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Research on the Early Warning Model of Environmental Desertification Based on Grid Scale

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ABSTRACT

Based on the causes of environmental desertification in the three aspects of climate, surface and human culture, the early-warning index system of desertification was constructed, and the early-warning model was established. Arc GIS was used to quantify and rasterize the data of each factor. In the past 60 years, the area of desertification increased from 53,000 km 2 to 114,000 km 2, bringing great harm to the ecological environment and social economy. The early warning model was used to realize the desertification degree distribution on the raster scale (30 m 30 m), in the three periods, in the research area. The results of the first two periods and the third period were respectively used for parameter correction and verification. On this basis, the development trend of desertification in the study area in 2021, under the condition of “intermittent water transfer” and “no water transfer”, is predicted. The simulation accuracy of desertification degree distribution in the study area is over 90% through parameter correction and early warning model, which has good applicability.

INTRODUCTION

Desertification is a process of land degradation in arid, semi-arid and partly semi-humid areas, which is mainly marked by wind-sand activities due to the incoordination between excessive human activities and resources and environment. In the past 60 years, the area of desertification increased from 53,000 km^2 to 114,000 km^2, and this land degradation has brought great harm to the ecological environment and social economy (Song & Yan 2017).

Based on the above problems, this article on grid scale research, considering the deficiency of the early warning system for desertification from desertification formation factors, to the lower reaches of Tarim river as the study area, plans to build early warning index system and warning model of high precision, based on the climate, surface, and cultural aspects of the data in the study area.

PAST STUDIES

At home and abroad, the relevant research on desertification early warning is far less than the research on its cause analysis, dynamic evaluation, remote sensing monitoring, physical and biological processes and other aspects. Yassoglou et al. (2017) performed the desertification monitoring by using decision tree classification based on Landsat 8 OLI image, and introduced the monitoring results into the “pressure-state-response” model, integrated the influencing factors of desertification and human response measures, and realized desertification warning. Based on Envi5.1 software, a recent study used TM image data from 1995 and 2015 to monitor and classify desertification land in Turpan region through the combination of maximum likelihood method and visual interpretation method (Ajaj et al. 2017). A study used field survey combined with remote sensing technology to monitor the development of desertification in Ningxia, and Arc GIS software was used to interpret and draw the current situation and classification of desertification (Ahmadybirgani et al. 2017). The human-computer interactive visual interpretation method was used to extract the land information of different degrees of desertification in the research area from 2000 to 2015 and analyse the distribution characteristics and change trend of different degrees of desertification in different elevations, slopes and upward slopes (Dai et al. 2017).

MATERIALS AND METHODS

Analysis of Influencing Factors of Desertification

The main research object of this paper is the lower reaches of Tarim river in Xinjiang. According to the previous research results on desertification, the causes of desertification can be divided into two aspects: natural factors and human factors, among which natural factors are divided into climatic factors and surface factors.

In terms of climate, this area is an extremely arid area, which is located in the middle of two deserts. The perennial precipitation is rare, and the summer high temperature evaporation is very strong. Such a climate with much less precipitation than evaporation makes the vegetation growth environment harsh, providing favourable underlying surface conditions for the activation of fixed dunes. At the same time, the huge diurnal temperature difference in the study area makes the wind speed very large, which provides a good dynamic condition for sand erosion. Therefore, the climatic factors affecting desertification in the study area are mainly precipitation, temperature and wind speed (Sherratt & Synodinos 2017).

On the surface, vegetation coverage, surface water resources and groundwater level are representative factors affecting desertification in the study area. In the case of normal sand-raising wind speed, the vegetation coverage of 30% ~ 50% of the land surface can play an obvious sand-fixing effect, but when the vegetation coverage is less than 20%, the sand-raising phenomenon is more serious, and when the local surface vegetation coverage is more than 60%, even if the wind speed is more than $10 m\cdot s^{-1}$, sediment transport rate is very small. Since the construction of Daxi Haizi reservoir in 1972, the source of surface water in the study area has been controlled, which has played a great role in promoting the development of desertification. In the study area, even in most arid and semi-arid areas, the groundwater level plays an important role in controlling desertification (Zhang et al. 2018).

