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ASSESSMENT OF LANDSCAPE-ECOLOGICAL POTENTIAL OF KHOVD PROVINCE, MONGOLIA USING SATELLITE IMAGERY AND THE SPATIAL MULTI-CRITERIA DECISION-MAKING METHOD

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KeyWords

Landscape-ecological potential, AHP, MCDM method, Landsat OLI

ABSTRACT

One of the most important concepts of the landscape-ecological theory of the interaction between man and nature is the landscape-ecological potential. The aim of this study was to assess landscape-ecological potential using optical remote sensing data and field-measured biomass samples in Khovd province, Mongolia. We used the spatial MCDM (Multi-Criteria Decision-Making) method and GIS-based AHP (Analytical Hierarchy Process). This method was trained to predict landscape-ecological potential using five environmental criteria derived from Landsat OLI, MODIS (MOD 11, MOD 16), TRMM and SRTM data. These five criteria were classified, and quality evaluation criteria were developed for thirteen sub-criteria, each with 5 levels. This was processed for each criteria layer's value by multiplying parameters for each criterion obtained from the pair comparison matrix with weight addition. In this study, we estimated a consistency ratio 0.053, suggesting that there was a reasonable level of consistency in judgment. The analysis of the spatial distribution of the landscape-ecological map showed that 6.8% of the area studied had very high potential, 25.3% had high potential, 42.6% had average potential, 17.6% had low potential, and 7.6% had very low potential. To assess accuracy of the evaluation, reference biomass data from a field survey of 34 sites were applied. The overall accuracy of site selection for landscape-ecological potential using spatial multi-criteria analysis was 79.4%. The study results confirmed that, in this evaluation, the landscape-ecological potential could be effectively obtained by the integrated use of GIS-based AHP and multi-criteria decision-making methods. The GIS-based AHP technique is a good indicator for estimating weighting values to create landscape-ecological potential maps based on landscape elements.

Introduction

Landscape ecology is an interdisciplinary field, the goal of which is to investigate the relationship between spatial patterns and ecological processes at a range of scales (Wu and Hobbs, 2007). The German biogeographer Carl Troll introduced the term landscape ecology in 1939, aiming to combine the two disciplines of geography and ecology (Francoise and Jacques, 1999). In this framework, the landscape is seen as the spatial expression of the ecosystem (Richard, 1975). Since the 1930s, many scientists (Troll 1968; Troll 1971; Zonneveld 1972; Forman 1981; Naveh and Liberman 1984; Risser et al 1984; Forman and Gordon 1986; Turner 1989; Naveh and Liberman 1994; Pickett and Cadenasso 1995; Nassauer 1997; Wiens 1999; Turner et al 2001; Wu and Hobbs, 2007) have devised several definitions for landscape ecology (a good definition is found in Wu, 2013). Until the early 1970s, landscape ecology was strongly dominated by the “geographical” component, which was developed in Eastern Europe and North America and had been applied to the study of the ecological potential of a wide range of territories. Landscape ecology has a long history in Europe (Naveh and Lieberman, 1984), and a more recent history in North America (Forman and Gordan, 1986). In Eastern Europe, geographers played a driving role in the formation of landscape science in close relation with issues of natural resource management (Preobrazensky, 1984).

Over the past decades, these two perspectives (European and North American) have dominated in landscape ecology studies (Wu, 2013). The two perspectives are not antagonistic but complementary. However, landscape ecology was not an acknowledged scientific field at the global scale until the 1980s, when remotely sensed data and computer techniques became broadly accessible to ecologists and geographers. Since then ecological ideas of spatial heterogeneity and non-equilibrium dynamics have developed (Wu, 2013). Moreover, landscape-ecological study has obtained a distinctive reality as it reassures efficient natural conservation and sustainable use of natural resources (Canters et al, 1991; Lathrop and Bognar, 1998; Liu and Taylor 2002; Francoise, 2003). The core of landscape-ecological study consists of researching the ecological state, the interrelation, management and significance of the constituents and morphological parts of the landscape (Preobrazenski and Alexandrove, 1987). The goal of analyses in landscape ecology is to understand the impact of landscape connectivity on species persistence (Turner, 2005). In particular, landscape ecology analysis helps us to understand the relationship between landscape patterns and processes (Turner, 1989; Pickett and Cadenasso, 1995; Knight and Landres, 2002).

Remote sensing (RS) and geographical information systems (GIS) have been fundamental in the growth of the landscape ecology field. RS data processed using GIS is the most popular form of data used to define land cover for the exploration of the relationship between landscape patterns and ecological processes (Chen et al, 2008; Metzger, 2008). Remote sensing data have the potential to describe broad-scale landscape patterns and relate them to ecological processes such as species persistence and distribution (Lechner, 2009). Furthermore, advances in remote sensing technology have allowed for the advancement of theoretical and empirical ecological studies that incorporate spatial heterogeneity at the landscape scale. Nowadays, landscape ecology is an established field of study, with active participation from ecological, geographical, and social scientists from around the world (Wu, 2013).

