Vol. 60 No 03 (235) 2020
DOI: https://doi.org/10.5564/pmas.v60i3.1418

PMAS
Proceedings of the Mongolian Academy of Sciences

ARTICLE

Assessment of Eco-geomorphological potential of Mongolia

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ARTICLE INFO: Received: 04 Aug, 2020; Accepted: 29 Sep, 2020

Abstract: *The eco-geomorphological analysis includes the impact assessment of relief under various ecosystem conditions in as much relief has various ecological roles, both direct and indirect. Rising elevation above sea level is mostly influenced by climate indirectly leading to reduced air pressure, oxygen deficiency, reduction of air temperature, excessive solar radiation, and creation of strong wind. The depth of relief dissection of the bumpy surface of mountainous areas created by floods and mudflows, and the depth of the bumpy surface increases energy consumption and poses risks during mountain climbing, and also has negative economic implications if economic activities are undertaken in such terrain. On the other hand, mountainous landscapes have a specific impact on human well-being and also have considerable potential for promoting tourism. Although, in the steppe environment, relief dissection increases the unique features of the landscape and increases the potential of tourism in other respects, however, it is assessed negatively to a large extent. The nature of corelationship between and the interdependence of the terrestrial surface and population, terrestrial surface and livestock, terrestrial surface and agriculture, which are significant in the study into the inter-relationship between environment and human society, was assessed and determined, and the relevant conclusion was drawn.*

Keywords: *human habitat; population; animal husbandry; agriculture; potential assessment;*

INTRODUCTION

The concept of eco-geomorphology was first used in science by a British geomorphologist Donald Coates in the early 1970s, while another scientist T.G. Runova proposed a consolidated idea of surface assessment and research during the mid-1980s [1; 2]. Humans take into account reliefs when choosing their habitat. Eco-geomorphological analysis has been conducted in the last decades, and the present study aimed to determine if a person's place of residence is comfortable for the person or not. Relief is one of the main factors of any chemical, physical, or biological process in the environment. Suitability assessment of human habitat and land has been changing gradually and methodological

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Vol. 60 No 03 (235) 2020
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approaches to modern research on eco-geomorphological assessment of landscape have aimed to develop indicators of suitable conditions for relief and to regulate the relationship between the surfaces, the population and the economy [1]. Besides, relief is the most important component of geographical coverage, and is also characteristic of other natural factors and its interactions depend greatly on the surface features. Relief is a key natural element that regulates the moisture and heat distribution on Earth, and its shape and size are closely related to the geological structure of the territory. Also, relief is a key factor (most important resource) in determining the distribution of natural resources, such as macro-microclimate, surface water, groundwater, soil, flora, and fauna [3; 4].

MATERIALS AND METHODS

***A. Study area**:* The area studied in this research work covered the entirety of Mongolia with a total territory of nearly 1564.1 thousand square kilometers [5] and the study area covered the high Altai Mountain ranges with perpetual snow to dry-hot Gobi desert zone, also the country's climate conditions vary between extreme continental and temperate zone with monsoon wind.

