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Degree of desertification based on normalized landscape index of sandy lands in inner Mongolia, China

Xiaowen Yu [a,1], Yi Zhuo [a,1], Huamin Liu [a,**], Qi Wang [a], Lu Wen [a], Zhiyong Li [a], Cunzhu Liang [a], Lixin Wang [a,b,c,*]

[a] College of Ecology and Environment, Inner Mongolia University, Hohhot, 010021, China
[b] Collaborative Innovation Center for Grassland Ecological Security (Jointly Supported by the Ministry of Education of China and Inner Mongolia Autonomous Region), Hohhot, 010021, China
[c] Ministry of Education Key Laboratory of Ecology and Resource Use of the Mongolian Plateau, Hohhot, 010021, China

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ABSTRACT

Desertification is one of the most serious ecological environmental problems over the past several decades in the arid regions. The quantitative assessment of the desertification degree in sandy lands has also been an essential part of landscape ecology. Based on the character of relief, we proposed a new indicator system, i.e., Normalized Landscapes Index (*NLI*) to calculate the dynamic trend of the desertification process. The data from three periods of Mu Us sandy land and Kubuqi sandy land in Inner Mongolia were used to verify the accuracy of this method. The results show that, from 1990s to 2010s, the *NLI* change amount of fixed sandy land and semi-fixed sandy land all had positive values while bare sandy land and water had all negative values for both regions. Over the past 20 years, the desertification reversal phenomenon occurs in Mu Us with the desertification process (*DP*) of −0.36%, while a positive development of desertification in Kubuqi with the DP of 0.01%. The *NLI* dynamic degree of two sandy lands had the same trend as land use dynamic degree, while *NLI* was more accurate than the landscape dynamic degree. These findings can provide an important method for comparing the desertification process of the desert and also the meaningful information for prevention and control of desertification and sustainable development for the sandy lands in the arid regions.

1. Introduction

Desertification can be defined as a kind of complicated land degradation process (UNEP; Wang et al., 2015; Wang et al., 2017; Zhao et al., 2017), which often occurs in the arid, semi-arid, and partly sub-humid areas due to the human activities and climate changes at the same time (Cui, 2013; Helldén and Tottrup, 2008). It is regarded as one of the most serious eco-environmental and socio-economic issues at the global scale and has attracted worldwide attentions (Wang et al., 2012; Yang et al., 2005). Mostly occurred in northern and northwestern China, the area of desertification is 182.63 × 10^4 km^2 which directly and indirectly results in the annual economic losses of 54 billion RMB (Yang et al., 2015). National government had

* Corresponding author. College of Ecology and Environment, Inner Mongolia University, Hohhot 010021, China.
** Corresponding author.
E-mail addresses: Liuhmimu@imu.edu.cn, liuhmimu@imu.edu.cn (H. Liu), Lx_wimu@163.com, Lxwang@imu.edu.cn (L. Wang).
[1] These authors contributed equally to this work.

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launched a series of ecological environmental protection and restoration projects in arid and semi-arid area for improving ecological environment, such as Sand Source Control Program Beijing-Tianjin Sand Source Control Program, Grain for Green Project and "Three-North" Shelterbelt Project, etc. (Wu et al., 2014; Xue et al., 2013; Zhang et al., 2017)While the desertification is still a serious problem. Quantitative assessment of desertification process at the extent of national and global scales is important for the prevention and control of desertification (Canora et al., 2015; Jafari and Bakhshandehmehr, 2013). At present, there is no unified and authoritative standard for monitoring indicators neither at home nor abroad (Verón et al., 2006).

Since 1980s, community indicators, such as reduction of above-ground biomass due to wind erosion or sand burial, have been widely used to describe desertification process (Chang and Gao, 2003; Zhu and Liu, 1984). With the rapid development of 3S technology (i.e., remote sensing, geographic information system, global positioning system) (Huang et al., 2001; Rui et al., 2011), desertification monitoring is divided into the following two aspects, long time series monitoring of MODIS or NOAA/AVHRR by using special indices such as normalized difference vegetation index (NDVI) (Sun et al., 2019), temperature vegetation dryness index (TDVI), net primary productivity (NPP) (Li et al., 2020), and Vegetation Coverage index (VCI) (Wei et al., 2019); otherwise, Landsat TM, ETM and OLI images have been developed to reflect spatial and temporal changes of desertification visually. Applying linear mixture model (LMM), Spectral mixture analysis (SMA) to monitor desertification land gives satisfactory results, researchers tend to use models to assess desertification (Okin and Gillete, 2001; Alfredo et al., 2002; Hansen et al., 2002; Gao et al., 2005). In many studies, the main indicators include land area, dynamic degree, desertification divided index (DDI) (Gou et al., 2019), landscape fragmentation index (LFI) (Qi et al., 2012), etc. Comparing the changes of land area between different years to reflect the processes of desertification, if the area or index increases, it indicates that the desertification is developing positively, on the contrary, the desertification will be reversely developed (Deng et al., 2007).

However, each method has its obvious deficiencies, its main manifestations are as follows: (1) Ignoring the problem of scale. Using the data of community indicators increase the workload for the current research on desertification in large scale, and the accuracy of data could affect the research as well. (2) Application of single indicator, such as NDVI, NPP or VCI, is difficult to obtain the overall characteristics of desertification degree, nor can it fully reflect the desertification process, if want to conduct a comprehensive study of desertification in the region, need to use a variety of indicators to comprehensive analysis. While the selection of comprehensive indicators in the study area is also different, this method is only applicable to a certain area and is not universal. (3) Two indexes, the dynamic degree and the desertification degree were usually used to indicate the process of desertification (Li et al., 2010; Zhu et al., 2009), which are related to the total area of the region, and then total area changes will have a direct impact on the results and further affect the analysis of the desertification process (Zhang et al., 2009).