Different techniques for landscape-ecological studies have been applied to RS datasets with different spatial and temporal resolutions. However, due to easy access and low cost, multi-spectral optical data are still the most widely used RS source to assess landscape-ecological potential. In these studies, various empirical, deterministic and mechanistic models such as regressions, metapopulation, and habitat suitability models were used (Turner et al, 2001). These models, analyses and methods range from the derivation of landscape metrics (Debuse et al, 2007; Lechner et al, 2007), change detection analysis (Weiers et al, 2004), population viability analysis (Southwell et al, 2008), conservation planning (Margules and Pressey, 2000). Moreover, some studies (Forman and Gordon, 1986; Preobrazenski and Alexandrova, 1987; Preobrajenski, 1997; Burel 2003; Исачинко, 2004; Hong et al, 2007; Muradyan and Asmaryam, 2015) suggested using four basic, integral indices for landscape-ecological analysis: (a) ecological potential, (b) ecological stability, (c) ecological load, and (d) ecological tension.

One of the most important concepts of the landscape-ecological theory is landscape-ecological potential (Исачинко, 2004). The aim of this study was to assess the landscape-ecological potential using optical remote sensing data, spatial Multi-Criteria Decision-Making (MCDM) and the GIS-based AHP approach.

Study area

The study area was the entirety (76060.3 square kilometers) of Khovd province, Mongolia (Figure 1). Khovd is divided into 17 administrative units, has a population of over 86.3 thousand, and has more than 6890 thousand livestock (NSOM, 2017a). 67.0% of the land surface is used as agriculture land (arable land 0.5%, and pasture 66.5%), 0.47% as villages and other settlements, and 0.36% as land under roads and networks. 6.14% is forest and forest resources, 0.57% is water and water resources and 25.44% is land for special needs (NSOM, 2017b). Annual average precipitation is 50-300 mm and the annual average air temperature is -0.3°C. The country averages 243 cloudless days a year and it is at the center of a region of high atmospheric pressure, with an average wind speed of 2.2-4.0 m/s.

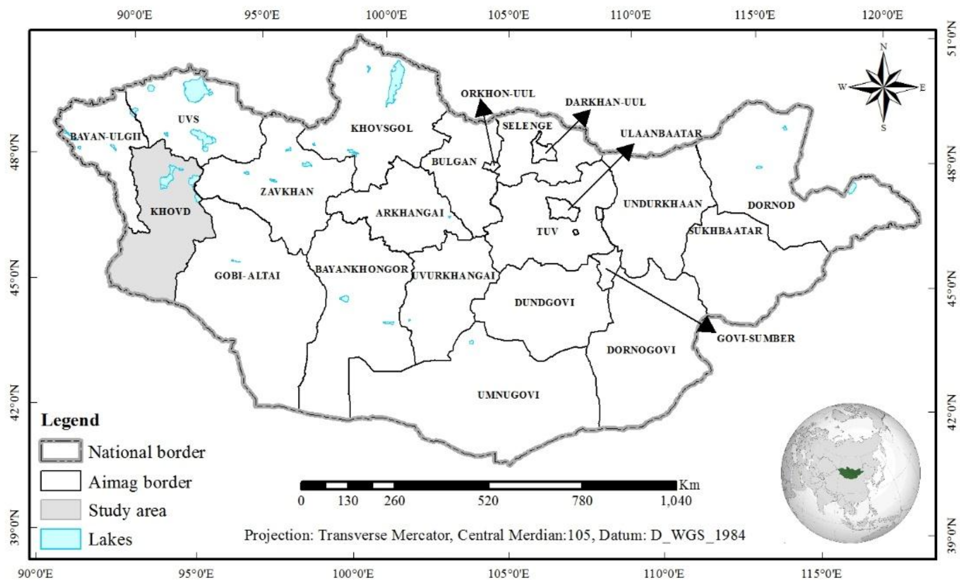

Figure 1. Study area

Data and methods

Data used

The goal of this study was to assess landscape-ecological potential in Khovd province based on satellite imagery and MCDM. In order to implement these goals five different datasets were used; four sources from satellite data and one from measured biomass data (Table 1).

Table 1. Data characteristics and data sources. The upper section refers to the raster data, while the lower section lists field data.

Raster data					
Type of data	Bands	Resolution	Path/Row	Acquisition date	Source
Landsat OLI	2-7	30 m	140/26-29 141/26-29	20180602 20180625	www.glovis.usgs.gov
MODIS	MOD11 MOD16	1000 m	h23v04 h24v04	16-day composites, from 1st June to 31st August 2000-2018	www.ipdaac.usgs.gov
TRMM	-	0.25×0.25 degrees	-	1st January to 31st December 2000-2014	https://pmm.nasa.gov/trmm
SRTM	-	30 m	h24v04	Version 5	www.glovis.usgs.gov
Field data					
Type of data	Number of sites	Sampling size [ha]	Unit	Date	Source
Biomass data	34	1	kg/ha	June 2018	IGG, MAS

OLI- Observation Land Imagery; MODIS-Moderate Resolution Imaging Spectroradiometer; MOD11- Land surface temperature; MOD16-Evapotranspiration; TRMM-Tropical Rainfall Measure Mission; SRTM- Shuttle Radar Topographic Mission; IGG- Institute of Geography and Geoecology; MAS- Mongolian Academy of Sciences.

