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Impact of Agricultural Activity and Climate Change on Spatio-Temporal Evolution in Soil Salinization in Manas River Basin, China

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Abstract

In this paper, our objectives were to: (1) explore the spatio-temporal evolution of soil salinization on a regional scale; (2) assess impact of application of modern agriculture; and (3) analyze the impact of climate change on soil salinization. Results from this research will further our knowledge of soil salinization processes and enhance regional environmental management.

Keywords

Soil salinization; Remote sensing; Modern agriculture; Climate change; Spatio-temporal evolution

Introduction

Soil salinization is recognized as a type of land degradation and has become a global problem. It is generally accepted that soil salinization in arid zone occurs as a consequence of groundwater resource overexploitation caused by improper management of irrigation facilities, unsuitable water quality, poor soil property, climate change etc. [1]. Therefore, we mainly take impact caused by human activities and the prevailing climate into consideration, when exploring the spatio-temporal evolution of soil salinization in Manas River basin, China.

Manas River plays a key role in the distribution patterns of oases in north of Xinjiang. In recent decades, with the development of modern agriculture, especially application of precision agriculture, agricultural production has been greatly improved. However, a large number of agricultural activities had caused negative effects. Cropland expansion along the Manas River, excessive exploitation of groundwater and unreasonable irrigation mode, which are main factors causing soil salinization. Much of cultivated land has been abandoned due to salinization. Impact of modern agriculture on soil salinization has been a significant problem. In addition, with change of global climate, climate in Xinjiang has a great change. Climate change can impact the water resource cycle and agricultural activities [2]. With no table increases in winter and spring precipitation [3], the variation of precipitation has a great impact on soil salinization and agricultural activities [4]. Hence, the impact of climate change should take into consideration, when assessing spatio-temporal evolution of soil salinization.

Methods

Study area

Manas River basin (85°01′-86°32′E, 43°27′-45°21′N; Figure 1) is located in the southern of Junggar Basin of Xinjiang Uyghur Autonomous Region, China. It is a typical mountain-basin system, drainage area of 31,000 km^2, Manas River has four branches from east to west, and its terrain tilts to the north. Due to located in inland of Eurasian continent, it has a temperate continental climate, with annual average temperatures of 4.7 to 5.7°C, average annual rainfall of 110-200 mm, and average annual evaporation of 1,500-2,100 mm. The main bodies of sedimentary system include fluvial, alluvial fan, alluvial plain and delta. Manas River basin is an economically important agriculture region in Xinjiang, so use of remote sensing to monitor and explore the spatio-temporal evolution of soil salinization is important for the sustainable development of eco-environment.

Data sources and preprocessing

The data used in the study included (1) Landsat MSS (1980-09-20), TM (2000-08-27), ETM+ (2010-09-14) data [5,6], which provided good products and critical information used an improved algorithm based on Mu et al. (2007, 2009, 2011), from 2000 to 2013. (3) Xinjiang Production and Construction Group Statistical Yearbooks, from 1990 to 2014.

For data preprocessing, ENVI4.8 version software was used to atmospheric calibration, geometric corrections, and subset via regions of interest (ROIs, vector border of study area). MODIS data used the MODIS Reprojection Tool (MRT) provided by NASA to transform the format (HDF to TIFF) and projection (from Sinusoidal projection to Geographic Lat/Lon, WGS1984).

Methods

Field study: According to landscape, land use type and salinization of land, we select 270 sites to acquire spectral data in three different geomorphic types. Description of sampling sites as shown in the Table 1.

Supervised classification

It can be used to cluster pixels in a dataset into classes corresponding to user-defined training classes. This classification type requires that select training areas for use as the basis for classification. In this study, we selected training areas (n=270) for spectral acquisition used ASD Field Spec 4Hi-Res Spectroradiometer. Applied supervised classification to interpret salinization area based on the spectral data, maximum likelihood classification is used, successfully extracted the water, desert, cropland, and salinization area etc.

Classification scheme of soil salinization

According to the field study, surface features of remote sensing image and previous salinization classification study, we identify the classification scheme of soil salinization (Table 2).