To accurately quantify and compare the desertification process between sandy lands, based on the method of spatial analysis by calculating the maximum expected value of landscape area, the new monitoring indicator system, i.e., Normalized Landscapes Index (*NLI*) that is easy to calculate was established. *NLI* eliminates the effects of climate, vegetation types and area sizes on analyzing the temporal and spatial dynamics of the landscape in sandy lands. The result was more accurate and suitable for studying the desertification process in Mu Us and Kubuqi sandy land in Inner Mongolia. *NLI* can be applied to analyze the dynamic change of landscape in the sandy lands. The result is helpful for us to understand the dynamics of the ecological environment in the region, and the contrast between different sandy lands. This article provides new ideas for the study of desertification process in arid and semi-arid areas and makes the degree of desertification comparable between sand lands. The *NLI* also provides the basic data for further analysis of the driving force of desertification.

2. Materials and methods

2.1. Study area

Our study sites are Mu Us sandy land and Kubuqi sandy land (hereafter referred to as Mu Us, Kubuqi for short), which represent major sandy lands in northern China. Located in the transitional zone between the Ordos Plateau and the Loess Plateau, Mu Us is the agricultural and pasture interlaced region of northern China (Zhang and Deng, 2019), and the study site (107°20′- 111°30′E; 37°27′- 39°22′N) covers ~ 23656.47 km^2 (Deng et al., 2007). Kubuqi is located in the southern part of the Hetao Basin, on the southern bank of the Yellow River, which is one of the main proximal deserts of the Loess Plateau (Sun et al., 2002) situated (107°00′- 111°30′E; 41°55′- 43°43′N). The main sandy land types include fixed, semi-fixed and bare dunes in sandy lands (Wu et al., 2002). The Mu Us is bordered by the Kubuqi in the north. The topography of the Mu Us is slightly undulating from west to east, elevation increases gradually from 950 m in the east to 1600 m in the west in Mu Us. The topography of Kubuqi is north-south slope gradient terrain (Fig. 1).

The Mu Us and Kubuqi belongs to temperate continental arid and semi-arid climate. In terms of the average annual precipitation, the western part of Mu Us is 250 mm, and the eastern part of Mu US is 450 mm; the western part of Kubuqi is 150 mm and the eastern part of Kubuqi is 400 mm (Arnon et al., 2014). The annual precipitation is extremely uneven, mainly occurring in summer (July—September), accounting for 80% of the annual precipitation. The mean annual temperature was 6.0—8.5 °C and 6.0—7.5 °C, respectively. On Mu Us, *Calligonum mongolicum* and *Artemisia desertorum* are main plants growing in the fixed and semi-fixed dunes. On Kubuqi, *Artemisia ordosica, Salix cheilophila* and *Caragana korshinskii* are predominant plants in the fixed and semi-fixed sandy land.

2.2. Data sources and preprocessing

We combined remote sensing (RS), global positioning system (GPS) and geographic information system (GIS) to investigate the land use dynamic change. RS data including Landsat-5 Thematic Mapper (TM), Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Landsat-8 Operational Land Imager (OLI) images in the 1990s, the 2000s and the 2010s were used (Table 1), which were the precious resource for a long-term record of land degradation processes at a regional scale (Alatorre and Beguería, 2009). These Landsat multi-spectral data were downloaded from the site http://glovis.usgs.gov and http://www.gscloud.cn. The satellite images chosen from August to September were used; the images were preprocessed with geometric and radiometric corrections at sub-pixel accuracy. All cloudiness of these images in our study were less than 5%.

According to the land use classification principles and classification system (Guo et al., 2005), the study areas can be divided into three categories: natural landscape, semi-natural landscape and artificial landscape, which are composed of 8 sub-categories, i.e., fixed sandy land, semi-fixed sandy land, bare sandy land, wetlands, water body, forestland, cropland and constructive land. Additionally, we used GPS to conduct a field survey of two sandy lands. After verification, the accuracy rate of interpretation reaches 90% (Liu et al., 2017; Yu, 2017).

All Landsat images after being preprocessed were interpreted manually using ArcGIS 10.3, and we employed statistical and overlay analysis methods to obtain changing data for different landscape types areas, as well as spatial and temporal dynamics of landscape patterns.

2.3. Data standardization

Due to the differences in the regional area, vegetation types and topography of the two sandy areas, it was hard to use the landscape area to analyze the changes of the same landscape in different sandy lands and periods. Therefore, the land-use area needs to be standardized.

2.3.1. Determine the maximum expected value of landscapes

Landscapes changes were caused by a variety of factors, including climate, topography, and human intervention. However, the terrain was a relatively stable factor that can be used to analyze the formation of the landscape. Topographic relief is an important index for quantitative description of geomorphic form and classification of geomorphic type. By calculating topographic relief, the distribution of sandy geomorphology can be obtained (Zhang and You, 2011). In this part, we mainly considered the influence of terrain on the dynamic change of land use. We used software ArcGIS 10.3 to carry out spatial analysis, and then calculated topographic relief. Finally, partition statistics of the relief were used to judge the distribution topography of the landscape and as the basis to estimate the landscape expectation value (Table 2). As the results, the fixed