Remote sensing data

In total, eight Landsat OLI satellite images from June 2018 were analyzed and processed (see Table 1). Data were available at a spatial resolution of 30 m, and covered six spectral bands in the visible, near and shortwave infrared. Before analysis, the Landsat 8 imagery was radiometrically and atmospherically corrected. The radiometric correction was implemented in ENVI (Environment for Visualizing Images) v5.1 software with the radiometric calibration module. Atmospheric correction was implemented with the SCP plugin in QGIS 2.18.2, parameterized with a mid-latitude summer, a rural aerosol model, no aerosol retrieval and 40 km initial visibility. The analysis also used time series MODIS products (MOD 11, MOD16) averaged over 16 days from 2000-2018 with a resolution of 1 km, and monthly rainfall data from 2000-2014 from the TRMM satellite with a resolution of 0.25 degrees. For MODIS data processing, the first step was to convert the input file format and coordinate system. Using MRT (MODIS re-projection tools) we read input datasets in HDF-EOS, which were then converted to the UTM coordinate system with a changed file format (*.tiff). All raster data were transformed to the same geographical coordinate system and spatial resolution (30 m). All image pre-processing used QGIS 2.18, ArcMap 10.4, and ENVI v5.1.

Field survey

From the IGG-MAS field survey, a total of 34 biomass samples were used. Biomass from each plot at each field was collected, sealed in plastic bags, sent to the institute and plotted for analysis. In the laboratory, each field-measured biomass was dried, and the dry weight was calculated. The dry weight was divided by the surface area of the plot, and the weight was converted to kg/ha. At the beginning of June 2018, when the data were collected, the value of field-measured biomass ranged from 20 kg to 490 kg per hectare with a mean biomass value of 153 kg and a standard deviation of 128 kg.

Method

In this study, a combination of the spatial Multi-Criteria Decision-Making (MCDM) and the Analytical Hierarchical Process (AHP) approaches were used. The MCDM method is divided into 4 groups and 7 classes (Malczewski, 1999). From these, the multi-objective methods are based on mathematical programming models, and the multi-attribute methods are data-oriented (Malczewski, 2004). The spatial MCDM approach is a process whereby geographical data can be combined and transformed into a decision (Prakash, 2003). The multi-objective models are tackled by transforming them into a single objective problem and solving the problem using standard linear/integer programming methods (Diamond and Wright, 1998). A few solutions to this problem have been proposed, including heuristic approaches (Brookes, 1997; Cova and Church, 2000) and artificial intelligence (AI) techniques. For multi-attribute (or multi-criteria) evaluation various GIS-based methods such as Weight Linear Combination (WLC) and its variants (Carver, 1991; Eastmen, 1997), ideal point methods (Pereira and Duckstein, 1993; Malczewski, 1995), concordance analysis (Carver, 1991), and the analytic hierarchy process (Banai, 1993) have been used. Of these procedures, WLC is focused on a weighted average value. In the decision-making criteria, Boolean logic has been used. Decision-makers dominate the weight of comparison significance to each map layer while using multi-attribute decision-making. Jian and Eastman (2000). suggested the Ordered Weighted Averaging (OWA) approach to improve MCDM. Another easy way to obtain criteria weights in MCDM is the AHP approach (Saaty, 1977; Saaty, 1980). Over the last two decades, GIS-based AHP in MCDM techniques has become more widespread, and it affects the capacity to integrate a large number of heterogeneous data and weight criteria. The AHP approach recognizes the relative weights associated with map layers with a matrix. In addition, the weights can be integrated with the map layers in a similar way to linear additive combination methods. The purpose of the method is to use a pairwise comparison approach for processing a large number of raster data (Eastman et al, 1993). The spatial MCDM method can extend the decision support capabilities of a GIS-based AHP approach (Malczewski and Rinner, 2015). This study's general procedure had several phases (Figure 2). The first phase was the selection of the evaluation criteria; the second phase was standardization of the criteria; the third phase was assessing the ranking and weights of the criteria; the fourth phase was to overlap the map layers; the fifth phase was accuracy assessment.

