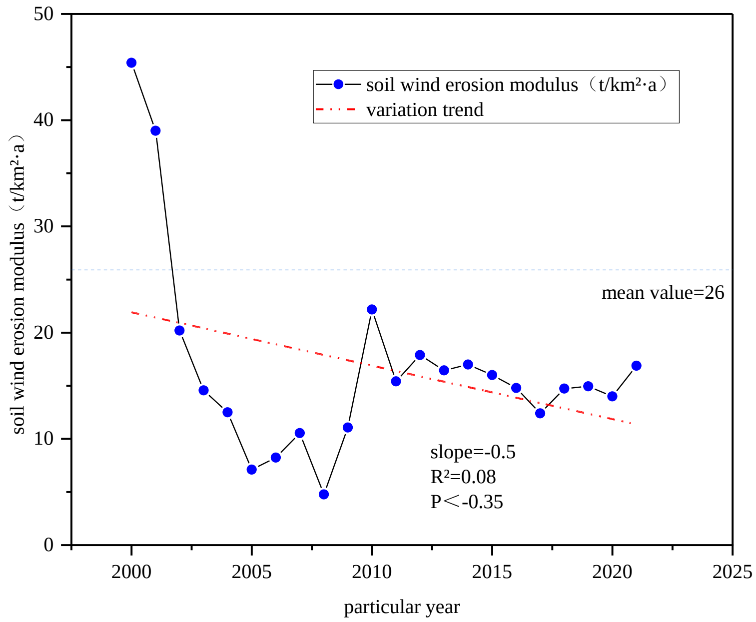

Fig.3 Changes of soil wind erosion time in Ordos City from 2000 to 2021

Table 2 Soil erosion classification standard (SL190-2007)

wind erosion intensity	Classification Standard of Soil Erosion / （t/km²·a）
Micro-erosion	0-2
light erosion	2-25
middle-extent erosion	25-50
intensive erosion	50-80
Very strong erosion	80-150
serious erosion	＞150

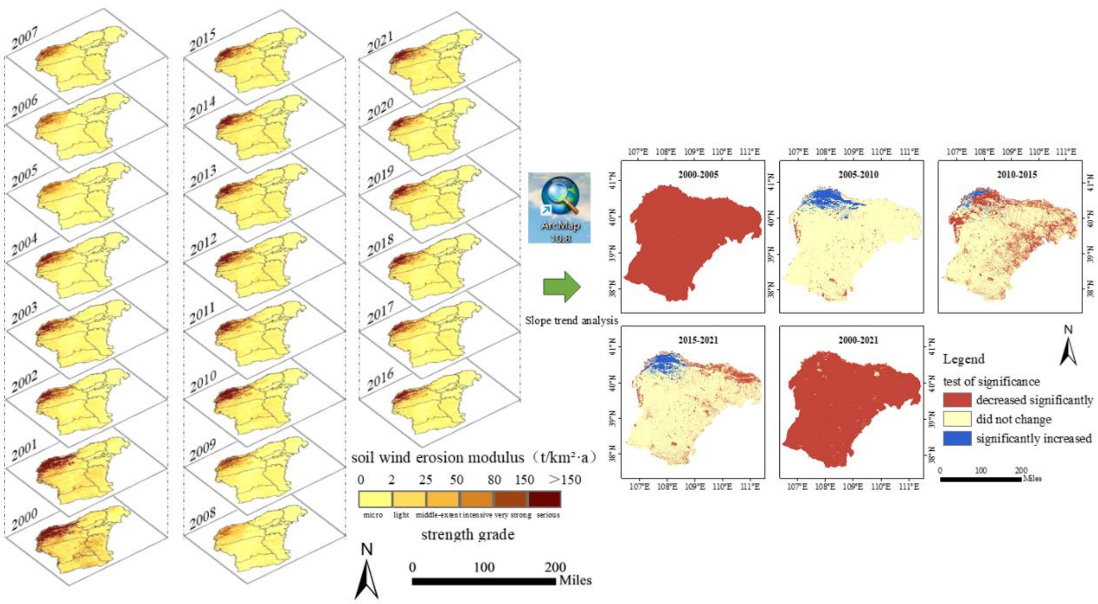

Fig.3 Spatio-temporal variation and trend analysis of soil wind erosion in Ordos City from 2000 to 2021

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4.2. Analysis of Influencing Factors of Soil Wind Erosion

