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Assessing environmentally sensitive land to desertification using MEDALUS method in Mongolia

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ABSTRACT

Desertification is a global phenomenon caused by various processes, including climate change, vegetation processes, and human activities. The need to combat desertification is increasing in many countries. A reasonable assessment of the vulnerability or sensitivity of land cover to desertification at national scales is crucial to formulate appropriate strategies or policies for combating it. The main purpose of this work was to quantitatively assess the sensitivity of land cover to desertification in Mongolia using the MEDALUS approach. The MEDALUS method is a widely known technique for assessing desertification in the Mediterranean area. In this study, the method was adjusted to be applied to Mongolia, while the numerical methods of the MEDALUS remained the same. The modified MEDALUS method used nine factors from 2003 and 2008 to quantify the sensitivity of land to desertification. As a result, our study resulted in the calculation and spatial distribution of the Environmental Sensitive Area Index (ESAI), produced throughout Mongolia. In 2003, the middle region of the southern Mongolia had the highest sensitivity to desertification, while sensitivity in 2008 increased in the western area. Mongolia's area with the highest ESAI range increased approximately five times, indicating rapid desertification occurring throughout Mongolia from 2003 to 2008.

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Introduction

Desertification is defined as land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Additionally, the United Nations Environment Programme (UNEP) defined desertification as land degradation in arid, semi-arid and dry sub-humid areas resulting mainly from adverse human impact (1990). Desertification has many definitions containing various aspects, but all definitions involve the phenomenon of land degradation affected by different factors. In this study, we followed the definition suggested by UNCCD.

Approximately 41% of global territory and 44% of cultivated land is dryland (Millennium Ecosystem Assessment 2005). While the semi-arid drylands are increasing triggered by human activities, combating land desertification to secure land productivity is important (Manaye et al. 2019). The effects of desertification are the degradation of ecosystems, adverse effects on human health such as respiratory problems,

and a reduction in cropland, leading to food availability issues. To lessen such adverse effects, combating desertification should begin with considering the assessment of desertification based on reliable data and approaches (Bouabid et al. 2010), so that it may later be utilized to set an appropriate management policy.

There are many studies that assess the sensitivity and progress of the desertification of semi-arid and arid regions using a combination of indices (Türkes 1999; Frattaruolo et al. 2009). However, a large number of studies have focused only on Europe and China, especially in the northern region of China or Inner Mongolia. Few studies have dealt with land degradation in Mongolia (Su et al. 2005; Wang et al. 2006; Yang et al. 2007). Despite the large territory of arid and semi-arid land in Mongolia, little research has been done to evaluate the phenomena (Sternberg et al. 2011).

According to the definition of desertification, 40% of the Mongolia territory is covered with desert (Batjargal 1997). The fostering of desertification in the Gobi Desert of Mongolia and the Yellow River basin

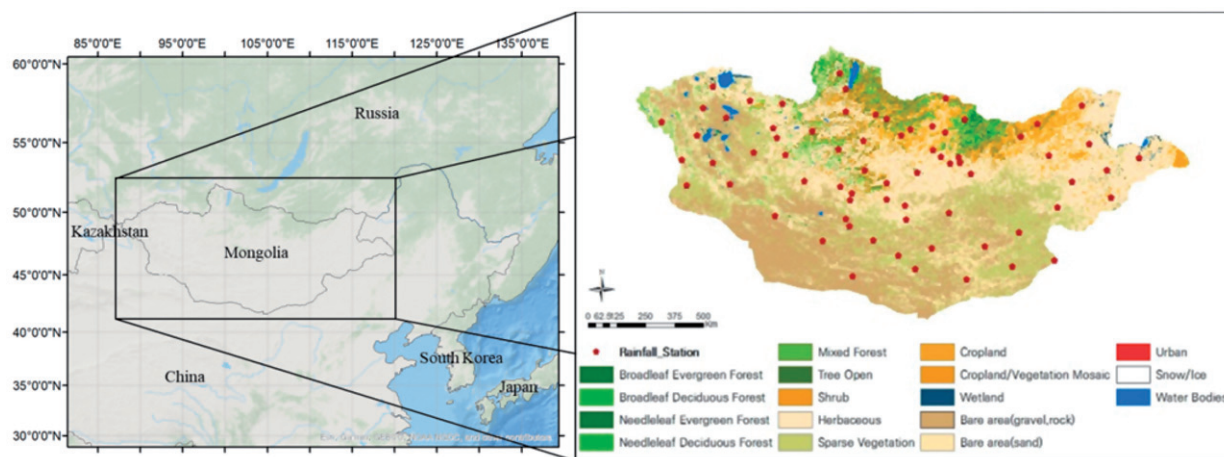


Figure 1. Land cover map in 2008 of the study area.

of China are the main sources of yellow dust (Northeast Asian Forest Forum 2006), which causes various ecosystem and health problems for the local people. The government of Mongolia is executing the National Action Programs to Combat Desertification, which mainly focuses on afforestation and enhancing forest management. Many studies also put effort to prevent desertification by planning afforestation and wind breaking in semi-arid region (Jo and Park 2017). However, a lack of capacity in various aspects has led to difficulties in solving the accelerating desertification process (Seoul National University 2015).

The main purpose of this work is to quantitatively assess the sensitivity of land cover to desertification in Mongolia by using the modified version of the Mediterranean Desertification and Land Use (MEDALUS) method. The MEDALUS method was adjusted to be applied to Mongolia using factors that influence the most in Mongolia.