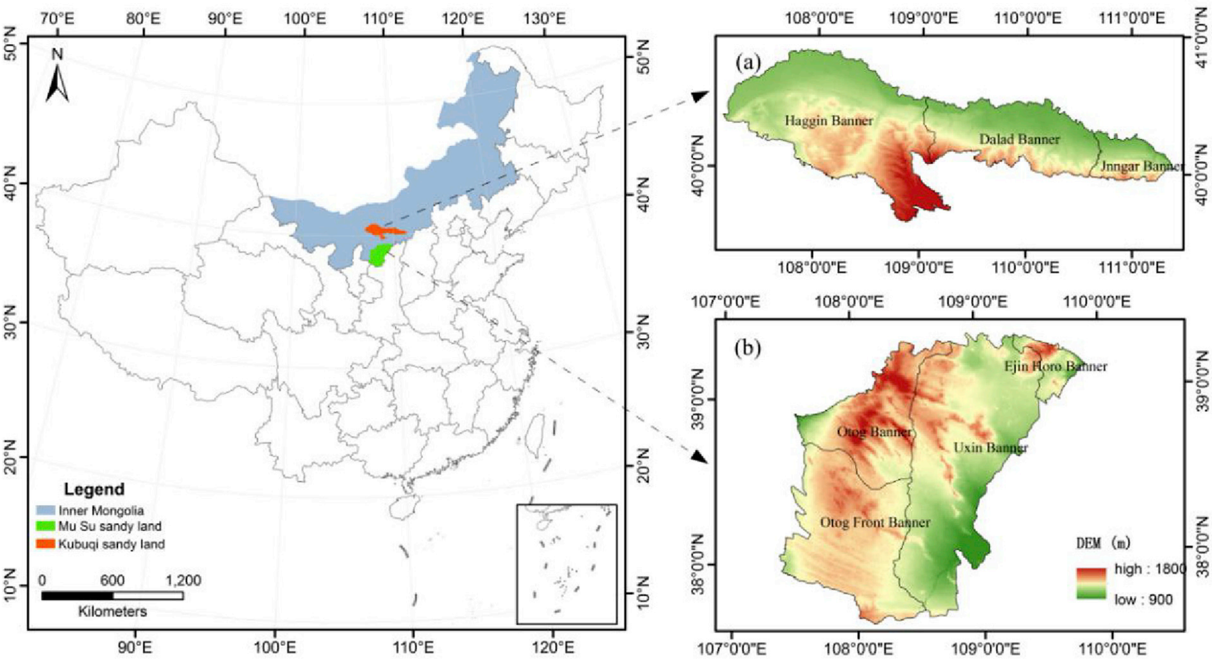

Fig. 1. Location of the two sandy lands in Inner Mongolia (a) Kubuqi sandy land (b) Mu Us sandy land.

Table 1
Parameters of remote sensing image of study area.

Sandy Land Type	Patch/Row	Landsat Sources		
		1990s	2000s	2010s
Mu Us sandy land	127/33 128/33	5TM	5TM	8OLI
Kubuqi sandy land	127/32 128/32 129/32	5TM	5TM	8OLI

sand, semi-fixed sand and bare sand have similar terrain relief values, and the relief values of wetland were much different from other landscape types.

We combined the terrain distribution of landscapes with the area change of landscape types to estimate the maximum expected value (LME) of the three sandy lands. LME represents the maximum area percentage of landscape in the sand, which is decided by the topography of sandy lands, the ratio of different landscape types in each sandy land and the transformation direction and degree between different landscape types. The expected value of the landscape type and estimation principles were shown in Table 3.

2.3.2. *Formulation of normalized landscapes index*

Previously, linear normalization method (Equation (1)) is used in data standardization processing (Zhu et al., 2009).

$$D_{ij} = (X_{ij} - X_{jMin}) /(X_{jMax}\text{-}X_{jMin}) \tag{1}$$

Where D_{ij} is Standard value, X_{ij} is actual value, X_{jMin} is Minimum value of index j, X_{jMax} is Maximum value of index j.

For this study, according to the analysis in Section 2.3.1, the X_{jMin} is 0, and the XjMax is LME. Therefore, based on data standardize processing methods, we build a Normalized Landscapes Index. The mathematical formulation is

$$NLI_i = P_i/LME \tag{2}$$

where *NLI* is the normalized landscapes index, P_i is the landscape types area percentage, i is the landscape types, LME is determined the maximum expected value of landscape area.

2.4. *Desertification process indicators*

To comprehensively evaluate the development of desertification degree in Mu Us and Kubuqi in recent 20 years, the desertification process index was established by selecting the desertification index with different ecological significance (Table 4). We introduced the concept of the landscape dynamic degree to reflect the degree of landscape changes for the sandy lands, which expressed as K . V is the *NLI* dynamic degree, it was used to describe the rate of change of landscape area. DG_i is the degree of desertification in the study area. *DP* is based on the definition of the degree of desertification, which indicates the strength of the desertification process. A positive *DP* value means a desertification process, while a negative value displays a reversal process of desertification (Chang and Gao, 2003).

We then calculated desert dynamic change information for the three periods in the study area in the 1990s, 2000s, and 2010s and applied origin2018 to make diagrams.

Table 2
Mean relief of Mu Us and Kubuqi sandy lands.

Landscape Type	1992		2002		2013	
	Kubuqi	Mu Us	Kubuqi	Mu Us	Kubuqi	Mu Us
fixed sandy land	41.08	29.29	41.85	28.98	41.13	29.34
semi-fixed sandy land	39.61	30.64	39.09	30.73	37.33	31.51
bare sandy land	38.05	31.30	37.74	31.66	37.42	30.78
wetlands	32.29	27.23	31.77	27.67	34.26	26.94
water body	38.92	35.41	40.63	35.50	39.23	38.38

Table 3
Estimated indicators of LME in Mu Us and Kubuqi sandy land.

Name	Estimated indicators		Use Factors
	Mu Us	Kubuqi	
LME-bare sandy land	0.85	0.76	except for the low-lying areas have becom bare sandy land
LME-fixed sandy land	0.77	0.58	semi-fixed sandy land and part of bare sandy land
LME-semi-fixed sandy land	0.68	0.38	fixed sandy transformed into semi-fixed sandy land
LME-wetlands	0.07	0.15	all the low-lying area
LME-water body	0.02	0.1	twice the current water area

Table 4
Indices of desertification process.