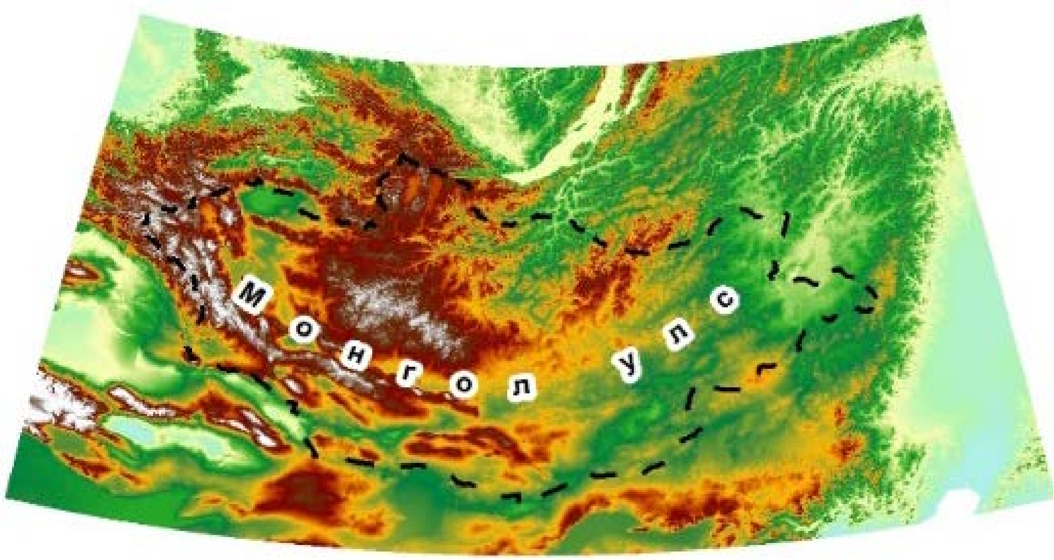

Figure 1. Study area

***B. Data and materials used**:* Raster and vector data were used to assess the eco-geomorphological potential of Mongolia. The basic morphometric parameters of the geomorphology (elevation, slope, aspect, depth of surface dissection, distribution of the solar radiation) originating from the Shuttle Radar Topography Mission – Digital Elevation Model (SRTM DEM) [6] were retrieved. When evaluating some terrain parameters, such as the density of surface dissection, which is difficult to retrieve, more accurate Multi Error Removed Improved Terrain – Digital Elevation Model (MERIT DEM) [7] was used. MERIT DEM has made significant improvements to flat areas (relatively flat plains, rivers, and valleys) that have experienced high levels of error beyond topographic fluctuations, making it easier to estimate geomorphological elements, such as river networks, steppes, and relatively low hills.

Thematic layers were developed for the evaluation of eco-geomorphological potential using climatic data that primarily affect morphometric measurements and hydrological, geological, and geomorphological factors, and for their processes.

Vol. 60 No 03 (235) 2020
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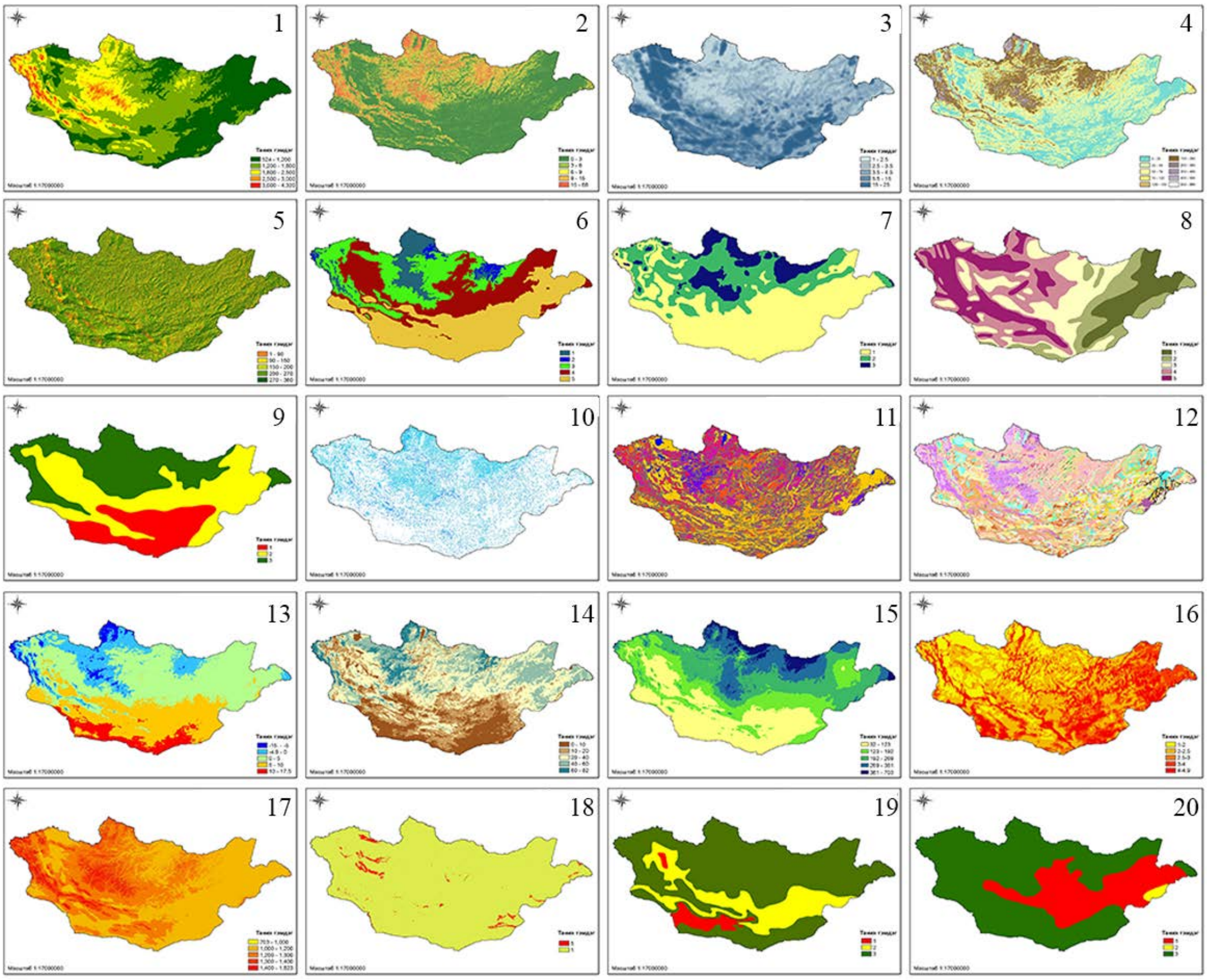