With the increase of the population, the cultivated area increases year by year and the livestock increases year by year, resulting in the barren land and the serious destruction of vegetation. Therefore, the human factors that can represent its desertification, are the number of population and the number of livestock.

Establishment of Early Warning Index System and Early Warning Model

According to the above analysis, considering the occurrence and development of desertification has a strong seasonal, mainly concentrated in the summer and winter, and the characteristics of remote sensing data acquisition period September, this study applied three aspects i.e. the desert climate, surface, and cultural of the nine factors extracted indicators and built an early warning index system, as shown in Fig. 1.

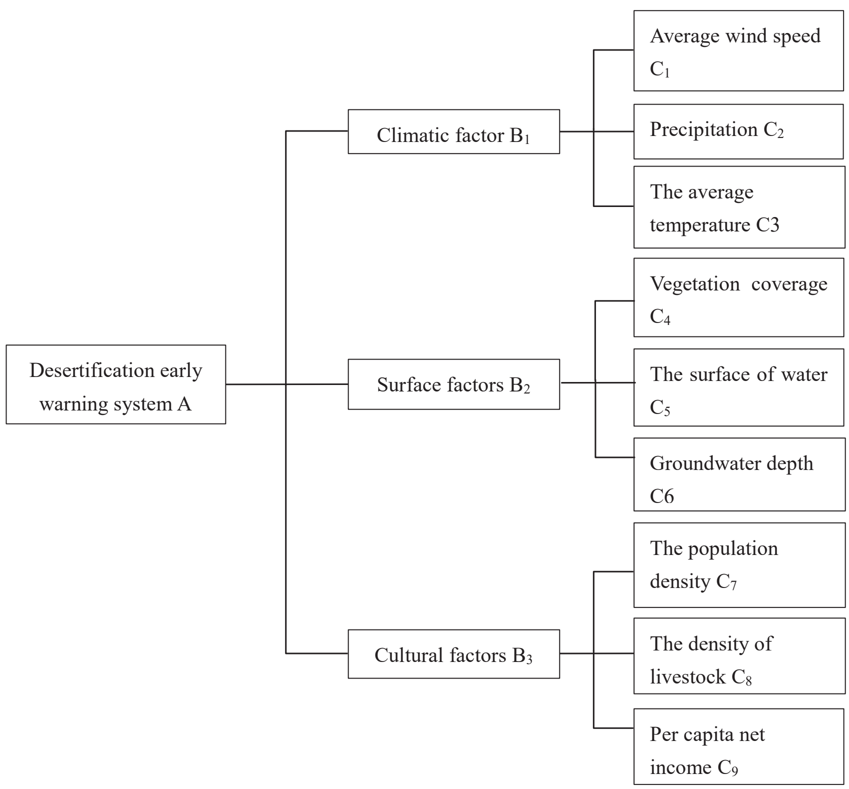

Fig. 1: Desertification warning indicator system.

Different indicator factors have different effects on desertification. Weight (W_{Ci}) is used to represent the contribution of factors in the indicator system to desertification, and the greater the weight value is, the greater the contribution will be, and vice versa (Tombolini et al. 2016). The mathematical expression of the early-warning indicator system is:

$$S_c = \begin{pmatrix} C_1, & W_{C_1} \\ C_1, & W_{C_1} \\ \dots & \dots \\ C_1, & W_{C_1} \end{pmatrix} \quad \dots(1)$$

In view of the defects of CA model in the accuracy of raster scale desertification simulation, a desertification warning model that can be modified is proposed:

$$SM = \eta \sum_{i=1}^{n} \left(Q_i W_{C_1} \right) \quad \dots(2)$$

Where, SM is the desertification degree index; η is the vertical adjustment parameter used to correct the model; N is the number of factors in the indicator system, where n = 9; Qi is the factor intensity index of the ith factor; W_{Ci} is the factor weight coefficient, and the product of the two represents the contribution of factor I to the degree of desertification (Budak et al. 2018).