Data and methods

Study area

Mongolia is the main area of this study. It is located in the northern portion of the mid-East Asia temperate zone; China is to the south and Russia is to the north. Mongolia ranges in longitude from $98^{\circ}58'$ to $105^{\circ}1'$ and in latitude from $49^{\circ}6'$ to $46^{\circ}41'$ (Figure 1), with area of approximately $1,565,000 \text{ km}^2$. Mongolia contains a large area of grass and shrub steppe grazing lands, which allows a large number of animals to graze there (Lamchin et al. 2015). Mongolia also has mountainous regions to the north and south, while the Gobi Desert comprises its southern region. The territory of Mongolia is comprised of 80% pasture land, 10% forest, 1% farmland, and 9% other types of land (Northeast Asian Forest Forum 2006). Mongolia has a dry subarctic climate, with relatively long winters and short summers. Precipitation in Mongolia ranges from less than 50 mm in the Gobi Desert region to over 500 mm in the mountainous regions in the north.

MEDALUS method

The European Environment and Climate Research developed the Mediterranean Desertification and Land Use (MEDALUS) project in 1999. The project was designed to assess and detect the sensitivity of desertification. The MEDALUS method mainly assesses the sensitivity of land cover to desertification in Mediterranean regions and provides a manual on the key indicators used for mapping a specific region on a national scale (EC-European Commission 1999).

To identify the sensitivity of land to desertification, the MEDALUS method requires the collection of data to create four main quality indices: soil, climate, vegetation, and management (EC-European Commission 1999). Within the four main quality indices, different indicators that affect land degradation are considered. To map the sensitivity of land to desertification for Mediterranean regions, the MEDALUS approach suggests there are 16 regional indicators that negatively or positively affect land sensitivity. All regional indicators are collected in geographic information system (GIS) based data, thereby enabling the detection of spatial distribution.

Various preceding studies have applied this approach to detect the spatial distribution of desertification sensitivity, mainly in European and Asian countries. The creation of desertification sensitivity maps of Iran, Algeria, Egypt, etc. were completed using the MEDALUS approach (Farajzadeh and Egbal 2007; Ali and El Baroudy 2008; Benabderrahmane and Chenchouni 2010). Farajzadeh and Egbal (2007) mapped the sensitivity of Iran using the modified MEDALUS method, consisting of using more indicators than the original and modified indices for a more accurate and local sensitivity map. They suggested that the MEDALUS method is one of the best for studying the presence of desertification using GIS mapping methods, and identifying the desertification-prone areas that need to be considered on a national scale (Farajzadeh and Egbal 2007). Benabderrahmane and Chenchouni (2010) pointed out that the usage of GIS in mapping desertification prone areas is highly precise, reliable, and saves a great deal of time. The use of remote sensing has been successfully applied to the

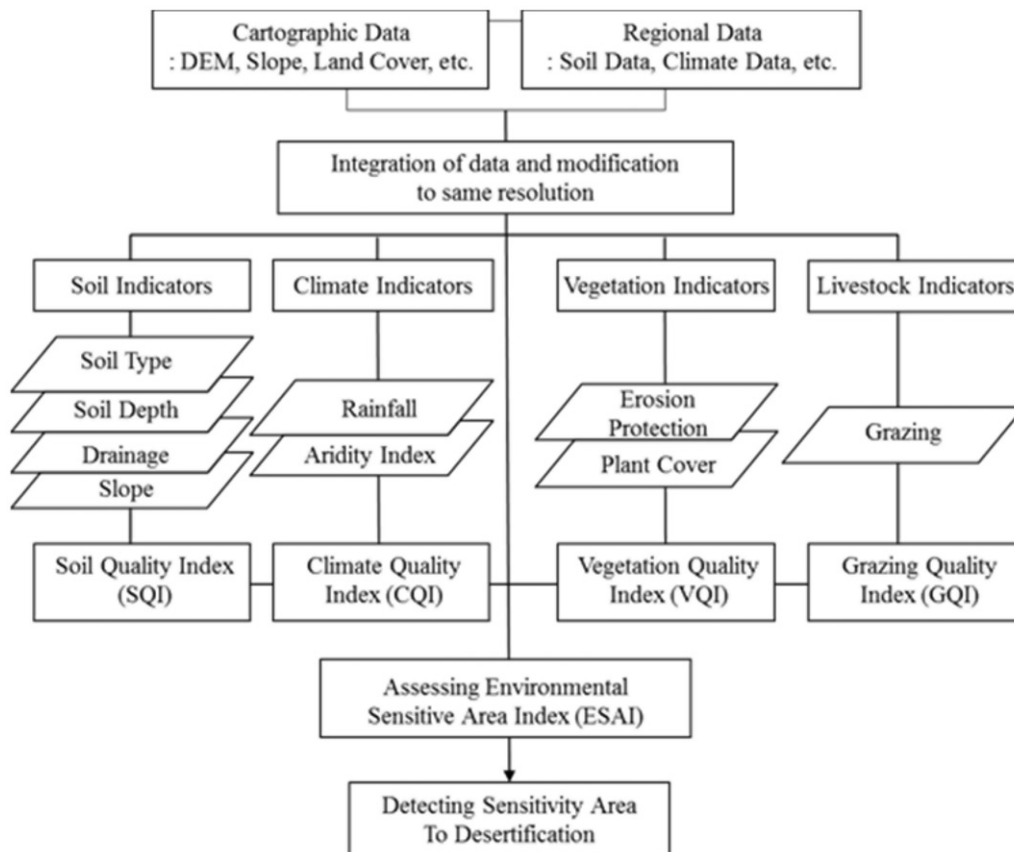


Figure 2. Overall scheme of the study. [Modified from the original by EC-European Commission (1999).]

process of monitoring desert expansion and to the assessment of factors that cause desertification (Kundu and Dutta 2011).

In this study, the MEDALUS approach was applied to quantify the sensitivity of land cover to desertification in Mongolia. Farajzadeh and Egbal (2007) suggested that the design of the MEDALUS method should be modified based on the condition of the study area. Here, the indicators for each quality index were modified for the condition of Mongolia and applied to the study (Figure 2). The main qualities used to assess and evaluate desertification in Mongolia were divided into Soil Quality Index (SQI), Climate Quality Index (CQI), Vegetation Quality Index (VQI), and Grazing Quality Index (GQI) to reflect regional conditions.