4.2.1. Effects of Climate Change on Soil Wind Erosion

There was no significant negative correlation between soil wind erosion and precipitation, which was mainly reflected in other areas outside the northwest of the study area, and the negative correlation area accounted for 98.18 % of the whole region. It is negatively correlated with temperature in Jungar Banner, western Otog Banner, Otog Front Banner and southern Uxin Banner, accounting for 55.4 % of the regional area. It is positively correlated with temperature in Dalate Banner, Dongsheng District and Ejin Horo Banner, accounting for 44.6 % of the regional area. There was no significant negative correlation between soil wind erosion and relative humidity in the north and south of the study area, accounting for 95.84 % of the area. There was a significant positive correlation between evaporation and evaporation, accounting for 85.64 % of the regional area, and no significant positive correlation accounted for 13.53 % of the regional area. There was no significant positive correlation between soil wind erosion and sunshine hours in Jungar Banner, Ejin Horo Banner, Dalate Banner and eastern Hangjin Banner, accounting for 61.17 %, and no significant negative correlation in other areas, accounting for 38.46 %. The wind speed was positively correlated with soil wind erosion in the southern part of the study area and the northern part of Dalad Banner, accounting for 40.76 % of the regional area. The wind speed was negatively correlated with soil wind erosion in Hangjin Banner, the central and northern parts of Otog Banner, Jungar Banner, the southern part of Dalad Banner, Ejin Horo Banner and the northern part of Uxin Banner, accounting for 58.38 % of the regional area.

In general, precipitation, temperature, relative humidity and wind speed have a negative correlation with soil wind erosion, while evaporation and sunshine hours have a positive correlation with soil wind erosion. It shows that the greater the evaporation and sunshine hours, the greater the soil wind erosion in this area, and the evaporation and sunshine hours have a significant effect on soil wind erosion. The precipitation, temperature and relative humidity have an inhibitory effect on soil wind erosion. Figure 4.

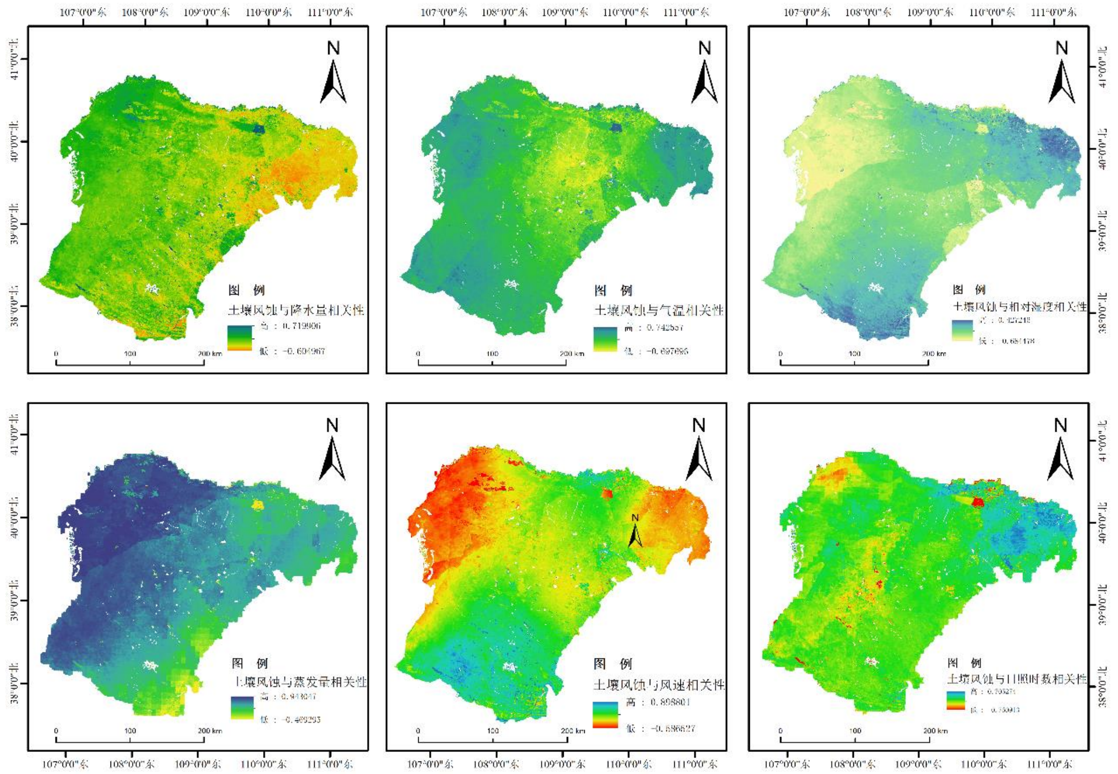

Fig.4 Correlation coefficient between soil wind erosion and various meteorological factors