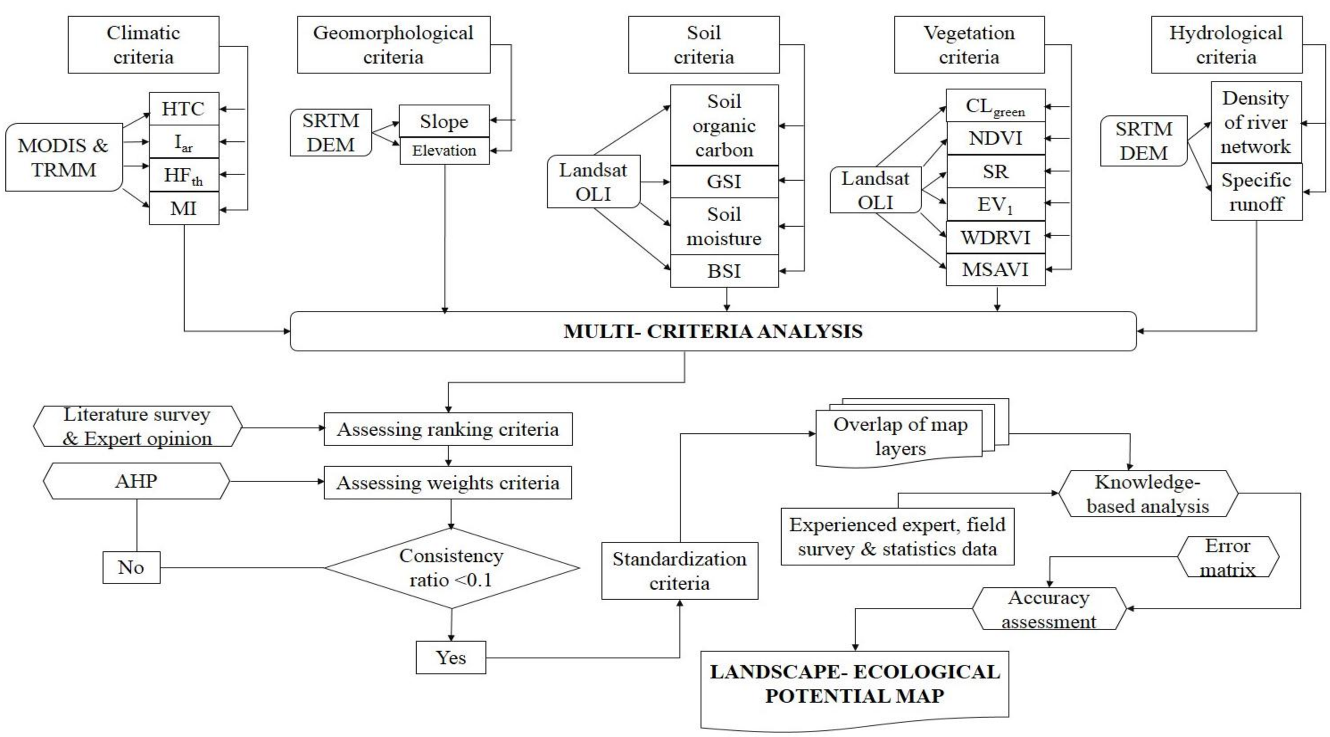

Figure 2. Workflow map for this study

Selection of evaluation criteria

In order to select evaluation criteria, objectives and attributes of each criterion should be considered. A set of criteria should appropriately represent the decision-making environment and contribute towards the final goal (Prakash, 2003). The evaluation criteria depend on the system that is being analyzed, and there is no set technique to choose the evaluation criteria. Literature review, analytical study, and a questionnaire are techniques that help in the selection of the evaluation criteria. Every element of the landscape (relief, climate, soil, vegetation, hydrology, geology etc.) can serve as an object for ecological assessment that can represent the scale of negative or positive impacts upon human life. Nonetheless, the ecological impact of natural factors depends on their pairing with other factors (Francoise, 2003). 5 main criteria and 13 sub-criteria for evaluation of landscape-ecological potential were selected. A criteria evaluation was developed based on our own, and other countries' practices, literature and expert knowledge (Table 2).

Standardization of evaluation criteria

All criteria used in the analysis were measured with different measurement values. Different criteria values needed to be transformed into common values (Ligmann-Zielinska, 2013). In this study a simple linear scaling equation based on the fuzzy set method was used.

$$E_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \tag{1}$$

Where: E_i is the value of standardized in pixels *i*, X_{min} is the minimum value criteria, X_{max} is the maximum value.

Assessing the ranking and weights of the criteria

In the last two decades, three methods have been widely used to define multi-criteria evaluation: AHP, the Ideal Vector Approach, and Fuzzy AHP. In this study the AHP approach was used to find a weighted value of criteria. AHP is one of the most commonly applied approaches in decision-making (Din and Yunusova, 2016) because it is useful for multiple parameters ranked according to experts' preferences (Wijenayake et al, 2016; Qureshi et al, 2018). Tomas Saaty developed the Analytic Hierarchy Process (AHP) in 1977. AHP is focused on the principles of decomposition, comparative judgement, and synthesis of priorities (Saaty, 2008). AHP considers the context of spatial planning decisions and identifies and arranges criteria into different groups (Saaty, 1977). AHP was calculated by weighting values of the criteria, and it can be expressed with the following equation.

$$W_{ij} = \frac{\sum X(ij)}{n} \tag{2}$$

Where: X_{ij}- the normalized value of a pairwise comparison matrix; n- the order of the matrix; W_{ij} - the weight of the criteria. The consistency ratio (CR) indicates the probability, and that the matrix ratings were randomly generated. The consistency of the pairwise comparison matrix is expressed by the consistency ratio index. When the CR exceeds 0.1 the weighting value is disagreeable, and when the index value is estimated below 0.1, the weighting value is agreeable.

$$CR = \frac{CI}{RI} \tag{3}$$

Where: CI- consistency index; RI-random index; CR- consistency ratio.
Calculation of the consistency index was done with the following equation.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

Where: CI- consistency index; $\lambda_{\max}$- maximum Eigenvalue, and *n* is the order of the matrix

Overlay of map layers

Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input data to create an integrated analysis (Saaty et al, 1991). After describing weight values of the criteria concerning their importance for landscape-ecological potential analysis, all criteria maps have been overlaid using the following equation. The equation used for calculating the landscape-ecological potential index of each layer was as follows:

$$LEp = \sum_{i=1}^{n} W_i \, Q_i \tag{5}$$

Where, W_i- weight values of the *i* component
Q_i – the landscape-ecological criteria of the *i* component
LEp- Landscape-ecological potential index

Accuracy assessment

Data validation accuracy assessment was calculated with a confusion matrix and compared with ground truth observation and field-measured biomass from a field survey by the Division of Physical Geography, Institute of Geography and Geoecology, Mongolian Academy of Sciences in 2018.