Indicators for quality indices of MEDALUS method

Nine indicators, which affect land sensitivity in Mongolia, were used to create four main quality indices and to identify the spatial distribution of land sensitivity to desertification (Table 2).

Soil quality index (SQI) and indicators

Soil quality is one of the dominant factors in terrestrial ecosystems, especially in sensitive ecosystems such as arid and semi-arid regions (Albaladejo et al. 1998; EC-European Commission 1999). The quality of the soil plays the most crucial role in determining the agricultural sustainability, environmental quality, and the

potential of the land to degrade (Doran and Parkin 1996).

In our study, the soil quality comprised of the following four indicators; soil type, soil depth, drainage, and slope (Figure 2). Because the soil quality varies by location and land type (Seybold et al. 1997), each of the different soil types should be assessed. Soil depth and drainage were also considered. Soil depth is one of the key factors which determine moisture storage and conservation capacity (Boer et al. 1996). Drainage can be one of the major constraints that control the soil yield (Abid and Lal 2008). Slope is one of the important determinants of soil erosion, which links directly to land degradation and desertification.

Climate quality index (CQI) and indicators

The spatial-temporal distribution of rainfall and evapotranspiration, and their impacts on surface ecosystems, are the most crucial factors in hydrology and ecology (Zhu and Meng 2010). Precipitation is the most important factor affecting land degradation and desertification, as it controls the drainage and water capacity of the soil (EC-European Commission 1999). The average annual precipitation of Mongolia, by land cover type, is 300–400 mm in mountainous areas, 150–250 mm in steppe areas, 100–150 mm in the steppe desert, and 50–100 mm in the Gobi Desert area (Lamchin et al. 2015). This indicates a high gradient depending on the longitude and land cover. The Aridity Index was calculated annual precipitation divided by the annual potential evapotranspiration.

Mongolia is situated in the temperate zone and as such the evapotranspiration rate is very high compared to other countries, approximately 90% (Batjargal 1997).

Vegetation quality index (VQI) and indicators

Vegetation quality is the dominant biotic land component (Bryan and Campbell 1986) in quantifying land sensitivity to desertification. In this study, vegetation quality is assessed by erosion protection and plant cover. Land cover is one of the important factors determining land erosion. According to the MEDALUS project, all forest land cover has a higher erosion protection rate than shrub, grassland, and cropland.

Plant cover is one of the main representatives of vegetation quality and it can be investigated using a vegetation index. The Normalized Differentiated Vegetation Index (NDVI) was first suggested by Rouse et al. (1974) and it consists of the ratio between the sum and difference of the Near Infrared (NIR) and red wavelength. In this study, the NDVI is used to represent the condition of plant cover and the degree to desertification.

Grazing quality index (GQI) and indicators

The overgrazing of livestock is the essential contributing factor to land degradation Mongolia which leads to desertification (Batjargal 1997). Therefore, grazing quality were applied to represent management activities which affect desertification instead of the management quality from the original MEDALUS method. The territory of Mongolia is used as rangelands, comprising over 30 million livestock (Batjargal 1997). Between 1990 and 2000, the number of goats, horses, cows, and sheep increased by 54%, 76%, 33%, and 51%, respectively, while the number of camels decreased by 8.1%. Overgrazing has degraded the pastureland, and over 1.3 million hectares of land lost its fertility and has been abandoned (Jazandaulam et al. 2005).

Assessment and classification of environmental sensitivity area index (ESAI)

The MEDALUS approach assesses the Environmental Sensitive Area Index (ESAI), using the four-quality indices (SQI, CQI, VQI, and GQI) for detecting the sensitive land to desertification. The four main quality indices were calculated by geometrically averaging the according indicators. The ESAI, representing the most sensitive land to desertification, was also calculated by geometrically averaging the four main quality indices. The following equations were used in calculating the indices.

$$SQI = (\text{Soil Type} * \text{Soil Depth} * \text{Drainage} * \text{Slope})^{1/4}. \quad (1)$$

$$CQI = (\text{Rainfall} * \text{Aridity Index})^{1/2}. \quad (2)$$

$$VQI = (\text{Erosion Protection} * \text{Plant Cover})^{1/2}. \quad (3)$$

Table 1. Range of the ESAI by type of sensitivity to land degradation.

	Type	Subtype	Range of ESAI
1	Critical	C3	>1.53
2	<<	C2	1.42–1.53
3	<<	C1	1.38–1.41
4	Fragile	F3	1.33–1.37
5	<<	F2	1.27–1.32
6	<<	F1	1.23–1.26
7	Potential	P	1.17–1.22
8	Nonaffected	N	< 1.17

$$GQI = (\text{Overgrazing}). \quad (4)$$

$$ESAI = (SQI * CQI * VQI * MQI)^{1/4}. \quad (5)$$

Every calculation of the quality index and the ESAI were processed in ArcGIS, by overlaying the indicators. The calculated ESAI results ranged from 1 to 2, they were then re-classified into three large types and 8 subtypes (Table 1).

Data preparation for indicators of MEDALUS method

Nine layers of topographic and alphanumeric data were preprocessed in ArcGIS version 10.3 and ENVI. Every cartographic, shape file and satellite images were resampled to 1 km spatial resolution using ArcGIS 10.3 programs. Every indicator was weighted from 1 to 2; the higher the weighting, the higher the sensitivity of the land to degradation according to the original MEDALUS method (EC-European Commission 1999). Each weighting of the indicators is shown in Table 2.

Data for SQI's indicators

The first indicator used for the soil quality index is soil type, with varied spatial distribution in Mongolia. The soil types for Mongolia were collected from the Institute of Geography, Mongolian Academy of Science. The various types of soil were appropriately weighted according to the location.