4.2.2. Effects of socio-economic factors on soil wind erosion

The explanatory power of each factor to the spatial heterogeneity of soil wind erosion is ranked as follows: Industrial waste gas emissions > tertiary industry > population density, coal mining > night light index > primary industry, secondary industry > industrial waste production > urbanization rate. The explanatory power of industrial waste gas emissions is greater than 0.85, which is far greater than other factors. The explanatory power of the tertiary industry, population density, coal mining and night light index is greater than 0.55, which is a secondary influencing factor. Secondly, the explanatory power of primary industry, secondary industry and industrial waste production is greater than 0.4. The effect of urbanization rate on soil wind erosion was not significant. see Figure 5.

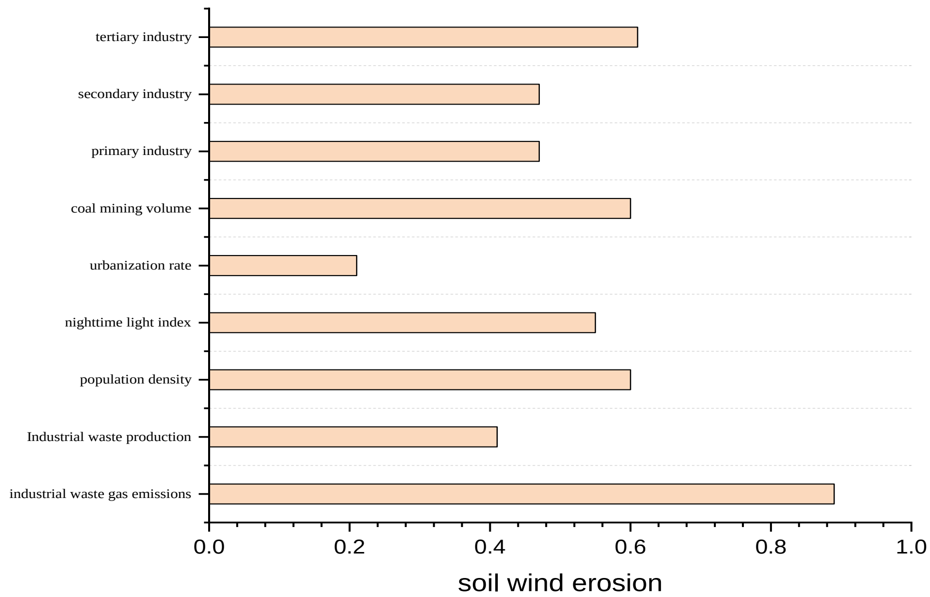

Fig.5 Correlation q value between soil wind erosion and socio-economic factors

5. Discussion

This study revealed the spatiotemporal variation and influencing factors of soil wind erosion in Ordos City from 2000 to 2021, and found that soil wind erosion in Ordos City decreased significantly, which is consistent with the conclusion of Li Dajing et al. [10] and Wu Xiaoguang et al. [11] that the erosion of wind erosion climate in northern China was reduced, and that vegetation coverage and precipitation were important factors to inhibit the occurrence and development of soil wind erosion, which was consistent with the results of Yang Zhenkang et al. [12], Guo et al. [13], and Li Qing et al. [14].

The wind erosion modulus of unused soil is the highest, which is due to the lack of vegetation cover, the soil is directly exposed to wind, and there is no blocking and fixing effect of vegetation, and the soil texture may be relatively loose, the cohesion between particles is weak, and it is more likely to be eroded under the action of wind. The water body has a certain damping effect on the wind, which reduces the wind speed and reduces the erosion ability of the wind to the surrounding soil. Construction land generally has buildings and hardened ground, and these structures can block the flow of wind and reduce the direct effect of wind on the soil. Some soil solidification measures may be taken during the construction process to improve the wind erosion resistance of the soil; The wind erosion modulus of grassland, cultivated land and woodland decreases sequentially, which may be due to the fact that grassland has a certain vegetation cover, which can reduce wind speed and fix soil particles, thereby reducing wind erosion. However, the vegetation coverage and root depth of grassland are smaller than those of woodland, so the wind erosion modulus is relatively large. When crops grow on cultivated land, crops can also play a certain role in preventing wind erosion. However, the risk of wind erosion varies depending on the stage of tillage and the soil exposure is different. The high vegetation coverage of the woodland and the developed root system of the trees can more effectively fix the soil and reduce the wind erosion modulus.