Index		Equation	Expression
K	$K=(U_b\text{-}U_a)/U_a \times 1/T \times 100\%$	U_a is the landscape type area for the previous year, U_b is the area for the recent year, and T is the time interval between U_a and U_b (Wang and Bao, 1999).	
V	$V=(NLI_1\text{-}NLI_2)/T$	NLI_1 is index for the recent year, NLI_2 is index for the previous year, and T is the time interval between NLI_1 and NLI_2.	
DG_i	$DG_i = NLI_{Mi} + k1NLI_{SM} + k2NLI_{Fi}$	NLI_{Mi} is the NLI of bare sand land; NLI_{SMi} is the NLI of semi-fixed sand land; NLI_{Fi} is the NLI of fixed sand land; i is a certain period; k1 = 0.6 and k2 = 0.3 (Chang and Gao, 2003).	
DP	$DP = (DG_{i+n}\text{-}DG_i)/T$	DG_{i+n} is index for the recent year, DG_i is index for the previous year, and T is the time interval between DG_{i+n} and DG_i (Chang and Gao, 2003).	

3. Results

3.1. Temporal and spatial trends of land use change

As shown in Fig. 2 and Fig. 3, from 1990s to 2010s, fixed sandy land, semi-fixed sandy land and bare sandy land were the main land use types in sandy lands. From the perspective of time, semi-fixed sandy land was the only land use type that had increases for all two time intervals in three study areas. For Mu Us, the semi-fixed sandy land increased from 28.2% of the total area to 30.17% from 1990s to 2010s, whereas bare sandy land had decreased from 17.76% of the total area to 8.99%. For Kubuqi, the semi-fixed sandy land increased from 4.57% of the total area to 8.62% from 1990s to 2010s, and the bare sandy land had decreased from 38.05% of the total area to 32.85%.

Spatially, in Mu Us, fixed sandy land, semi-fixed sandy land and wetlands were distributed throughout the area, bare sandy land was mainly located over the middle and southern part. In Kubuqi, fixed sandy land and semi-fixed sand were mainly distributed in eastern and southern part; bare sandy land was distributed in middle and western part, wetlands were distributed in the north boundary of study area. During 1990s–2010s, bare sandy land all mainly converted to semi-fixed sandy land in two sandy lands (Fig. 3). Because bare sandy land, fixed sandy land and semi-fixed sandy land were important indicators of desertification process, when bare sandy land mainly converted to semi-fixed sandy land and fixed sandy land, there is a negative development of desertification (Zhang et al., 2009) in this region from 1990s to 2010s.

3.2. NLI and NLI dynamic degree

We normalized the landscape area of Kubuqi sandy land and Mu Us sandy land to obtain the *NLI* of the sandy land. From the dynamic changes of *NLI*, bare sandy land and water all had negative values while fixed sandy land and semi-fixed sandy land had all positive values for both sandy lands in all two-time intervals. Wetlands show different trends in two sandy lands at in two-time intervals. For two sandy lands, the *NLI* of wetlands had decreased in both periods except the second time interval in Mu Us (Table 5). These results indicate that the landscapes change trends of the research areas with similar geographical locations are the same over the last two decades.

From 1990s to 2010s, the *NLI* dynamic degree (V) of fixed sandy land, semi-fixed sandy land and wetlands in Mu Us were 0.24%, 0.14% and 0.26% respectively, and the V of bare sandy land and water were −0.52% and −0.09% respectively. In Kubuqi, the V of fixed sandy land and semi-fixed sandy were 0.1% and 0.53% respectively, and the V of bare sandy land, wetlands and water were −0.34%, −0.63% and −0.75% respectively. These results indicate that bare sandy decrease speed in the Mu Us is greater than that in the Kubuqi; On the contrary, the semi-fixed sandy land increase speed in the Mu Us increased speed lower than that in the Kubuqi. In general, over the past 20 years, bare sandy land was decreased in two sandy lands, but Kubuqi had the greatest change degree, it shows that the governance of the kubuqi is more significant (Fig. 4).

3.3. Desertification process

It can be seen from Table 6 that in the 20 years, the average desertification degree of Kubuqi and Mu Us were 0.75 and 0.59 respectively. These results indicate that the desertification degree of Kubuqi sandy land was more serious than that of Mu Us.

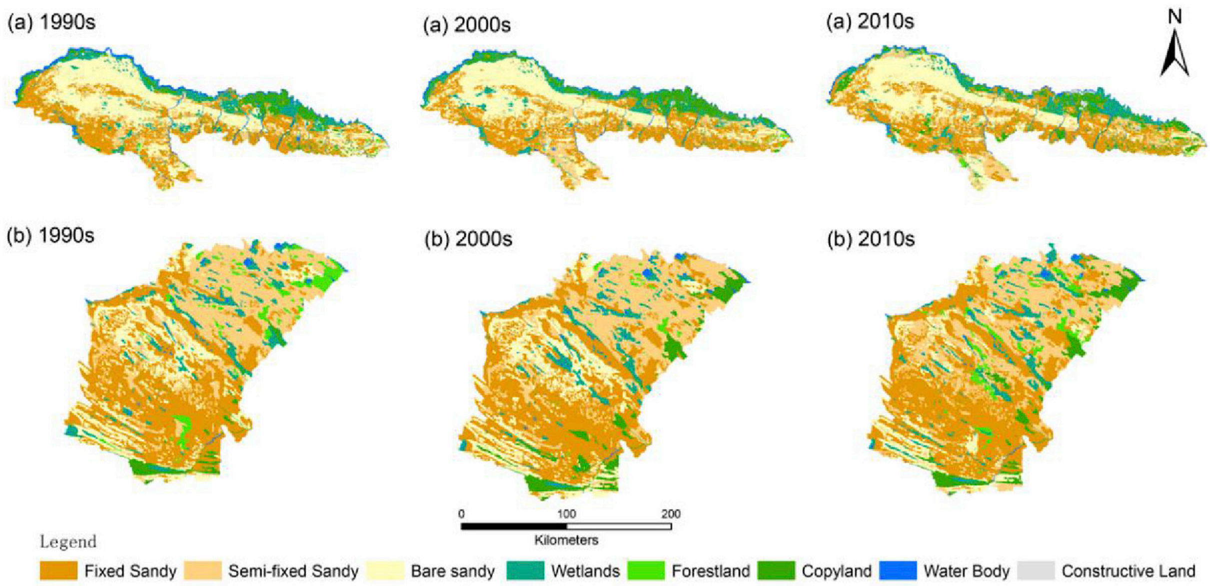

Fig. 2. Distribution of landscapes in Kubuqi and Mu Us sandy land from 1990s to 2010s.