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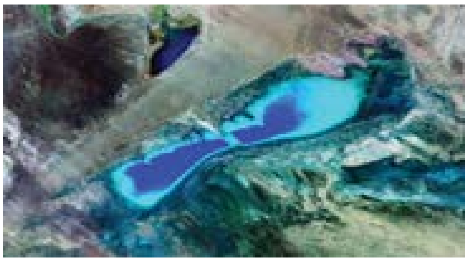

Figure 1 : Location of Manas River basin in Xinjiang, China. Administrative map, including: three counties (Manas, Shihezi, Shawan), labeled by acronym, respectively. River 4 represents Manas River, River 5 represents the branches (four) of Manas River. According to the sedimentary system, geomorphic type of study area, including: alluvial fan, alluvial plain, delta.

Table 1: The coordinates and description of sampling sites.

landscape	Longitude(E) Latitude(N)	Elevation (m)	Vegetation Type	Surface Feature
Alluvial fan	85°22′07.6″-85°23′09.2″ 44°21′02.6″-44°29′01.3″	400	*Phragmites australis*, *Karelinia caspica*, *Salsola* spp.	Salt efflorescence
Alluvial plain	85°22′08″-86°55′25.06″ 44°29′36.2″-44°59′35″	340	*Halostachys caspica*, *Alhagi sparsifolia*.	Salt crust
Delta	85°06′57.05″-86°43′12″ 44°09′11.3″-45°11′23″	300	*Reaumuria soongorica*, *Nitraria* spp., *Suaeda* spp.	Salt speckles

Table 2: Classification scheme.

Classification	Description
Water	River, Reservoir, Lake, Pool
Non-salinization	Distribute in cultivated land, including: cropland, grassland
Mild salinization	Distribute in between non-salinization and cropland, with vegetation cover less than 20%
Moderate salinization	Distribute sporadically, with vegetation cover less than 10%
Severe salinization	Obvious salt crust and salt speckles on the surface, with little vegetation cover

Regression analysis

Linear regression analysis can be used to simulate the changing trend of each pixel. Describing both the direction and steepness of the regression line, the slope coefficient of the fitted regression line at each pixel, where a slope >0 indicated an increasing trend for evapotranspiration (ET) and a slope <0 indicated a decreasing trend, was defined as:

$$\text{Slope} = \frac{n \times \sum_{i=1}^{n}(i \times MET_i) - \sum_{i=1}^{n} i \times \sum_{i=1}^{n} MET_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \quad (1)$$

Where n is 14 (years from 2000 to 2013), and MET_i is the year i maximum ET value from 2000 to 2013.

Estimation of cropland expansion areas

Since the popularization of drip irrigation technology, a significant amount of water has been conserved, but annual water consumption has not declined due to the subsequent reclamation of new cropland based on the increase in saved water. We estimated new reclaimed cropland areas based on the statistical data from the Statistical Yearbook of the Xinjiang Production and Construction Group, with the formula defined as:

$$S_n = S_w \times W_s / W_d \quad (2)$$

Where S_n is the new reclaimed cropland, S_w is the area (hectare) using water-saving irrigation, W_s is the saved irrigation water capacity per ha per year (here, 690 m^3) and W_d is the irrigation water consumption per ha per year (here, 7500 m^3), according to the usability research.

Results

Spatio-temporal changes of soil salinization from 1980 to 2010

Based on interpretation and classification of remote sensing, extracted the information of soil salinization (Figure 2), and tested the classification accuracy. According to our results (Table 3), overall accuracy were 89.17%, 92.2% and 91.53%, in 1980, 2000 and 2010, respectively; Kappa coefficients were 0.86, 0.9 and 0.88, in 1980, 2000 and 2010, respectively.

As shown in Figure 2, for the spatial distribution tendency, areas of soil salinization mainly distributed in alluvial plain and delta during the study period. For the temporal tendency, there was a great change in the distribution range of soil salinization in Manas River basin. For instance, from 1980 to 2000, severe salinization obviously increased, and then decreased in 2010.