Soil wind erosion is positively correlated with evaporation and sunshine hours, which may lead to rapid water loss in the soil due to higher evaporation and sunshine hours, and the soil structure becomes more loose, and the soil surface layer forms dry and hard crusts, which are easy to break and be transported by the wind, which aggravates the wind erosion process. Precipitation, air temperature, relative humidity, and surface air temperature were negatively correlated with soil wind erosion, which was consistent with the results of Wang et al. [15], because precipitation promoted vegetation growth and improved vegetation coverage. Lower air and surface air temperatures may condense moisture in the soil, increasing soil moisture; Higher relative humidity may promote the dissolution and precipitation of chemicals in the soil, improve soil structure, and increase the soil's resistance to wind erosion. In this study, soil wind erosion was positively correlated with wind speed in the south and negatively correlated in the north. This may be due to the fact that the southern part of Ordos City has more windy days, and according to historical data and meteorological records, the southern part of Ordos City is often affected by strong winds in spring and summer. Spring is one of the seasons with frequent winds, and the number of spring windy days in the city is between 5~15 days, which still belongs to the windy period. The number of windy days in the northern part of Ordos City is more in spring, and the specific number of days is 5~10 days, which indicates that spring is the season when the windy weather in the northern part of Ordos City is more frequent, and the number of windy days is less.

In this study, the GIS kriging interpolation method is used to achieve regional coverage, and the accuracy of interpolation is uncertain, so a large amount of data need to be supplemented in the study of the influencing factors of soil wind erosion. In addition to the wind speed, precipitation and vegetation coverage selected in previous studies, this study added climatic factors such as surface air temperature, relative humidity, sunshine hours, evaporation, etc., as well as the effects of different land use patterns on soil wind erosion. The change of soil wind erosion intensity is the product of the combined influence of many factors, among which climatic conditions, vegetation cover, and land cover change are the key factors determining the change of soil wind erosion modulus intensity [17], and a series of measures to improve the ecological environment have been carried out since 2000, which have played a certain role in regional soil and water conservation and windbreak and sand fixation [16].

6. Conclusion

(1) From 2000 to 2021, soil wind erosion showed a decreasing trend, from 45.42 t/km2·a in 2000 to 14 t/km2·a in 2021. There are great differences in soil wind erosion in the region, and the soil wind erosion is mainly micro-erosion and mild erosion, which are mainly distributed in the southern and eastern parts of the study area, mainly in the southern and eastern parts of the study area, such as Etog Banner, Etog Front Banner, Uxin Banner, Yijin Horo Banner, Dongsheng District and Jungar Banner, accounting for 56.42% and 12.36% of the wind erosion area. The intense and extremely intense areas are distributed in Hangjinqi in the northwest of the study area.

(2) From 2000 to 2021, there were significant differences in soil wind erosion modulus among different land use types, among which the largest wind erosion modulus was unused land, followed by water, construction land, grassland, cultivated land and forest land. The soil wind erosion modulus of various land use types showed a decreasing trend, and the cultivated land,

forest land, grassland, water area, construction land and unused land decreased by 10.1 t/km²·a, 6.4 t/km²·a, 24 t/km²·a, 46.3 t/km²·a, 97.9 t/km²·a and 240.7 t/km²·a, respectively.

(3) There was a negative correlation between soil wind erosion and vegetation coverage, that is, the higher the vegetation coverage, the less soil wind erosion. The vegetation coverage of the Kubuqi Desert in the northern part of Hangjinqi did not change much, which made the soil wind erosion tend to be stable. Among the meteorological factors affecting soil wind erosion, evaporation and sunshine hours were positively correlated, while precipitation, temperature, relative humidity and surface air temperature were negatively correlated with soil wind erosion. Wind speed was negatively correlated with soil wind erosion in the northern part of the study area, and positively correlated with soil wind erosion in the southern part of the study area.

(4) The influence of socio-economic factors on soil wind erosion is ranked as follows: industrial waste gas emissions > tertiary industry > population density, coal mining > nighttime light index > primary industry, secondary industry > industrial waste generation > urbanization rate.

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