Data analysis

A comprehensive analysis of ecological potential demands consideration of many of criteria. Five major environmental criteria (climate, geomorphology, soil, vegetation, and hydrology) were selected for landscape-ecological potential assessment at the primary level. There were divided into 13 sub-criteria at the secondary level (Table 2, column 2).

Several studies mentioned that different scientists (Исаченко, 2004; Свидзинская, 2006) generalized that the primary factors in landscape-ecological evaluation are climate indices (Muradyan and Asmaryan, 2015). Climate is a key indicator of landscape stability (Огурцов and Дмитриев, 2017). Heat and humidity parameters are the most essential in the landscape-ecological potential evaluation, upon which biological productivity depends (Исаченко, 2004; Свидзинская, 2006). Therefore, four different climate indices (hydrothermal coefficient, aridity index, humidity factor, and moisture index) were applied for climatic factor analysis. Selyaninov, De Martonne, Thornthwaite and Mezentsev developed this formula (Table 3). Climate is also essential because it affects the growth of vegetation, while hydrology determines the amount of water available for plant growth (Munkhdulam et al, 2017). The analysis used three meteorological elements including air temperature, precipitation, and evapotranspiration derived from MODIS (MOD11, MOD16), and TRMM data (Table 1). Air temperature (T_{air}) is often measured in thermometer shelters 1.5-2.0 m above the ground at meteorological stations (Vancutsem et al, 2010; Benali et al, 2012; Urban et al, 2013), and these recorded data are limited by the sparse distribution of meteorological stations. Hence, the spatial resolution of recorded air temperature data is coarse (Westerling et al, 2006; Stisen et al, 2007; Peon et al, 2014). Satellite remote sensing can provide high spatiotemporal resolution data of land surface temperature (LST) (Zhang et al, 2011; Benali et al, 2012; Lin et al, 2016). LST is not equivalent to T_{air}, and in this research, T_{air} estimated derived from MODIS LTS based on Colombi's linear equation (Colombi et al, 2007).

Terrain is important for maintaining slope stability and is critical to the distribution of other variables at a regional and local scale (e.g., a steep terrain should not be tilled to prevent soil erosion). Slope exposition and elevation were chosen as criteria for analysis of the contribution of terrain to the landscape-ecological potential. An increasing surface inclination requires a synchronous drop in bio-productivity (Погосян, 1986) and reduction of the value of solar radiation balance (Григорьев and Зайцев 2003). The analysis was undertaken with a spatial resolution of 30 meters STRM DEM, which can be inferred from the remote sensing data.

Soil governed the type of vegetation that could grow most productively in that area, and vegetation (e.g. its presence and health conditions) showed whether the land could be used productively. Four different soil indices (soil organic carbon, top green size index, soil moisture index, and bare soil index) derived from Landsat OLI data were applied for soil factor analysis (Table 2, Table 3). To estimate the ecological potential of landscapes, it is beneficial to apply vegetation indices, which illustrate the density of vegetation, its productivity, and mass. To estimate vegetation criteria, we used six vegetation indices (Table 3) derived from Landsat OLI based on the following linear equation for vegetation biomass (Munkhdulam et al, 2018).

$$\mathbf{BM} = -0.331 + 0.415\times \mathbf{CL}_{green} + 2.125\times \mathbf{NDVI} + 0.415\times \mathbf{SR} + 3.860\times \mathbf{EV}_1 + 1.987\times \mathbf{WDRVI} + 4.082\times \mathbf{MSAVI}_2 \quad (6)$$