The soil depth and drainage data were downloaded from the International Soil Reference and Information Centre (ISRIC) World Soil Information database. The ISRIC-WISE global data set of derived soil properties on a 0.5 by 0.5 degree grid was used to map the soil depth and drainage of the soil in Mongolia, and they were weighted accordingly within the index. Quantification of the drainage in Mongolia contained classes shown in Table 2, which are drainage classes according to Food and Agriculture Organization (FAO) soil classification. The slopes of Mongolia were calculated using the digital elevation model (DEM) data collected by the ASTER Global Digital Elevation Model (ASTER GDEM) at a resolution of 30 m. The slopes of Mongolia were reclassified into four different classes according to the slope (%).

Data for CQI's indicators

The annual rainfall data used in the study were collected by the Meteorological Institute of Mongolia. The monthly precipitation data for the years 2003 and 2008

Table 2. Weighted scores to each indicator for 4 quality indices.

Quality index	Indicators	Class or types	Scores	
Soil	Type of soil	Soil of humid areas	1	
		Piparian Soil	1.17	
		Other soils and bare land	1.34	
		Mountain soil	1.51	
		Saline soil	1.68	
		Low mountains and rolling hills soil	1.85	
		Soil of steppe valley and depression	2	
		Soil depth	Oceans and water bodies	1
			110 < x ≤ 140	1
			50 < x ≤ 140 (complex)	1.2
	80 < x ≤ 110		1.4	
	110 < x (complex)		1.6	
	x ≤ 80 (complex)		1.8	
	Drainage by FAO soil unit	x ≤ 50	2	
		Glaciers/Oceans and water bodies	–	
		Greyzems	Well Drained	1.3
		Podzols and Lithosols	Somewhat excessively drained	1.7
		Vertisols	Imperfectly Drained	2
		Planosols	Imperfectly drained	2
	Slope (%)	Solonetz and Planosols	Imperfectly drained	2
<6			1	
6–18			1.2	
18–35			1.5	
>35			2	
Climate	Rainfall (mm)	<100	2	
		100–150	1.75	
		150–200	1.50	
		200–300	1.25	
		>300	1	
	Aridity Index (AI)	Subhumid to humid (AI > 0.65)	1	
		Dry subhumid (0.50 < AI < 0.65)	1.3	
		Semi-arid (0.20 < AI < 0.50)	1.5	
		Arid (0.03 < AI < 0.20)	1.8	
		Hyperarid (AI < 0.03)	2	
Vegetation	Erosion Protection by Land Cover Type	Very high	1	
		(Evergreen Forest/Mixed Forest/Wetland/Water Bodies)		
		High (Tree Open)	1.3	
		Moderate (Deciduous Forest/Urban)	1.6	
		Low (Shrub/Cropland)	1.8	
	Plant Cover (Range of NDVI)	Very Low (Herbaceous/Sparse Vegetation/Paddy Field/Bare Area)	2	
		0.5 < NDVI (non)	1	
		0.4 < NDVI < 0.5 (low)	1.25	
		0.32 < NDVI < 0.4 (medium)	1.5	
		0.25 < NDVI < 0.32 (high)	1.75	
Grazing	Number of Livestock	NDVI < 0.25 (severe)	2	
		0–50,000	1	
		50,000–100,000	1.2	
		100,000–200,000	1.4	
		200,000–300,000	1.7	
	300,000–400,000	2		

consisted of 67 and 63 station measurements, respectively. The monthly precipitation data for Mongolia were summed to a yearly precipitation total for 2003 and 2008. A Kriging method was used in ArcGIS 10.3 program to map the yearly precipitation data. The Kriging method is a widely used method for interpolating point measured data to a wider scale raster.

In this study, to calculate the Aridity Index (AI) the Potential Evapotranspiration (PET) was calculated using the Thornthwaite method, because the measured Evapotranspiration data were not collected. The Thornthwaite method of calculating the PET was developed by Thornthwaite (1948) and uses meteorological data to calculate PET. It is one of the commonly used methods of calculating PET. Then, AI was calculated by the ratio of precipitation and PET. According to the classification of UNESCO (1979), the

AI was reclassified, ranging from 1 to 2 in the Climate Quality Index.

Data for VQI's indicators

Erosion protection was classified according to land cover. Different types of forest cover vary in their ability to protect the land against erosion. Evergreen forests provide the most erosion protection, while deciduous forests have a lesser ability to protect due to fewer fallen leaves on the surface (EC-European Commission 1999).

To classify each land cover type, the Global Land Cover by National Mapping Organizations (GLCNMO) data was downloaded from the International Steering Committee for Global Mapping created by Geospatial Information Authority of Japan,

Chiba University and collaborating organizations. The GLCNMO data used in this study are as follows: version 1 for 2003 and version 2 for 2008. The GLCNMO versions 1 and 2 had the spatial resolution of approximately 1 km and 500 m, respectively. The global map was then masked to a map of Mongolia using a GIS tool. The land cover maps for the years of 2003 and 2008 were used to compare the sensitivity of land in Mongolia to desertification.

The plant cover was classified by calculating the Normalized Differentiated Vegetation Index (NDVI). In this study, the maximum NDVI for the growing season months (May to October) was used to represent the class of plant cover. Six months of NDVI data in Mongolia were downloaded from the NASA Land Processes Distributed Active Archive Center (LP DAAC). MOD13A2 images taken by the MODIS sensor TERRA have the spatial and temporal resolution of 1 km and 16 days respectively. Ten satellite MODIS images were mosaicked to compose a full image of Mongolia.

Data for GQI's indicators

The National Statistical Office of Mongolia collected the data concerning the number of livestock. In the year 2003, the number of livestock in sum scale ranged from 5026 to 279,234, while in the year 2008 it ranged from 13,000 to 384,824. The total number of livestock in Mongolia increased by approximately 58%; from 24,723,948 to 42,377,569.