Among them, the maximum value of desertification degree (DGi) was 0.613 in 1990s in Mu Us, and 0.763 in 2000s in Kubuqi, which showed that a downward trend of desertification degree existed in Mu Us and the desertification degree of Kubuqi increased first and then decreased at the same time.

From 1990s to 2000s, It is in the early stage of desert control, *DP* were −0.05% and 0.14% in Mu Us and Kubuqi respectively. The Mu Us decreased slower, while the Kubuqi had a positive value of desertification process during the first period. The 2000s−2010s was the period of comprehensive sand governance, the value of desertification process all had negative values for both zones in the second intervals, and the decrease rate of desertification in Mu Us was higher than that in Kubuqi. Currently, the desertification reversal phenomenon desertification occurs in Mu Us, while the degree of desertification in the Kubuqi was close to 1990s.

3.4. The significant difference of the index between two sandy lands

The descriptive statistics analysis and Independent-sample *t*-Test of Desertification index in Mu Us and Kubuqi using Spss17.0 software were shown in Table 7. The Desertification Process (*DP*) and Normalized Landscapes Index (*NLI*) of semi-fixed sandy land, bare sandy land and wetlands were extremely significant difference ($P < 0.01$) in two sandy lands. However, there was a significant difference ($P < 0.05$) in *NLI* of fixed sandy land. Although there were differences in Desertification degree (DG_i) and *NLI* of water body between sandy lands, they were not significant difference ($P > 0.05$).

4. Discussion

4.1. Practicality and advantages of NLI

To quantify the process of desertification for the sandy lands, many studies introduced the concept of dynamic degree and the desertification degree (Reynolds et al., 2011). In this study, based on remote sensing data and the calculation formula of land use dynamic degree, we normalize the data to get *NLI* dynamic degree.

By comparing the results of land use dynamic degree (Fig. 5) and *NLI* dynamic degree (Fig. 4), we found that the land-use dynamic degree and *NLI* dynamic degree showed the same trend in both sandy land, i.e. fixed sandy land, semi-fixed sandy land and wetlands showed an increasing trend, and bare sandy land, water showed a decreasing trend in Mu Us; in Kubuqi, fixed sandy land, semi-fixed sandy land were reflected increasing trends, and bare sandy land, water, wetlands were decreasing. Therefore, *NLI* data can be used to compare the landscapes dynamic changes.

To further clarified the *NLI* dynamic degree accuracy, correlation analysis used to reveal the relationship between land use dynamic degree and *NLI* dynamic degree. A person correlation analysis was conducted to assess the correlations of two indexes in Mu Us and Kubuqi (Table 8). *NLI* dynamic degree exhibited an extremely significant correlation with land use dynamic degree ($p < 0.01$) in Mu Us and two indexes had significant correlation ($p < 0.05$) in Kubuqi, indicating that the value of *NLI* dynamic degree can be more accurately reflect the spatial-temporal dynamic changes of landscape. The land use dynamic degree is related to the total area of the region, and then total area changes will have a direct impact on the results and further

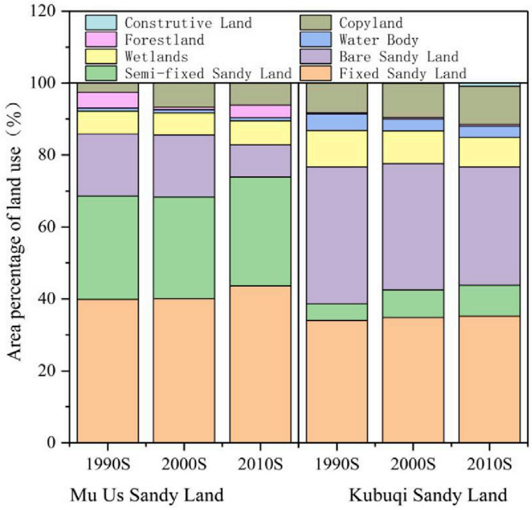

Fig. 3. Area percentage of landscape in two sandy lands from 1990s to 2010s.

Table 5
Normalized Landscapes Index of two sandy lands.

Landscapes Type	1990s		2000s		2010s	
	Mu Us	Kubuqi	Mu Us	Kubuqi	Mu Us	Kubuqi
Fixed sandy land	51.78%	58.72%	52.02%	60.01%	56.67%	60.72%
Semi-fixed sandy land	41.47%	12.02%	41.55%	20.18%	44.36%	22.68%
Bare sandy land	20.90%	50.07%	20.23%	46.21%	10.57%	43.22%
Wetlands	90.83%	67.51%	88.14%	60.34%	95.96%	54.83%
Water body	44.46%	45.90%	44.05%	33.47%	42.69%	30.98%

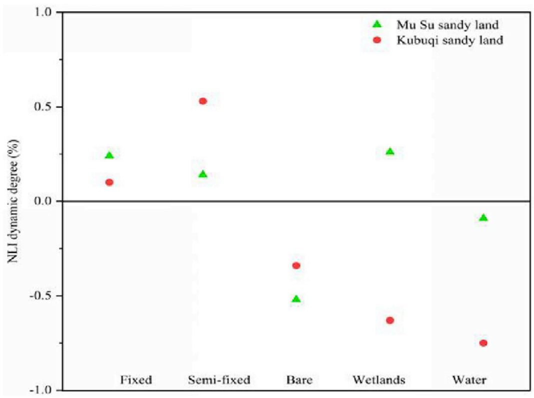

Fig. 4. *NLI* dynamic degree of two sandy lands.