Table 2. The criteria for evaluation of landscape-ecological potential

Criteria	Sub-criteria	Unit	Evaluation level				
			Very high (5 scores)	High (4 scores)	Moderate (3 scores)	Low (2 scores)	Very low (1 score)
Climatic	Hydro-thermal condition (HTC)	-	1.3-2.0	1.0-1.3	0.7-1.0 ≥2.0	0.4-0.7	≤ 0.4
	Aridity index (I_{ar})	мм/°C	35-55	24-35	20-24; ≥55	10-20	≤10
	Humidity factor (HF_{th})	-	40-55	31-40	≥55; 23-31	15-23	≤ 15
	Moisture Index (MI)	-	1.1-1.5	0.7-1.1	0.4-0.7	0.2-0.4	≤ 0.2
Geomorphological	Slope (S)	Degree	≥2	2-6	6-12	12-24	≤24
	Elevation (E)	Degree	≥1500	1500-2000	2000-2500	2500-3000	≤3000
Soil	Soil Organic Carbon (SOC)	-	≥0.50	0.35-0.50	0.25-0.35	0.15-0.25	≤ 0.15
	Top of Green Size Index (GSI)	-	≥0.6	0.5-0.6	0.5-0.25	0.25-0	≤0
	Soil Moisture Index (MSI)	-	≥0.50	0.35-0.50	0.25-0.35	0.15-0.25	≤ 0.15
	Bare Soil Index (BSI)	-	≤015	0.15-0.25	0.25-0.35	0.35-0.50	≥0.50
Vegetation	Pasture biomass (BM)	%	≥75	50-75	50-25	5-25	≤ 5
Hydrological	Density of river network (DR)	Km/km^2	≥0.4	0.2-0.4	0.1-0.2	0.05-0.1	≤ 0.05
	Specific Runoff (SR)	$l/sec\ km^2$	≥4.0	2.0-4.0	1.0-2.0	0.5-1.0	≤0.5

Table 3. Indices used in this study

Indices	Abbr.	Formula	Reference
Hydro-Thermal Coefficient	HTC	$HTC = \frac{\sum P}{[0.1 * \sum T_{>x^oC}]}$	Selyaninov. 1937
Aridity Index	I_{ar}	$I_{ar} = \frac{P}{T+10}$	De Martonne. 1925
Humidity Factor	HF_{th}	$HF_{th} = \frac{P_{I-XII}}{E_o}$	Thornthwaite. 1948
Moisture Index	MI	$MI = \frac{P}{[0.2 * \sum T_{>10^oC} + 306]}$	Мезенцев. 1969
Soil Organic Carbon Concentration	SOC	$EXP(a + b \times Red + c \times Green + d \times Blue)$	Chen et al. 2000
Top of Green Size Index	GSI	$\frac{(Red - Blue)}{(Red + Blue + Green)}$	Xiao et al. 2006
Soil Moisture Index	MSI	$\frac{SWIR)}{(NIR)}$	Datt & Ravallion. 1990
Bare Soil Index	BSI	$\frac{(SWIR + Red) - (NIR + Blue)}{(SWIR + Red) + (NIR + Blue)} \times 100 + 100$	Rikimaru & Miyatake. 1997
Green Chlorophyll Index	CL_{green}	$\frac{NIR}{Red} - 1$	Gitelson et al. 2005
Normalized Difference Vegetation Index	NDVI	$\frac{(NIR - Red)}{(NIR + Red)}$	Rouse et al. 1974
Simple Ratio	SR	$\frac{NIR}{Red}$	Jordan. 1969
Enhanced Vegetation Index	EV_1	$2.5 \times \frac{(NIR - RED)}{(1 + NIR + 6 \times Red - 7.5 \times Blue)}$	Liu & Huete. 1995
Wide Dynamic Range Vegetation Index	WDRVI	$\frac{(\alpha \times NIR - Red)}{(\alpha \times NIR + Red)}$	Gitelson. 2004
Modified Soil Adjusted Vegetation Index 2	$MSAVI_2$	$\frac{NIR + 1 - \sqrt{(2 \times NIR + 1)^2 - 8 \times (NIR - RED)}}{2}$	Qi et al. 1994

$\sum P$- Annual total precipitation in a warm period, mm (daily mean temperature >10^{0}C), $\sum T_{>x^oC}$- Air temperature >10^{0}C, P- Monthly precipitation sum (mm), T- Monthly mean air temperature (^{o}C), P_{I-XII}- Annual precipitation sum (mm), E_o- Annual evaporating capacity (mm), BM- vegetation biomass, NIR- near-infrared wavelength, Red- Red wavelength, Green- Green wavelength, Blue- Blue wavelength, SWIR- Short wavelength infrared, α a value of 0.3, a,b,c and d are coefficients where a= 1.71499, b= -0.01576, c=0.01281, d= -0.0113

Results

The results showed the weights of thirteen criteria (Table 4) based on a literature review and expert consultations, along with the weights calculated using the GIS-based AHP tool present the distribution of the suitability value within our study area using a continuous level with values ranging from low to high (Figure 3).

After weighting the importance of different criteria for landscape ecological potential analysis, all criteria maps were overlaid using the following model.

$$\mathbf{LEp = 0.0634 \times CF + 0.1290 \times GF + 0.5128 \times SF + 0.2615 \times VF + 0.0330 \times HF} \qquad (7)$$

In this study, we estimated a CR = 0.053, suggesting that there was a reasonable level of consistency in judgment. The analysis of the spatial distribution map of the landscape-ecological map showed that 6.8% of the area studied had very high potential, 25.3% had high potential, 42.6% had average potential, 17.6% had low potential, and 7.6% had very low potential (Figure 4, Table 5).