Results and discussion

Quality indices

The four quality indices were mapped to identify the spatial distribution in Mongolia. The four quality indices for the years 2003 and 2008 are shown in Figures 3 and 4. Using the same legend range for all of the

quality indices, a comparison of each index from 2003 and 2008 was performed. Every index ranged from 1 to maximum of 2; the higher the index, the higher effect the quality has on land sensitivity. Every quality map was rasterized with the spatial resolution of 1 km. Climate, vegetation, and grazing quality differ between the years 2003 and 2008, while the SQI was considered to be the same. This is due to the difficulty of collecting data for Mongolia, and the fact that soil type, depth, drainage, and slope indicators do not change rapidly over time. The CQI and VQI for both 2003 and 2008 indicate a clear spatial distribution; high index in southern region and lower in the northern region. Changes in the climate quality index indicate either a decrease in rainfall or an increase in potential evapotranspiration in the southwest region between 2003 and 2008. The distribution of VQI is similar; however, an increase in the index is found for the western region of Mongolia. This region borders the northwestern part of China, where it is the main area of land desertification (Plit et al. 1995). The GQI shows an increase over all regions in Mongolia, as the number of livestock has increased almost five times from 2003 to 2008. However, the northern region where there is a great amount of forest cover continues to have a small amount of livestock.

Overall, the regions with the highest CQI, VQI, and GQI were located in the mid southern part of Mongolia in 2003. However, the regions with the highest indices in 2008 were detected in the western areas of the southern Mongolia. This can be explained by the decrease in rainfall and plant cover, and the rapid increase in the number of livestock.

Spatial distribution of environmental sensitive area index (ESAI)

Figure 5 shows the spatial distribution of the ESAI, or sensitivity to desertification. By comparing the spatial

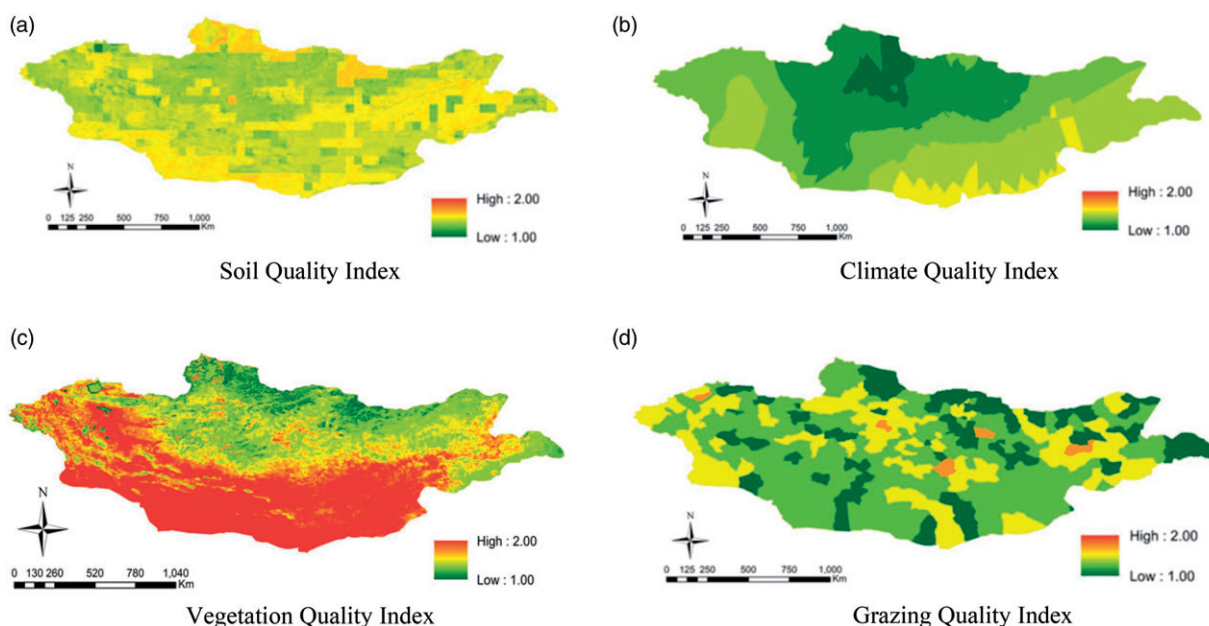


Figure 3. Spatial distribution of Quality Indices of 2003.

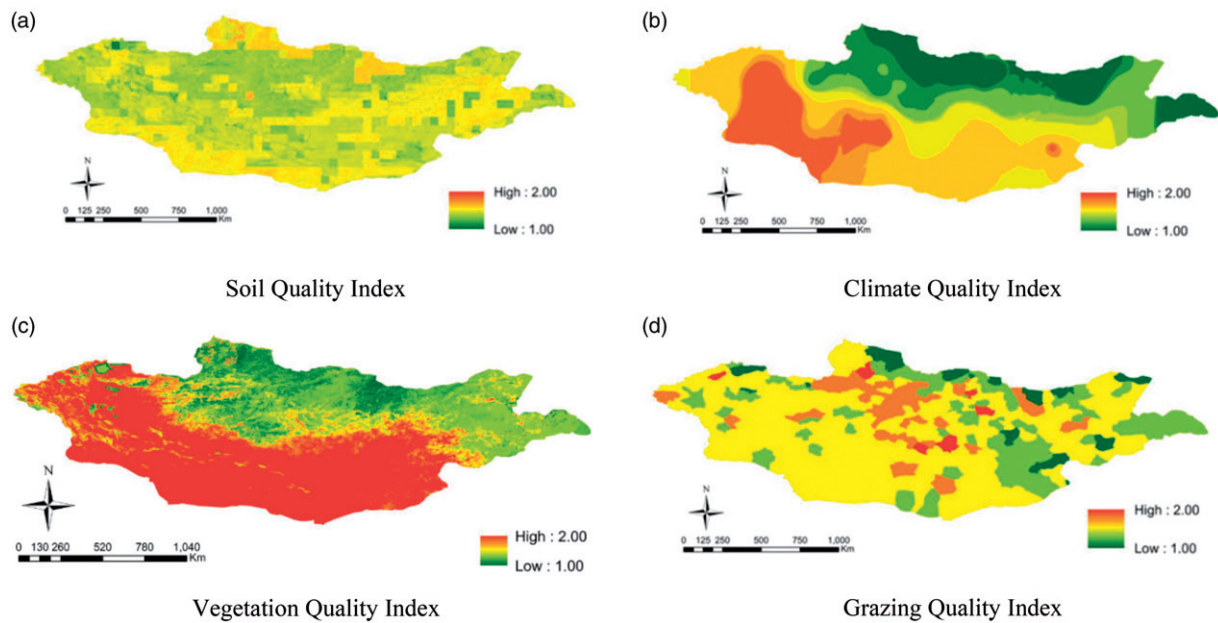


Figure 4. Spatial distribution of Quality Indices of 2008.