Table 6
Desertification changes in Mu Us and Kubuqi sandy lands from 1990s to 2010s.

Sandy Land Type	Desertification degree (DG_i)			Desertification process (*DP*)		
	1990s	2000s	2010s	1990s–2000s	2000s–2010s	1990s–2010s
Mu Us Sandy Land	0.613	0.608	0.542	−0.05%	−0.66%	−0.36%
Kubuqi Sandy Land	0.749	0.763	0.750	0.14%	−0.13%	0.01%

Table 7
Desertification index in Mu Us and Kubuqi sandy lands.

Index		Mu Us	Kubuqi	*t* Value	*p* Value
Normalized Landscapes Index (*NLI*)	Fixed sandy land	53.49% ± 2.76	59.82 ± 1.01	−3.73	0.02*
	Semi-fixed sandy land	42.46% ± 1.65	18.29% ± 5.57	7.20	0.002**
	Bare sandy land	17.23% ± 5.78	46.5% ± 3.43	−7.54	0.002**
	Wetlands	91.64% ± 3.97	60.89% ± 6.36	7.104	0.002**
	Water body	43.73% ± 0.93	36.51% ± 7.53	1.65	0.175
Desertification degree (DG_i)		−0.36 ± 0.31	0.01 ± 0.14	−7.13	0.132
Desertification Process (*DP*)		0.59 ± 0.40	0.75 ± 0.08	−1.89	0.002**

Note: * means the difference is significant at the 0.05 level, ** means the difference is significant at the 0.01 level, Unmarked means the difference is not significant at the 0.05 level.

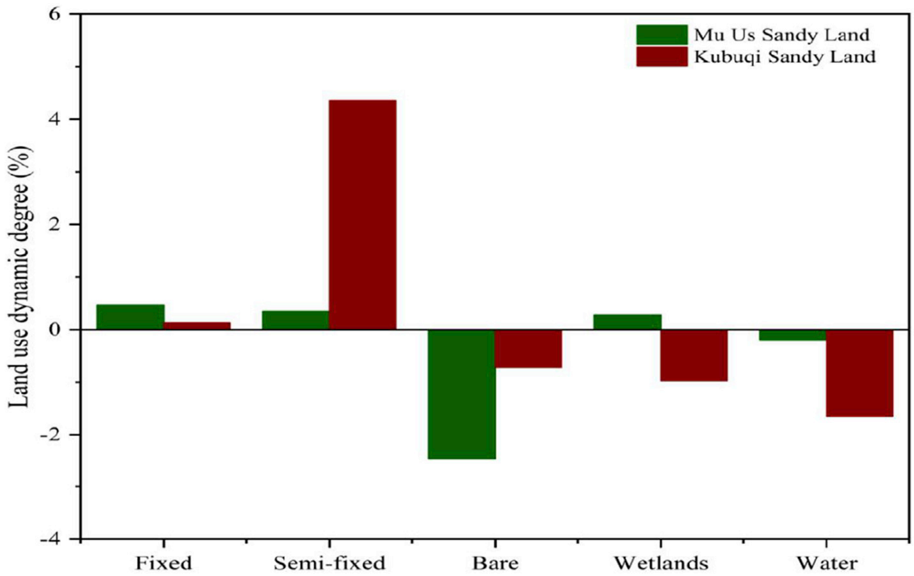

Fig. 5. Land use dynamic degree of two sandy lands from 1990s to 2010s.

affect the analysis of the desertification process, while after normalizing the data, it has advantages for studying the desertification process, which the results are not influenced by changes in the total area. It can be used to compare the desertification dynamic changes between different regions, which will play an important role in desertification research.

4.2. The limitation of NLI

In this study, DG_i and *DP* were created based on the *NLI*. However, the *NLI* was related to land use and can be affected by terrain factors. Also, on a short time scale, human activities were the main drivers of land-use change; the climate, terrain and geographical location factors are the main driving forces for changes in the land use on a long time scale. Terrain as one of the important drivers of land-use change (Chang et al., 2019; Yu et al., 2009), and it is also the basic background data of the region. There are seasonal differences in its impact on land-use change (Nill et al., 2019). Some researches also use terrain as basic data to establish estimation methods and obtain good results (Abanco and Hurlimann, 2014). This paper, according to the landforms of the study area, only the factor of terrain relief is selected to represent the terrain characteristics of different land types in the study area, and based on this estimated the maximum possible area of a certain land use type. The results showed that the land-use dynamic degree had the same trend as *NLI* dynamic degree (Figs. 4 and 5). Therefore, the *NLI* can efficiently identify desertification process. However, the terrain factors have a slope, aspect, elevation and topographic relief (Mottet et al., 2006), But relief did not fully represent the terrain characteristics of the area. Therefore, to make the data more accurate, the data needs to be normalized based on careful consideration of elevation, slope and aspect.

5. Conclusion

Based on the terrain factors, a new index (*NLI*) was developed to compare and analyze the desertification processes in two sandy lands in Inner Mongolia, China. The *NLI* dynamic degree showed the same trend as the landscape dynamic degree both in sandy lands, so this method can be used to analyze the dynamic changes of landscapes. Considered with eliminating the

Table 8
Correlation of the land use dynamic degree and *NLI* dynamic degree.