SM defines the degree of desertification from the mathematical category. For the classification of the degree of desertification and the definition of the corresponding index, the 0-1 scale method is used to represent SM, and the corresponding classification of SM and the degree of desertification is shown in Table 1.

Similar to SM, Qi also quantifies the impact of factors on desertification in the index category. As the development degree of each factor is different, the effect on desertification is obviously different, so Qi can also be understood as the mapping of the development degree of each factor on the degree of desertification. Qi was quantified based on the upper and lower limits of the impact of factors on desertification (Xu et al. 2016). Based on the existing research results of desertification in the research area and the long-term field observation results, the upper and lower limits of the intensity of each factor are determined, as shown in Table 2.

The calculation methods of index factor W_{Ci} mainly include principal component analysis (PCA) and analytic hierarchy process (AHP). Based on the discontinuity of long-term data, AHP is adopted to construct judgment matrix, calculate weight, consistency test, factor weight synthesis and other steps, and the weight coefficients of each factor are obtained as shown in Table 3.

Table 1: Classification of desertification degree and corresponding desertification degree index.

Divide content	A typology				
	Desertification	Moderate desertification	Moderate desertification	Severe desertification	Extremely severe desertification
Desertification Degree index	[0，0.20]	（0.20，0.40]	（0.40，0.60]	（0.60，0.80]	（0.80，1.00]

Table 2: The upper and lower limits of the intensity of desertification warning factors were studied.

Factor	Maximum	Minimum
Average wind speed/($m \cdot s^{-1}$)	2.62	1.42
Precipitation/mm	100	10
Average temperature/°C	35	5
Vegetation coverage/%	50	10
Amount of surface water resources/ (Ten thousand $m3 \cdot km^{-2}$)	21.48	1.23
Groundwater depth/m	7.8	4.86
Population density/($People \cdot km^{-2}$)	60	7
Density of livestock ($Head \cdot km^{-2}$)	25	5
Per capita household net operating income/Yuan	1100	450

Table 3: The weight coefficient of early warning indicators of desertification.

Factors affecting (Bi)	Weight coefficient (WBi)	index factor (Ci)	Weight coefficient (WCi)
Meteorological factors B1	0.3275	Average wind speed C1	0.1802
		Precipitation C2	0.0787
		Average temperature C3	0.0685
Surface factors B2	0.4126	Vegetation coverage C4	0.2036
		Amount of surface water resources C5	0.0808
		Groundwater depth C6	0.1282
Cultural factors B3	0.2599	Population density C7	0.0509
		Density of livestock C8	0.1282
		Per capita household net income C9	0.0808

DATA COLLECTION AND PROCESSING

Vegetation coverage in surface data is obtained through remote sensing data processing, surface water resource amount is calculated based on ecological water transport volume of the study area over the years, and groundwater depth data is obtained through spatial interpolation based on the recorded data of monitoring wells in the lower reaches of Tarim river.

Meteorological data as a single point of data cannot be achieved in the spatial distribution of grid scale. Using projection transformation of global daily meteorological data and the data extraction, resampling (grid resolution 30m×30m) after processing, and then, using the data from weather stations meteorological elements in the study area after modification on grid scale spatial distribution.

For humanities data first calculate population density and the density of livestock in the study area. Population density, for example, first according to the research between land use types in densely populated areas (land), sparsely populated area (woodland and grassland) and nonhuman estuary (desert, water), based on the actual investigation of population distribution, the woodland and grassland according to the proportion of 5:1 and 10:1 converted into arable land, calculated based on the total population of arable land, population density, then based on the conversion percentage reduction of woodland and grassland population density, the resulting grid scale distribution of population density in the study area, the same livestock concentration areas can get grid scale livestock density distribution.