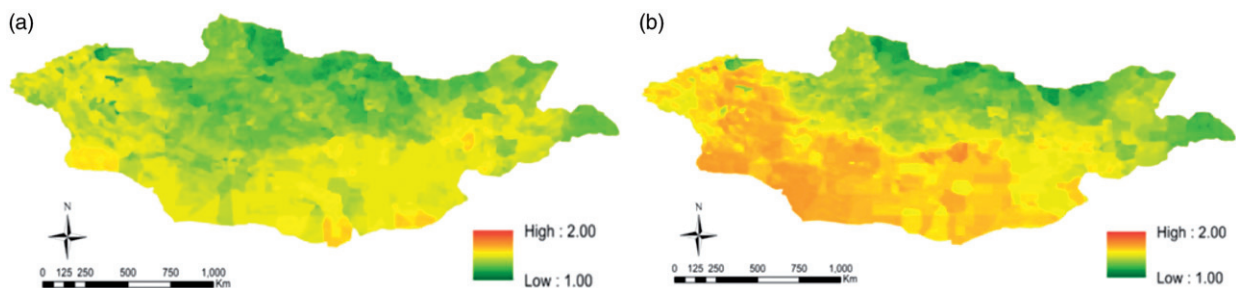


Figure 5. Spatial distribution of ESAI in (a) 2003 and (b) 2008.

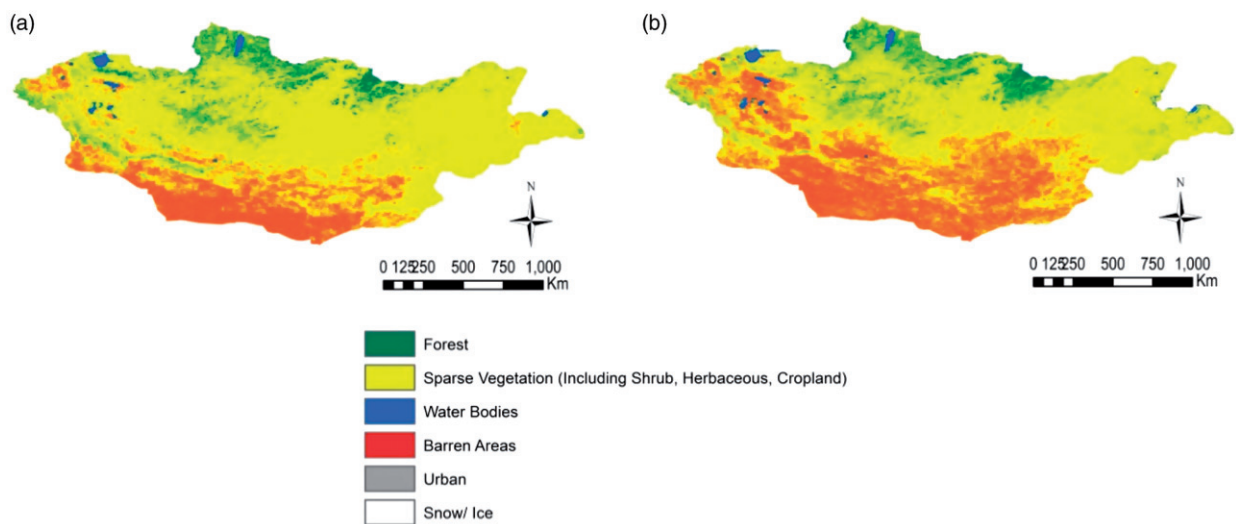


Figure 6. Land Cover map of Mongolia in (a) 2003 (b) 2008.

distribution of each quality indices (Figures 3 and 4) with the ESAI (Figure 6), the land sensitivity to desertification in 2003 appeared to be influenced most by climate quality, while the ESAI of 2008 seemed to be mostly influenced by vegetation quality. The change in type of land cover to barren land and the decrease in the distribution of vegetation had the greatest impact on the expansion of land degradation. The overall spatial distribution of ESAI, or sensitivity to

desertification, shows a shift from the mid areas of the southern region, more to the north and to the western area of the southern region from 2003 to 2008.

By mapping the spatial distribution of ESAI (Figure 5) with land cover (Figure 6), and NDVI change (Figure 7), we were able to compare ESAI with the actual change in Mongolia during 2003 and 2008. The distribution of change in land cover from 2003 to 2008 is shown in Figure 6. Using the land cover of

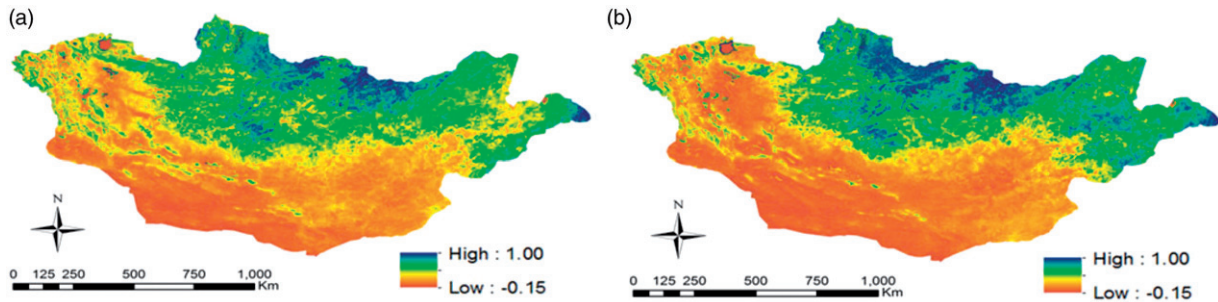


Figure 7. Spatial distribution of the NDVI in Mongolia in (a) 2003 and (b) 2008.