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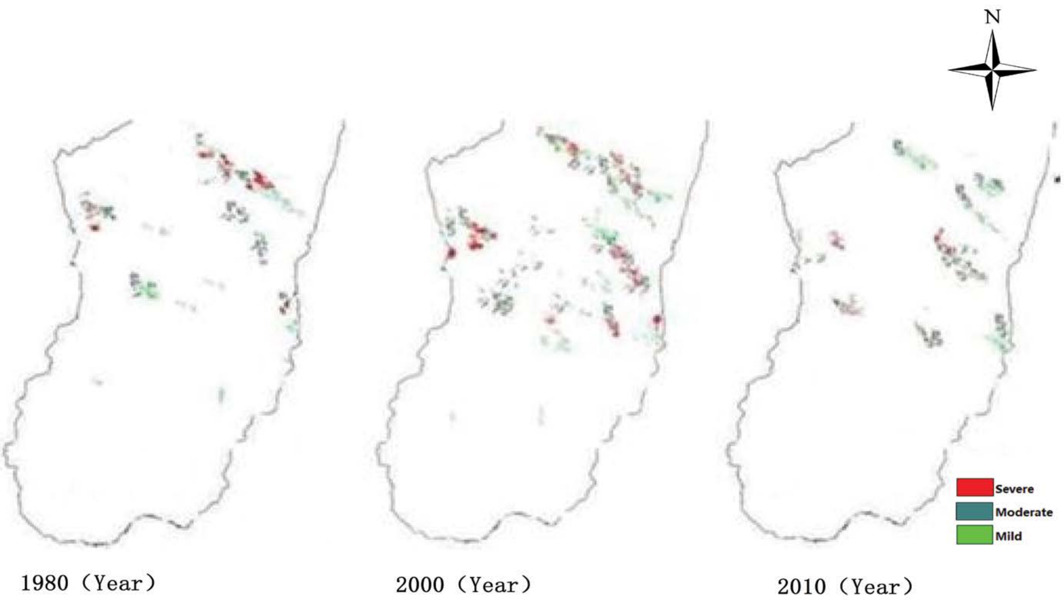

Figure 2: Distribution of soil salinization in Manas River basin.

Table 3: Classification of precision test.

	1980	2000	2010
Overall accuracy(%)	89.17	92.20	91.53
Kappa coefficient	0.86	0.90	0.88

Table 4: Statistics on different classification areas in different years (unit: km^2).

Classification/Year	1980	2000	2010
Severe salinization	165.07	279.49	242.14
Moderate salinization	342.02	595.63	508.06
Mild salinization	413.11	383.30	350.17

According to our results (Table 4), area of salinization increased from 927.2 km^2 in 1980 to 1,102.37 km^2 in 2010. In addition, from 1980 to 2010, there was a different change in different salinization types. Take moderate salinization as an example, in 1980, it was 342.02 km^2, and then increased to 595.63 km^2 in 2000, while in 2010, it shrank partially, with an area down to 508.06 km^2. By contrast, the area of mild salinization presented a decreased tendency, in 1980, it was 413.11 km^2, and then decreased to 383.3 km^2, while in 2010, with an area down to 350.17 km^2.

Area transfer matrix of different classification

As shown in Table 5, a significant change in the distribution area of different classification was observed. From 1980 to 2000, 21.62 km^2 of moderate salinization, 13.35 km^2 of mild salinization, and 9.14 km^2 of non-salinization, 44.11 km^2 in total area, was transformed into area of severe salinization. In contrast, there was 80.12 km^2 in total area transformed into area of moderate salinization and 245.31 km^2 transformed into area of mild salinization.

From the statistic results (Table 6), from 2000 to 2010, 36.18 km^2 of moderate salinization, 33.65 km^2 of mild salinization, and 31.47 km^2 of non-salinization, 101.3 km^2 in total area, was transformed into area of severe salinization. In contrast, there was 149.45 km^2 in total area transformed into area of moderate salinization and 175.64 km^2 transformed into area of mild salinization.

As far as whole study period concerned, according to the results (Table 7), from 1980 to 2010, 104.42 km^2 of severe salinization, 171.54 km^2 of moderate salinization, and 207.83 km^2 of mild salinization, 483.79 km^2 in total area, was transformed into area of non salinization. In contrast, there was 115.41 km^2 in total area transformed into area of severe salinization and 199.48 km^2 transformed into area of moderate salinization.