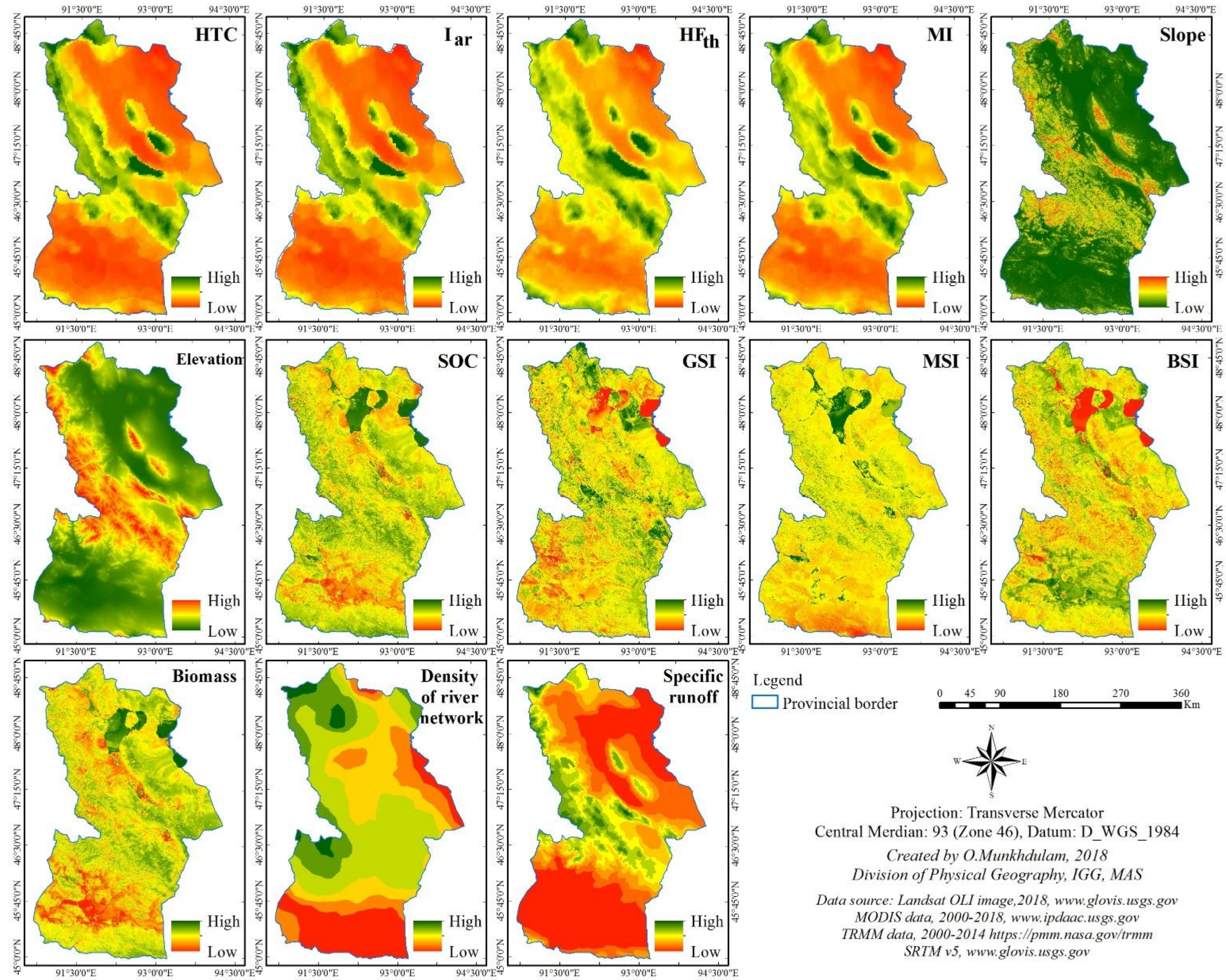

Figure 3. The 13 sub-criteria of assessment of landscape-ecological potential

Table 4. Defined ranking and weights of the criteria

Criterion	Weight	Sub-criteria	Ranking	Weight	Function
Climate (CF)	0.0634	Hydrothermal coefficient (HTC)	1	0.5650	Linear
		Humidity factor (HF_{th})	2	0.2622	Linear
		Aridity index (I_{ar})	3	0.1175	Linear
		Moisture Index (MI)	4	0.0553	Linear
Geomorphology (GF)	0.1290	Slope (S)	1	0.6667	Non-linear
		Elevation (E)	2	0.3333	Non-linear
Soil (SF)	0.5128	Soil Organic Carbon (SOC)	1	0.5806	Linear
		Bare Soil Index (BSI)	2	0.2554	Non-linear
		Soil Moisture Index (MSI)	3	0.1141	Linear
		Top of Green Size Index (GSI)	4	0.0499	Linear
Vegetation (VF)	0.2615	Pasture biomass (BM)	-	-	Linear
Hydrology (HF)	0.0330	The density of the river network (DR)	1	0.6667	Non-linear
		Specific Runoff (SR)	2	0.3333	Non-linear
Consistency Ratio (CR): 0.053					