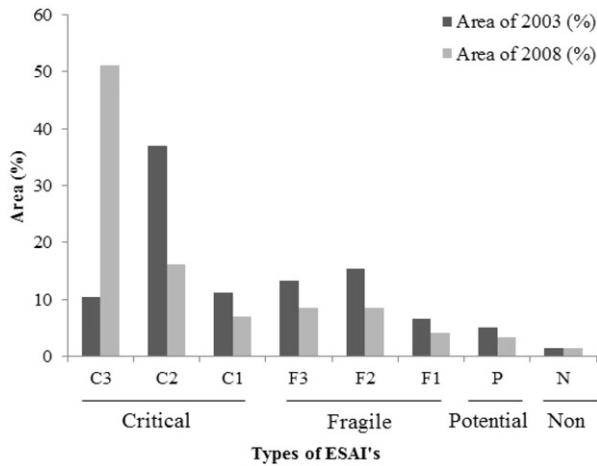


Figure 8. Change in area of type of ESAI. (Refer to Table 1.)

GLCNMO, changes in area of different land cover were detected. Notable trends in change of land cover are the decrease in forest and sparse vegetation area, and the increase in barren area. The barren area of southern region in 2003 has expanded to the north by invading the sparse vegetation land in central area by 2008 (Figure 6). This trend in change of land cover has similar changes in ESAI from 2003 to 2008. This shows that the increase in all quality indices (SQI, CQI, VQI, and GQI) for 5 years fostered the change of land cover to barren land in the southern east part of Mongolia. Change in distribution of NDVI is shown in Figure 7. The overall distribution of NDVI in Mongolia has not much changed from 2003 to 2008. However, it is shown that low NDVI region in the southern region has expanded more widely to the mid and northern region of Mongolia, similar to the expansion of critical area of ESAI and barren land of land cover.

Portions of each of the ESAI ranges are shown in Figure 8. It is clear that the percentage of area classified as extremely critical (C3) has increased remarkably, almost five times between 2003 and 2008. Except for the C3 area, every area of the ESAI classification has decreased. This indicates that a large amount of land that was not extremely critical to desertification in the 2003, has changed to land that is extremely critical to desertification (C3) in 2008.

Table 3 shows the change matrix of ESAI from 2003 to 2008. 3.4% of nonaffected, 11.6% potential, and 51.8% of fragile land in 2003 has changed to critical land in 2008, while 94.9% critical land in 2003

Table 3. Change matrix of ESAI from 2003 to 2008.

		2008				(Unit: km ²)
		Nonaffected	Potential	Fragile	Critical	Total
2003	Nonaffected	8033 (31.1%)	8355 (32.4%)	8510 (33.0%)	882 (3.4%)	25,780 (100%)
	Potential	7682 (13.1%)	12,271 (21.0%)	31,651 (54.1%)	6822 (11.6%)	58,426 (100%)
	Fragile	8856 (1.9%)	15,855 (3.4%)	194,695 (42.7%)	236,141 (51.8%)	455,547 (100%)
	Critical	47 (0%)	174 (0%)	37,979 (5.0%)	720,375 (94.9%)	758,575 (100%)

Table 4. Area and percentage of classified ESAI for barren land.

	Nonaffected	Potential	Fragile	Critical	Total
2003					
Barren Land (km ²)	0 (0%)	2 (0%)	5984 (3.0%)	194,248 (97.0%)	200,234 (100%)
2008					
Barren Land (km ²)	31 (0%)	42 (0%)	549 (0.2%)	338,243 (99.8%)	338,865 (100%)

remained the same in 2008. It is notable that nearly half of the area of fragile land in 2003 was changed to critical land in 2008.

Comparison of ESAI with land cover and NDVI changes in Mongolia

Comparison with land cover change

Table 4 shows the comparison of spatial distribution in land cover and ESAI. The area of each ESAI for barren area in 2003 and 2008 is calculated. Nonaffected, potential, fragile, and critical land of barren land in 2003 took part of 0%, 0%, 3%, and 97%, respectively. This trend is very similar to that of 2008. 97% and 99.8% of critically classified ESAI accords to the barren land. This implies that the ESAI can well represent the barren land.

To compare ESAI with land cover change, the ESAI changes were analyzed for the land that were not barren land in 2003, but changed into barren or sparsely vegetated land in 2008; therefore, land that has gone through desertification. By comparing the distribution of ESAI in such land, area of non-affected and potentially sensitive land to desertification composed of very small area and did not have a significant change (Figure 9), while most of the land was classified “critical” in both 2003 and 2008. 89.4% and 10.5% of such land was classified “critical” and “fragile”, respectively, in 2003, changed to barren land in 2008. The result implies that land which has the highest potential

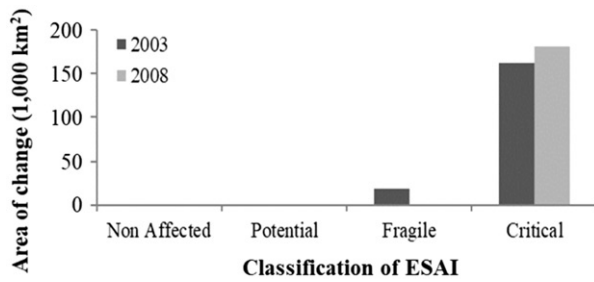


Figure 9. Change in area of ESAI classification for the area.