Impact of agricultural activities on soil salinization

According to our statistic results (Figure 3), including three agricultural divisions (six, seven, eight) in Manas River basin, by the end of 2014, 47% of sown area was cotton, 25% of sown area was grain crops, such as wheat, maize, and other economic crops. There was a gradual increasing change in cotton during the research period, which has already become a pillar production. The other types exhibited both increasing and decreasing changes. Furthermore, with the increase of agricultural activities, water consumption has a significant demand. As seen in Figure 4, the number of agricultural pumps from 1990 to 2014 has a great increase, around 2,000 pumps in 1990 increased to about 6,000 pumps in 2013, the increasing tendency was obvious, and R^2 value was 0.913.

For the area of cropland expansion, as shown in Table 8, cropland area from yearbook data showed an expansion tendency, increasing from 4,598 km^2 in 2009 to 5,476.9 km^2 in 2014. Drip irrigation technology was widely applied in the study area from 2008 onwards, particularly for cotton cultivation. Yearbook data showed that the water-saving area increased from 2,906.7 km^2 in 2009 to 4,071.6 km^2 in 2014. Moreover, our estimated area of newly reclaimed cropland also showed an increase from 267.416 km^2 in 2009 to 374.584 km^2 in 2014.

Impact of climate change on soil salinization

To analyze the impact of climate factors on soil salinization, we collected two meteorological stations (Shawan, Shihezi) data and evapotranspiration to confirm their change tendency.

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Table 5 : Area transfer matrix of different classification from 1980 to 2000 (unit: km^2).

1980 2000	Severe salinization	Moderate salinization	Mild salinization	Non-salinization
Severe salinization	——	21.62	13.35	9.14
Moderate salinization	44.27	——	16.45	19.31
Mild salinization	39.53	141.55	——	64.23
Non-salinization	74.74	171.47	185.70	——

Table 6: Area transfer matrix of different classification from 2000 to 2010 (unit: km^2).

2000 2010	Severe salinization	Moderate salinization	Mild salinization	Non-salinization
Severe salinization	——	36.18	33.65	31.47
Moderate salinization	19.24	——	76.73	53.48
Mild salinization	5.03	15.63	——	154.98
Non-salinization	39.68	10.07	32.13	——

Table 7: Area transfer matrix of different classification from 1980 to 2010 (unit: km^2).

1980 2010	Severe salinization	Moderate salinization	Mild salinization	Non-salinization
Severe salinization	——	47.79	37.01	30.61
Moderate salinization	53.51	——	83.18	62.79
Mild salinization	34.56	147.18	——	209.21
Non-salinization	104.42	171.54	207.83	——

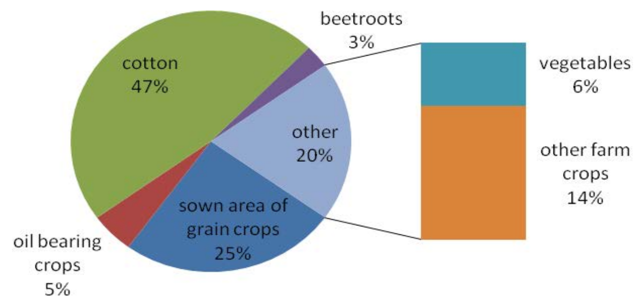

Figure 3: Total sown areas of farm crops by different types.

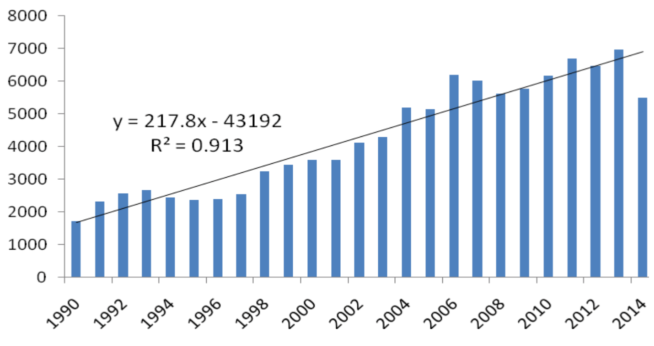

Figure 4: Number of agricultural pumps from 1990 to 2014.

As shown in Figure 5, from 1990 to 2013, yearly mean precipitation and temperature both presented an increasing tendency, and R^2 values were 0.147, 0.198. In addition, according to the statistic results (Figure 6), third quarter mean precipitation and temperature from 1990 to 2013 have a great variance in different year. The third quarter mean temperature showed an increasing tendency, and R^2 value was 0.292, while the third quarter mean precipitation showed a decreasing tendency, and R^2 value was 0.047.