Index	Mu Us land use dynamic degree		Kubuqi land use dynamic degree	
	r Value	*p* Value	*r* Value	*p* Value
NLI dynamic degree (Mu Us and Kubiqi)	0.917**	<0.01	0.965*	<0.05

effects of climate, vegetation types and area sizes on assessing the desertification processes for different sandy lands, the *NLI* method was more accurate than the method of land-use dynamic degree. The main conclusions are as follows: Firstly, through the result of temporal and spatial trends of land use change and *NLI*, fixed sandy land and semi-fixed sandy land showed an increasing trend over the two decades; bare sandy land and water showed a decreasing trend in Mu Us and Kubuqi. Secondly, during the study period, bare sandy decrease speed in the Mu Us is greater than that in the Kubuqi; while the semi-fixed sandy land increase speed in the Mu Us increase speed lower than that in the Kubuqi. Finally, the DP_i and DG_i indicated that the desertification reversal phenomenon desertification occurs in Mu Us, and the desertification degree in Kubuqi was more serious than Mu Us. Although topographic factors are not fully considered, this study proved that the *NLI* method is effective in comparing desertification processes in different areas. This method is useful to assess desertification process and to combat desertification in different sandy regions.

Author contributions

Lixin Wang, Xiaowen Yu and Yi Zhuo conceived the ideas and designed this study; Xiaowen Yu, Yi Zhuo and Huamin Liu interpreted Landsat images and analysis, Xiaowen Yu and Yi Zhuo wrote the manuscript; Qi Wang, Lu Wen, Zhiyong Li, Cunzhu Liang, Lixin Wang reviewed the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e01132.

References

Alfredo, D.C., Emilio, C., Camarasaw, A., 2002. Satellite remote sensing analysis to monitor desertification processes in the crop-rangeland boundary of Argentina. J. Arid Environ. 52 (1), 0-133.
Alatorre, L.C., Beguería, S., 2009. Identification of eroded areas using remote sensing in a badlands landscape on marls in the central Spanish Pyrenees. Catena 76, 0-190.
Abanco, C., Hurlimann, M., 2014. Estimate of the debris-flow entrainment using field and topographical data. Nat. Hazards 71, 363–383. https://doi:10.1007/s11069-013-0930-5.
Arnon, K., Zhihao, Q., Bo, W., Natalya, P., Feng, Y., 2014. Spatio-temporal dynamics of land-use and land-cover in the Mu us sandy land, China, using the change vector analysis technique. Rem. Sens. 6, 9316–9339.
Chang, X.L., Gao, Y.Z., 2003. Quantitative characterization of desertification in regional desertification research. China Desert 23, 106–110.
Cui, Y., 2013. Interpretation and dynamic analysis in desertification – a case study of kubuqi desert. Appl. Mech. Mater. 295–298, 2102–2106.
Canora, F., D'Angella, A., Aiello, A., 2015. Quantitative assessment of the sensitivity to desertification in the Bradano River basin (Basilicata, southern Italy). J. Maps 11, 745–759.
Chang, Y., Hou, K., Li, X.X., Zhang, Y., 2019. Analysis of dynamic changes in the urbanization of Xixian National New Area and its driving forces. Indoor Built Environ. 28, 1181–1189. https://doi:10.1177/1420326x18809784.
Deng, H., Shu, S., Song, Y., Xing, F., 2007. Distribution of sand dunes and sand shifts along the southern fringe of the Mu Us Desert since the Ming Dynasty. Chin. Sci. Bull. 52, 3128–3138. https://doi:10.1007/s11434-007-0423-6.
Gao, X.H., Guo, Y.Z., Yan, C.Z., Wang, Y.M., Ieee, 2005. Study on the dynamic changes of land desertification in Yulin Prefecture, northwestern China based on RS and GIS. Geosci. Rem. Sens. Symp. 210–213.
Guo, L.Y., Liu, Y.S., Ren, Z.Y., 2005. Analysis of land use pattern change and its driving mechanism in ecologically vulnerable areas: a case study in yulin, shaanxi. Resour. Sci. 127–132.
Gou, F., Liang, W., Sun, S.B., Jin, Z., Zhang, W.B., Yan, J.W., 2019. Analysis of the desertification dynamics of sandy lands in Northern China over the period 2000-2017. Geocarto Int. https://doi.org/10.1080/10106049.2019.1678677.
Huang, S.E., Ying-Chun, L.I., Yin, J.M., 2001. Application of "3S" technology in climatic feasibility study of ratooning paddy growing in jiangxi province. Acta Agric. Univ. Jiangxiensis 23 (4), 573–576. https://doi.org/10.13836/j .j jau .2001143.