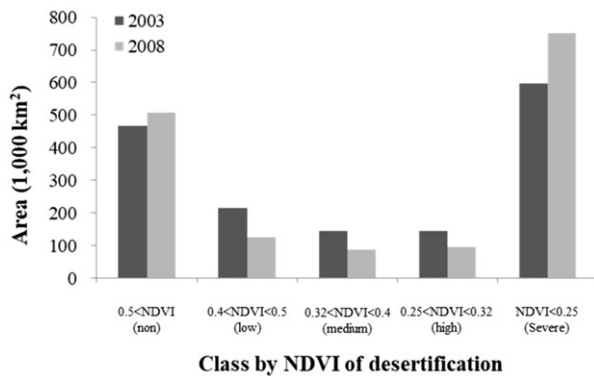


Figure 10. Area of desertification class by NDVI.

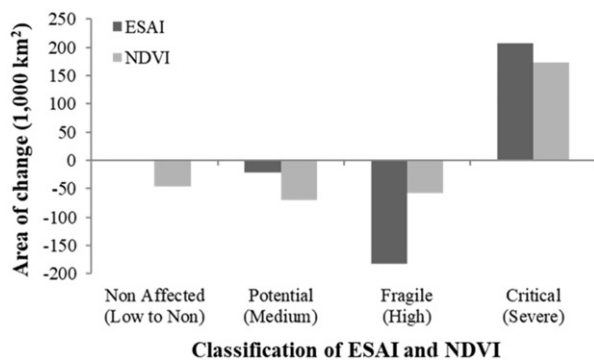


Figure 11. Comparison of change in area of different classes of ESAI and NDVI.

to change into barren land is classified as critical ESAI, thus extremely sensitive to desertification.

Comparison with NDVI

NDVI values ranging from -1 to 1 (Figure 7) were classified into five categories (non, low, medium, high, severe; refer to Table 2) in terms of sensitivity to desertification. The result showed that the severely degraded area has increased by 38% of the total Mongolian territory to 48%, while the portion of low, medium, and high degraded areas have decreased (Figure 10).

Change analysis of NDVI and ESAI class from 2003 to 2008 was done to compare the NDVI and ESAI trend. ESAI and NDVI were each classified into four classes, and area change in each class of ESAI and NDVI from 2003 to 2008 were compared (Figure 11). The change of critical area of ESAI and severe area of NDVI increased from 2003 to 2008, and the both trend shows a high similarity. It implies that critical

area of ESAI can represent well severe area of NDVI, which is sensitive area to desertification.

Discussion

The MEDALUS method is a quick and simple way to assess the sensitivity of land to desertification. It could clearly show the spatial distribution of desertification prone areas. Although the method uses such simple equation to calculate the index representing the most sensitive region to desertification, modification of the indicators and inputs is very common to represent desertification (Lamqadem et al. 2018). In this study, the MEDALUS method was modified into four different quality indices and 9 indicators. Especially, the Grazing Quality Index (GQI) was replaced as one of the four indicators, representing the livestock grazing affects in accelerating land degradation. The dramatic increase of livestock and overgrazing since 1988 and its direct effect to soil and vegetation degradation were reflected to identify and calculate the grazing quality as well as ESAI results (Li et al. 2008).

Limitations of this study hold the lack of obtainable data and its low temporal and spatial resolution. The lack of data and information for Mongolia, led to a small number of indicators. Therefore, the interpreting MEDALUS results needs to understand that the method is very dependent upon input data. Additionally, in this study, the low spatial and temporal resolution of data was considered a limitation. Soil indicators had the spatial resolution of 55 km, which is very rough when attempting to monitor and assess soil on a national scale. Thus, the results of the ESAI were shown in blocks and the temporal resolution of the study was too rough. However, this paper tried to suggest and concentrate on the basic methodology and approach to assess the desertification using the MEDALUS approach in Mongolia in national level. The assessment was conducted using the most detailed data available in macro scale, and we expect future studies using more detailed and updated data to analyze site-specific desertification assessment using the modified MEDALUS methodology suggested in this study. Which means, the spatio-temporal scale and resolution matter should be considered with data availability and proper desertification indicators based on established assessment and policy aims in certain region (Liu et al. 2015).

The calculation of the ESAI using the MEDALUS method does not provide an absolute estimation of the land sensitivity to desertification. The ESAI is a combination of dependent and independent variables and it requires further investigation on a local scale (Ferrara et al. 2012). On-site measurements to validate the results of this study could help increase its accuracy. Containing such limitations, the distribution of ESAI was compared and validated with land cover and vegetation indices. In this study, it was accomplished with the change and distribution of land cover and NDVI. It showed a high similarity in the trend of change in all three spatial distributions; ESAI, land

cover and NDVI. Thus, we can conclude that the usage of modified MEDALUS approach provides a satisfactory method in assessing the sensitivity of land cover to desertification in Mongolia from 2003 to 2008.

Conclusions

This study presented a methodology to quantify the sensitivity of land to desertification using the modified MEDALUS method. The results indicated that from 2003 to 2008, Mongolia has experienced a high rate of desertification. The Environmental Sensitive Area Index (ESAI), a quantified range of numbers explaining sensitivity of land cover to desertification, showed that the area of the most critically sensitive land (ESAI > 1.53) has increased approximately 5 times in the southern region of Mongolia. However, the total area of regions with fragile to moderately critical sensitivity has decreased. By comparing the ESAI maps with land cover and NDVI maps, the results implied that there is a high similarity in the trend of all three spatial distributions. The results showed in common that the western area of southern region of Mongolia, which has mountainous topography, is rapidly progressing toward desertification. Also, land with the highest sensitivity to desertification in 2003 expanded more to the north invading the sparsely vegetation and herbaceous land.

The extraction of areas sensitive to desertification is a crucial process in evaluating and predicting the expansion of desertification, especially in dry zones of arid and semi-arid areas. The application of the results of this study can suggest a target area to plan management practices to combat desertification, or a guideline for a methodology to detect the sensitivity of land cover to desertification.

Disclosure statement

No potential conflict of interest was reported by the authors.

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