For the whole basin, evapotranspiration presented an evidently different tendency, with the changing spatial distribution trend of yearly ET maximum values from 2000 to 2013 decreasing in alluvial fan, with an increasing in the alluvial plain and delta, especially artificial oasis zone.

Discussion

Spatio-temporal distribution patterns of soil salinization from 2000 to 2013

During the research period, areas of soil salinization mainly distributed in alluvial plain and delta, which was due to they were important agricultural zones in Xinjiang. In these zones, where salinity of soil was large, groundwater level was shallow, and degree of mineralization was high. With impact of above factors on salinization, these regions were vulnerable to secondary salinization [7].

According to our results, from 1980 to 2010, there was a different change in different salinization types. From 1980 to 2000, severe salinization and moderate salinization obviously increased, and then decreased in 2010, because that a lot of prevention and amelioration measures were carried out since 2000. For mild salinization, it presented a decreased tendency from 1980 to 2010, which may be related to the increase in precipitation and amelioration measures accelerating ecosystem restoration. As far as area transfer matrix of different classification concerned, from 1980 to 2010, 104.42 km^2 of severe salinization, 171.54 km^2 of moderate salinization, and 207.83 km^2 of mild salinization, 483.79 km^2 in total area, was transformed into area of non salinization. It indicated that during the research period, soil salinization in Manas River basin has mitigated. Although general situation has decreased, in contrast, there was still 115.41 km^2 in total area transformed into area of severe salinization and 199.48 km^2 transformed into area of moderate salinization. It illustrated that partly area still existed severe salinization that need to relieve.

Impact of agricultural activities on soil salinization

Our statistic results showed that, in Manas River basin, 47% of sown area was cotton, 25% of sown area was grain crops, such as wheat, maize. In recent years, with the improvement of modern agriculture, especially application of precision technology and mechanization, as well as the influence of a market-oriented and

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Table 8: Cropland area (unit:km^2).

Source/Year	2009	2010	2011	2012	2013	2014
Cropland area from yearbook [i]	4598	4618.6	5493.9	5481.7	5481.7	5476.9
Area of water-saving irrigation from yearbook [ii]	2906.7	3101.1	3350.7	3577.4	3809.7	4071.6
Area based on estimate method [iii]	267.416	285.301	308.264	329.121	350.492	374.587

Note: i: Cropland area from yearbook, including cropland area of three agricultural division (6,7,8) in the Manas River basin, with other municipalities ignored due to their absence in the yearbook. ii: Area of water-saving irrigation from yearbook, same as i. iii: Estimated area based on formula (2).

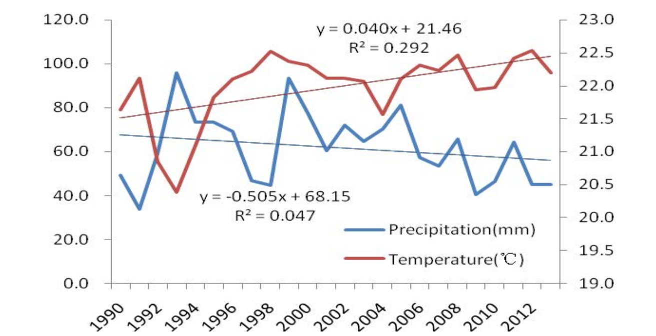

Figure 5: Yearly mean precipitation and temperature from 1990 to 2013.

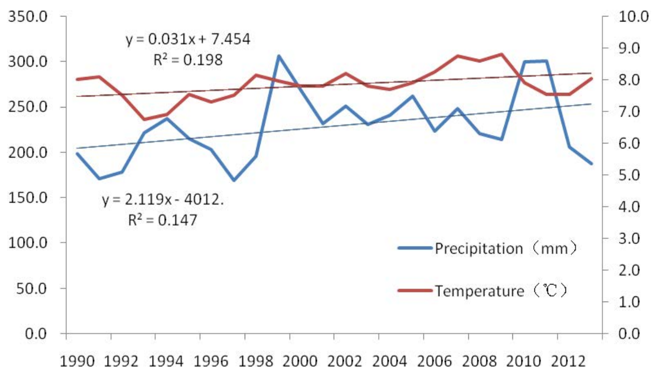

Figure 6: Third quarter mean precipitation and temperature from 1990 to 2013.