Hansen, M.C., Defries, R.S., Townshend, J.R.G., et al., 2002. Towards an operational MODIS continuous field of percent tree cover algorithm: examples using AVHRR and MODIS data. Rem. Sens. Environ. 83 (1−2), 303−319.
Helldén, U., Tottrup, C., 2008. Regional desertification: a global synthesis. Global Planet. Change 64, 0-176.
Jafari, R., Bakhshandehmehr, L., 2013. Quantitative mapping and assessment of environmentally sensitive areas to desertification in Central Iran. Land Degrad. Dev. 27, 108−119.
Li, J.C., Wei, Z.H., Zhang, C.X., 2010. Annual Variation of Climate Comprehensive Index in the Desertification Process of Minqin County in China, vol. 18, pp. 357−374.
Liu, J., Liu, H.M., Zhuo, Y., Liu, D.W., Wang, L.X., 2017. Landscape pattern changes and driving forces in Mu us sandy land from 1990 to 2014. Pratacultural Science 34 (2), 255−263. https://doi.org/10.11829/j.issn.1001-0629.2016-0258.
Li, F., Meng, J.J., Zhu, L.K., You, N.S., 2020. Spatial pattern and temporal trend of land degradation in the Heihe River Basin of China using local net primary production scaling. Land Degrad. Dev. https://doi.org/10.1002/ldr.3468.
Mottet, A., Ladet, S., Coque, N., Gibon, A., 2006. Agricultural land-use change and its drivers in mountain landscapes: a case study in the Pyrenees. Agric. Ecosyst. Environ. 114, 296−310. https://doi:10.1016/j.agee.2005.11.017.
Nill, L., Ullmann, T., Kneisel, C., Sobiech-Wolf, J., Baumhauer, R., 2019. Assessing spatiotemporal variations of Landsat land surface temperature and multispectral indices in the arctic mackenzie delta region between 1985 and 2018. Rem. Sens. 11. https://doi:10.3390/rs11192329.
Okin, G.S., Gillete, D.A., 2001. Distribution of vegetation in wind-dominated landscapes: implications for wind erosion modeling and landscape processes. J. Geophys. Res. 106 (D9), 9673−9683.
Qi, Y.B., Chang, Q.R., Jia, K.L., Liu, M.Y., Liu, J., Chen, T., 2012. Temporal-spatial variability of desertification in an agro-pastoral transitional zone of northern Shaanxi Province, China. Catena 88, 37–45. https://doi:10.1016/j.catena.2011.08.003.
Reynolds, J.F., Grainger, A., Smith, D.M.S., Bastin, G., Garcia-Barrios, L., Fernandez, R.J., Janssen, M.A., Jurgens, N., Scholes, R.J., Veldkamp, A., et al., 2011. Scientific concepts for an integrated analysis OF desertification. Land Degrad. Dev. 22, 166−183. https://doi:10.1002/ldr.1104.
Rui, Z., Zhang, Y., Zhou, S., 2011. The application of spatial information technology in modern flood and disasters control. In: International Conference on Information Science & Engineering.
Sun, D.H., Bloemendal, J., Rea, D., et al., 2002. Grain-size distribution function of polymodal sediments inhydraulic and aeolian environments, and numerical partitioning of the sedimentary components. Sediment. Geol. 152, 263−277.
Sun, J., Hou, G., Liu, M., Fu, G., Zhan, T.Y., Zhou, H.K., Tsunekawa, A., Haregeweyn, N., 2019. Effects of climatic and grazing changes on desertification of alpine grasslands, Northern Tibet. Ecol. Indicat. 107. https://doi:10.1016/j.ecolind.2019.105647.
UNEP. World Atlas of Desertification.
Verón, S.R., Paruelo, J.M., Oesterheld, M., 2006. Assessing desertification. J. Arid Environ. 66, 0-763.
Wang, X.L., Bao, Y.H., 1999. Study on the methods of land use dynamic change research. Adv. Earth Sci. 18 (1), 81−87.
Wu, B., Ci, L.J., 2002. Landscape change and desertification development in the Mu us sandland, northern China. J. Arid Environ. 50, 0-444.
Wang, T., Yan, C.Z., Song, X., Xie, J.L., 2012. Monitoring recent trends in the area of aeolian desertified land using Landsat images in China's Xinjiang region. ISPRS J. Photogram. Rem. Sens. 68, 184−190.
Wu, Z.T., Wu, J.J., He, B., et al., 2014. Drought offset ecological restoration program-induced increase in vegetation activity in the beijing-tianjin sand Source region,China. Environ. Sci. Technol. 48, 12108−12117.
Wang, T., Xue, X., Zhou, L., Guo, J., 2015. Combating aeolian desertification in northern China. Land Degrad. Dev. 26, 118−132.
Wang, Y., Zhou, L.H., Chen, Y., et al., 2017. Relationship between the farmers' livelihoods capital and the desertification reversion trend: a case study in Yanchi County,Ningxia. Acta Ecologica Sinica 37 (6), 2080−2092. https://doi.org/10.5846/stxb201510082024.
Wei, H.D., Li, Y., Zhang, B., Li, J.J., Ding, F., Chen, F., 2019. Spectral characteristics of desertification land in gansu hexi corridor. Spectrosc. Spectr. Anal. 39, 3508−3513. https://doi:10.3964/j.issn.1000-0593(2019)11-3508-06.
Xue, Z., Qin, Z., Li, H., Ding, G., Meng, X., 2013. Evaluation of aeolian desertification from 1975 to 2010 and its causes in northwest Shanxi Province, China. Global Planet. Change 107, 102−108.
Yang, X., Zhang, K., Jia, B., Ci, L., 2005. Desertification assessment in China: an overview. J. Arid Environ. 63, 0-531.
Yu, L.P., Pan, Y.T., Wu, Y., 2009. Mountain.Research on standardization methods of comprehensive evaluation data for academic journals. Lib. Inf. Service 53, 146−149.
Yu, X.W., 2017. Landscape Spatial Distribution Pattern and Wetland Dynamics of Kubuqi Sandy Land. Inner Mongolia University.
Zhu, Z.D., Liu, S., 1984. Judgment on the concept of desertification and its development degree. Journal of Desert Research 4 (3), 1–8.
Zhang, J.P., Chang, X.L., Cai, M.Y., et al., 2009. Effects of land use on desertification in typical regions in the Horqin Sandy Land. Arid Zone Res. 39−44, 026(001).
Zhu, L., Li, J.X., Qin, F.C., et al., 2009. Dynamic change of aeolian desertification landscape pattern in otog Banner,Inner Mongolia. Journal of Desert Research 29 (6), 1063−1068.
Zhang, J.M., You, X., 2011. Investigating optimum statistical unit of relief. J. Geomat. Sci. Technol. 28 (5), 369−373.
Zhao, C., Lu, R.j., Li, J.F., 2015. Land desertification and Grain size characteristics of landsurface deposits in the qinghai lake watershed. J. Desert Res. 35 (2), 276−283. https://doi.org/10.7522/j.issn.1000-694X.2014.0030.
Zhang, L.X., Cao, W., Fan, J.W., 2017. Soil organic carbon dynamics in xilingol grassland of northern China induced by the beijing-tianjin sand Source control Program. Front. Earth Sci. 11, 407–415.
Zhang, D., Deng, H., 2019. Historical human activities accelerated climate-driven desertification in China's Mu Us Desert. Sci. Total Environ., 134771 https://doi.org/10.1016/j.scitotenv.2019.134771, 10.1016/j.scitotenv.2019.134771.