The intensity index distribution of the spatial distribution of the above 9 factors on the raster scale was converted and calculated, and the intensity index distribution of the raster scale was obtained. Taking factor Ci as an example, the specific process is as follows: suppose the measured value of factor Ci is X1 ~ Xn; when Ci is Xi (X1 Xi Xn), it starts to play a role in desertification; when Ci is Xj (X1 Xi Xj Xn), it plays a decisive role in desertification; therefore, Xi and Xj are the lower limit and upper limit of Ci respectively. When Ci Xi, the intensity index Qi of factor Ci is all set to 0. When Xi < Ci < Xj, Qi = (Ci-Xi)/(Xj-Xi) (0 < Qi < 1); When Ci Xj, Qi is equal to 1. So, the value of Qi is [0,1].

RESULTS AND ANALYSIS

The degree of desertification predicted by the early-warning model is based on the prediction of the indicator factors. Therefore, the development prediction of the factors is the premise of the degree of desertification forecast in the research area. In this paper, the degree of desertification in the study area in 2021 is predicted, and considering that ecological water transport has a strong effect on the surface water resources, vegetation coverage and groundwater depth of the study area, and thus affects the change of desertification, it is necessary to make a distinction between "intermittent water transport" and "no water transport". Among them, the condition of "intermittent water transfer" refers to the condition that the current water transfer frequency and water amount remain unchanged, that is, the water transfer is carried out every two years, each time the water amount is the same and equal to the annual average of the previous water amount (3.134 ×108m^3).

INDEX FACTOR PREDICTION

Ignoring the climate change in a short time and the influence of water, so based on the meteorological site history data using conventional linear model and moving average model to realize the study area in 2021 sites prediction, and accordingly the change of the site to realize the whole wind speed, temperature and precipitation in the study area factor grid scale data transformation. Surface factors, which involve vegetation coverage, groundwater depth and surface water resources, are strongly affected by water transport and must be analysed differently. Under the condition of "intermittent water transfer", vegetation coverage improved to a certain extent. Based on the vegetation coverage distribution in 2012, the vegetation coverage distribution in the study area in 2021 was calculated according to the average annual change of the raster vegetation coverage. Under the condition of no water conveyance, vegetation coverage was calculated by using the difference of vegetation coverage in 1996 and 2006. Because only one water conveyance was completed before the image (September 4, 2006), the water conveyance this time was small and short, which had a negligible impact on vegetation coverage. Therefore, vegetation coverage distribution in 2021 under the condition of no water conveyance was calculated. According to the changes of monitoring data of groundwater between the eighth water conveyance (September 25, 2012) and the ninth water conveyance (October 10, 2013), the average annual decrease rate of groundwater depth is deduced, and then the groundwater depth distribution in 2021 without water conveyance is calculated. In the prediction of human factor population density and livestock density, the data are also obtained based on the statistical data and predicted by the linear regression model, which is not affected by the water transmission conditions, so as to obtain the above distribution on the grid scale. Under the condition of intermittent water transfer, the amount of surface water resources is calculated according to the set annual average water transfer volume. The distribution of surface water resources under the condition of no water transfer is the same as that in 1996.

PREDICTION OF DESERTIFICATION DEGREE

Based on the modified parameters and warning model, the desertification degree distribution of each grid scale in 2015 was calculated according to the distribution data of indicator factors under the two conditions of "intermittent water transfer" and "no water transfer".

ANALYSIS OF PREDICTION RESULTS

It can be seen from the analysis of Fig. 2, that under the condition of "intermittent water transfer", the land area of the study area increased by 57.16km^2 due to extremely severe desertification during the period of 2012-2021; increased land area by about 42.24km^2 due to mild desertification; moderate desertification with a reduction of about 85.89km^2; The other two changes are smaller. This indicates that the ecological water transfer has a great impact on the land of mild and moderate desertification in the study area, alleviating the continuous deterioration of desertification to a certain extent, but has a weak impact on the reversal of severe desertification, and even cannot prevent the continuous expansion of the land caused by extremely severe desertification.

Under the condition of "no water transfer", the non-desertification, mild desertification and moderate desertification land volume in the study area in 2021 were reduced, with the mild desertification land volume decreased the fastest and the most, reducing about 102.91km^2. At the same time, the volume increased by about 15.74km^2 in the case of severe desertification, and the volume increased significantly in the case of extremely severe desertification compared to the former, reaching 142.41km^2. The above changes indicate that the desertification process in the study area will accelerate under the current state after stopping the ecological water transfer.