policy-induced economy, farmers have planted large amounts of cash crops to increase economic returns [8]. Accordingly, we estimated that newly reclaimed cropland increased from 267.416 km^2 in 2009 to 374.584 km^2 in 2014. Drip irrigation technology was widely applied in the study area from 2008 onwards, particularly for cotton cultivation. Yearbook data showed that the water-saving area increased from 2,906.7 km^2 in 2009 to 4,071.6 km^2 in 2014. Shallow groundwater was dominant factor for influence of soil salinization [9] using drip irrigation as a deficit irrigation strategy to save water, but may enhance soil salinization [10]. In drip irrigation that soil water content decreased and soil salinity increased with distance from emitters [11]. With the increase of cropland and application of drip irrigation, soil salinization has become a serious problem in agricultural zones.

Moreover, although water resources are limited in arid areas, agricultural activities have a large water demand, which can induce the excessive exploitation of groundwater resources. From pumps of statistic results we knew that, there has been a great increase in the number during research period. Excessive exploitation has result in groundwater level rise and runoff of Manas River decreased. Factors above mention can contribute to increased soil humidity, latent heat flux, and evapotranspiration, which would accelerate the form of soil salinization, notably in arid zones [12].

Impact of climate change on soil salinization

Climate change has a great impact on soil salinization, climate change can effect vegetation cover, albedo, surface temperature, soil humidity, and soil roughness, which were main factors for salinization.

According to our results, from 1990 to 2013, yearly mean precipitation and temperature both presented an increasing tendency. The increase of precipitation and temperature would enhance soil humidity and surface temperature, which gave a natural condition to form of salinization. In arid land, precipitation mainly occurred in spring and summer, however, with substantial evaporation in summer, it was easy to trigger salinization. In addition, third quarter precipitation and temperature played dominant roles in soil salinization. Because that it was maturation stage of crops, surface temperature, soil humidity, and soil roughness have a great variance during this period. As shown in our results, the third quarter mean temperature showed an increasing tendency, while the precipitation showed a decreasing tendency. With decrease of soil humidity and increase of surface temperature which would strengthen soil salinization. Evapotranspiration also mainly affected by above factors, for the whole basin, evapotranspiration presented a decreased tendency in alluvial fan, with an increased tendency in the alluvial plain and delta, especially artificial oasis zone from 2000 to 2013. It manifested that why soil salinization mainly occurred in alluvial plain and delta, evapotranspiration in farmland was higher than other regions, which led to soil salinization more easily form.

Conclusions

The purpose of this paper was to analyze the spatio-temporal changes in soil salinization in the Manas River basin and the impact of agricultural activities and climate change. By analyzing the spatio-temporal changes in soil salinization, we found that soil salinization from 1980 to 2010 has a great changes with impact of agricultural activities and climate change. Our research indicated that, in regards to spatial distribution, areas of soil salinization mainly distributed in alluvial plain and delta during the study period, for the temporal tendency, there was a great change in the distribution range of soil salinization in Manas River basin, area of severe and moderate salinization increased, area of mild salinization decreased, from 1980 to 2010. The variation of distribution of soil salinization was mainly affected by agricultural activities and climate change in Manas River basin.

As far as impact concerned, Manas River played a key role in soil salinization. The distribution patterns of artificial oases were driven by the arid land water resources [13]. In regards to agricultural activities, human activity mainly produced along Manas River, hence, soil salinization were mainly in agricultural region. For climate change, it has a great influence on the variation of Manas River, it can affect the run off of Manas River and groundwater [14]. Evapotranspiration exhibited an obvious increase in the artificial oasis zones where irrigation enhanced vegetation transpiration and soil evaporation.

In addition, the increase in evapotranspiration promoted the form of soil salinization and was a critical factor for arid land salinization.

Although evapotranspiration analysis was introduced in this study, we did not demonstrate a direct relation between climate and the soil salinization due to the complex relationship between natural factors. Furthermore, the precipitation data used was sourced from only two meteorological stations, which did not reflect the practical situation of the whole basin, notably climate change in the oases regions. More detailed and accurate data is required to reduce uncertainties of impact.

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