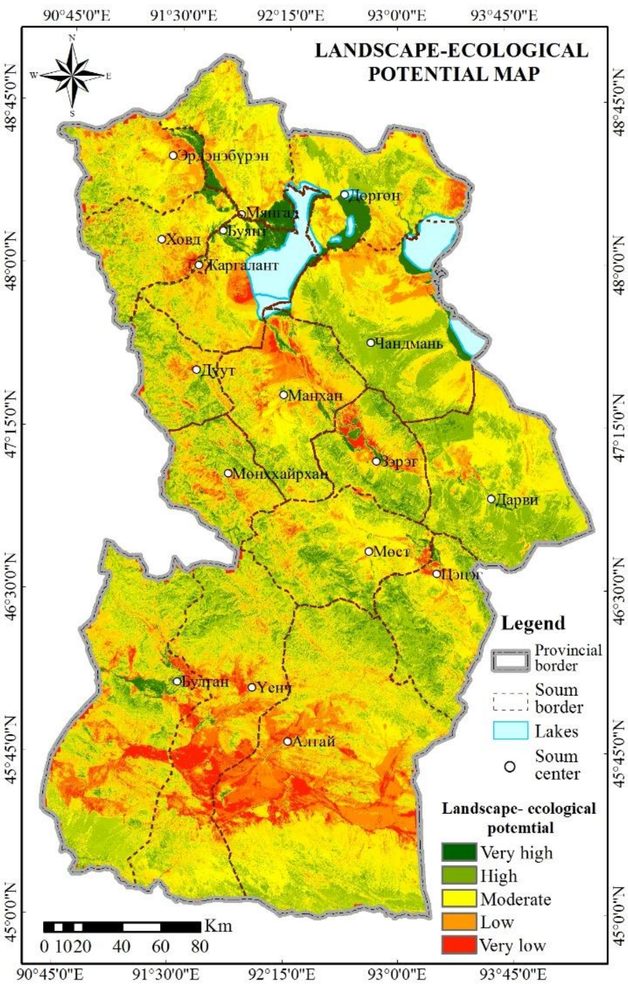

Figure 4. Spatial distribution map of landscape-ecological potential, Khovd province, Mongolia (Scale 1:100000)

Table 5. The result of landscape-ecological potential evaluation

Evaluation level	Area	
	ha	%
Very high	519913.3	6.8
High	1925635.4	25.3
Moderate	3238961.7	42.6
Low	1340386.8	17.6
Very low	581140.8	7.6

Accuracy assessment

Ground truth observation and field-measured biomass data were carried out from 28 May to 15 June 2018 at randomly selected locations with different terrain. Table 6 shows the results- the error matrix calculated based on ground truth and field-measured biomass data. The analysis was applied to 34 sites' data. A total of seven sites' calculated unsuitability for landscape-ecological potential was confirmed by field observation. The overall accuracy of site selection for landscape-ecological potential using spatial multi-criteria analysis was 79.4%.

Table 6. Error matrix

	Field observation					Misidentification	Total	Accuracy
	Very high	High	Moderate	Low	Very low			
Very high	-	-	-	-	-	-	-	-
High	-	3	2	-	-	2	5	0.60

Moderate	-	-	17	2	2	4	21	0.80
Low	-	-	-	4	-	-	4	1.00
Very low	-	-	-	3	1	1	4	0.75
Total	**-**	**3**	**19**	**9**	**3**	**7**	**34**	**0.79**
Total accuracy: 79.4 %								

Discussion and conclusion

Various multi-criteria procedures can be performed with GIS. However, weighted linear combination (WLC) and the analytical hierarchy process (AHP) have proven to be the best and most repeatedly employed procedures (Eastman et al 1993; Malczewski, 2004). Several studies (Pechanec et al 2009; Vizzari, 2011; Michaeli et al 2013; Muradyan and Asmaryan, 2015) showed GIS analysis techniques combined with WLC and AHP-based Multi-Criteria Evaluation (MCE) methods can support the definition and estimation of spatial components. It permits evaluation and interpretation of the landscape's potential quality, the ecological potential of the landscape, and ecological stability. For instance, Vizzari (2011) used GIS-based MCE methods to estimate landscape potential quality in the Assisi area, Italy. In this study, the results strongly confirmed the **regularity** of GIS-based MCE methods for modeling landscape quality complexity. Muradyan and Asmaryan (2015) estimated the landscape-ecological status of Synik marz based on different four indices (ecological potential, ecological stability, ecological load, and ecological tension). The value of each index was calculated as the sum of respective criteria expressed in scores and multiplied by their corresponding coefficients. The analysis applied the weighted sum function using ModelBuilder in ArcGIS.

The aim of our study was to assess the landscape-ecological potential using optical remote sensing data. For this study, we used MCDM and GIS-based AHP methods, and thirteen environmental criteria derived from four different remotely sensed data sources. The study results confirmed that in this evaluation, landscape-ecological potential could be obtained and effectively modelled with the integrated use of GIS-based AHP and Multi-Criteria Decision-Making methods. This is because the GIS-based AHP technique is a good indicator for the creation of a map of landscape-ecological potential based on landscape elements. AHP effectively illustrated the hierarchy and landscape elements of the weighting phases. In the future, it may be possible to validate the suitability of other more advanced methods used in the field of decision support. The GIS-based MCE procedure should be tested by means of a sensitivity analysis to determine the robustness of the model and to explore visually how the output changes with appropriate variations in the input criteria parameters (Crosetto et al, 2000; Malczewski, 2005).

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Disclosure statement

The authors reported no potential conflict of interest.

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