In general, under the condition of "intermittent water transfer", the degree of desertification in the study area is partially reversed. Under the condition of "no water conveyance", the degree of desertification in the study area was completely deteriorated. The reverse effect of ecological water transfer on the degree of desertification in the study area is mainly manifested in the reverse transformation of land desertification type along the river. The effect on the degree of desertification is weak, which is reflected in the continuous deterioration of the severe desertification areas outside the river channel area. If the "intermittent water transfer", then the degree of desertification along the river will continue to improve, the two sides of the desert will not be connected, "green corridor" will be full of vitality. If the water is no longer transported, the degree of desertification in all areas in the study area will increase rapidly, and the areas along the river will be reduced to moderate or even severe desertification, the desertification on both sides of the river will be integrated, the "green corridor" will no longer exist, and the residents will be forced to move. Then, the abandoned farmland will soon be controlled by desertification, and the entire research area will become a complete desert.

CONCLUSION

According to the results of this paper, contrast "intermittent water" and "free water" two cases of desertification and slight desertification types of land of ecological water conveyance of the most significant response: the area to increase the "intermittent water", "water" the area is reduced, the manifestation of the geographical position of Daxi Haizi reservoir area along the river, under this also demonstrates the regional ecological environment vulnerability and the strong dependence of surface water resources.

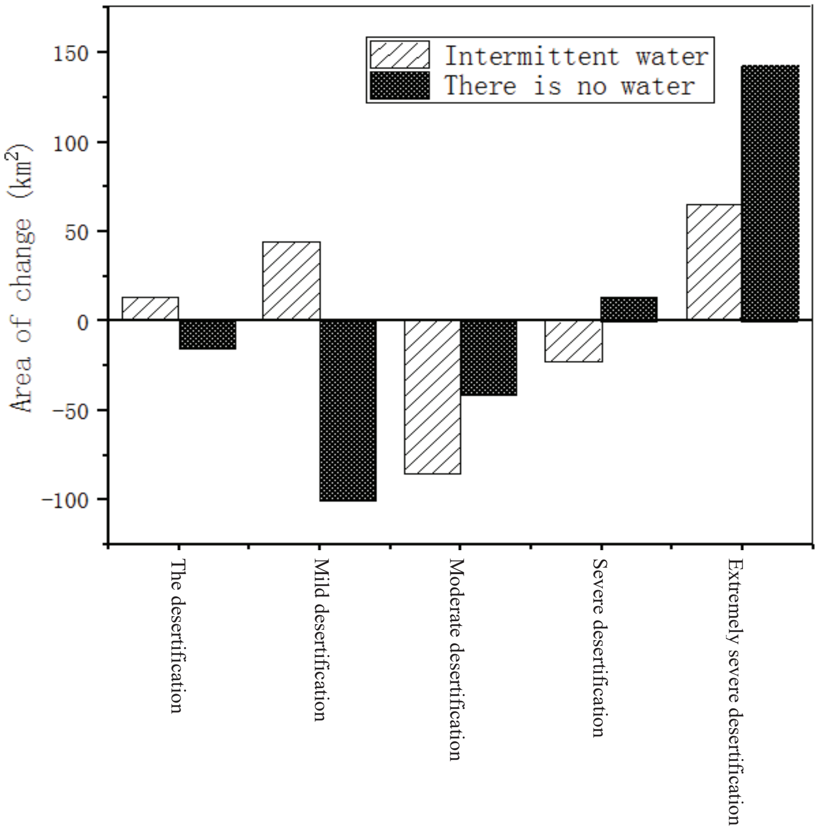

Fig. 2: Land area change map of different desertification degree types in the study area from 2012 to 2021.

According to the prediction results, it can be seen that the method can simulate the distribution of the degree of desertification in the study area with more than 90% accuracy through parameter correction and early warning model, and the early warning model has good applicability.

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