Figure 2. Key factors for evaluation of eco-geomorphological potential (1. Elevation, 2. Slope, 3. Density of surface dissection, 4. Depth of surface dissection, 5. Aspect, 6. Permafrost, 7. Density of river network, 8. Earthquake, 9. Number of windy days, 10. Hydrology, 11. Sediment, 12. Morphogenetic process, 13. Surface temperature, 14. Snow cover, 15. Total rainfall, 16. Wind power, 17. Total solar radiation /irradiance/, 18. Moving /unfixed/ sand, 19. Dust storm, 20. Snowstorm)

C. Methods: Methods of quantitative analysis (mathematical, modeling, and scoring) have been used for the evaluation of the eco-geomorphological study. Scoring is an important indicator of how eco-geomorphological studies combine natural conditions and resources in an area [8]. Eco-geomorphological research is aimed at assessing the geomorphological conditions of the area for any business activity. In other words, this kind of research is important in solving problems, such as choosing the suitable form and condition of relief for optimal planning of population, livestock and agricultural location, protecting the particular object from exogenetic processes that change the relief, and anticipating the difficulties caused by relief condition. Eco-geomorphological research is a descriptive study, especially when new cities, settlements, roads, electrical and engineering networks are built, ensuring their normal operation and determining whether the engineering geomorphological condition can, in turn, affect the ability to run a business in the area and to live comfortably in the future or not. First of all, criteria need to be defined to conduct an eco-geomorphological assessment. In order to choose this criterion, it is necessary to inform the differences between engineering geomorphology and eco-geomorphology (Table 1) [3]

Vol. 60 No 03 (235) 2020
DOI: https://doi.org/10.5564/pmas.v60i3.1418

Table 1. Principles of evaluating eco-geomorphology and engineering geomorphology. Source (Evseeva N.S., 2013)

Criteria	Territorial assessment	
	Engineer	**Ecology**
	Geomorphological	
Types of relief	Assess the stability level of the surface: Evaluation of endogenous and exogenous processes	Assess the surface and landscape features from a safety perspective
Paleo relief	Assess the hydrogeological condition and the impact of paleo relief: activity of karst, earthquake, etc.	Assess the safety
Surface dissection * Density of relief dissection * Depth of relief dissection	Evaluate the potential level of construction: assess the extent of risk of landslides, erosion processes, floods, etc.	Assess the impact of these processes on habitat and public health
Slope	Estimate the risks that may arise during architectural planning, road, and pipeline connection work	Estimate the risk of being polluted by surface water, and possible risks in communication
	Geological	
Earthquake-tectonic structure	Assess the seismic resilience of the territory	Assess the seismic hazard, the degree of danger, and the preparedness of the population for earthquake
Types and origins of sediments	Sediment properties, territorial stability, negative geological process of the surface, and assessment of geochemical conditions	Assess the adverse effects of these engineering conditions on human and animal settlements
	Hydrological and hydrogeological	
Groundwater	Assess local drainage system and groundwater pollution	Evaluate the consumption and use of drinking water
Surface water	Assess the flood risk levels and the feasibility of constructing a protection facility in the reservoir area	Evaluate drinking and natural water and explore the possibility of using it for recreational purposes
	Climatic	... etc.

The objective of this research was to determine the eco-geomorphological potential of the surface components of the area. Engineering geomorphological assessment takes into account the engineering characteristics of the surface (mainly to determine the stability of the relief), while eco-geomorphological assessment aims to take into account the following characteristics and features of the surface in order to create comfortable living conditions: the consequences of people's living conditions, health, and safety (and psychological well-being). This assessment considers the appearance of the surface, differences, and unique formations [3; 4; 8]. The general scheme of the methodology for this study is shown in Figure 3.

In order to calculate the overall assessment of eco-geomorphological potential, firstly, the eco-geomorphological assessments for the population, livestock and agriculture were evaluated on a scale of 1-5 points for the values of the spatial distribution of the selected factors. When many factors are compared, one is more important than the other and is likely to have a higher importance. Therefore, the AHP (analytical hierarchy process) method was used to rank the evaluation criteria [9].

Vol. 60 No 03 (235) 2020
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$$\boldsymbol{B} = e + s + a + h + v + g + f + r + w + sa + gm + ge + t + sn + sr + ps + w + ws + ss + sd \quad (1)$$

$$\boldsymbol{C} = e + s + a + h + v + g + f + r + w + sa + t + sn + sr + ps + w + ws + ss + sd$$

$$\boldsymbol{C} = horse + cattle + camel + sheep + goat \quad (2)$$

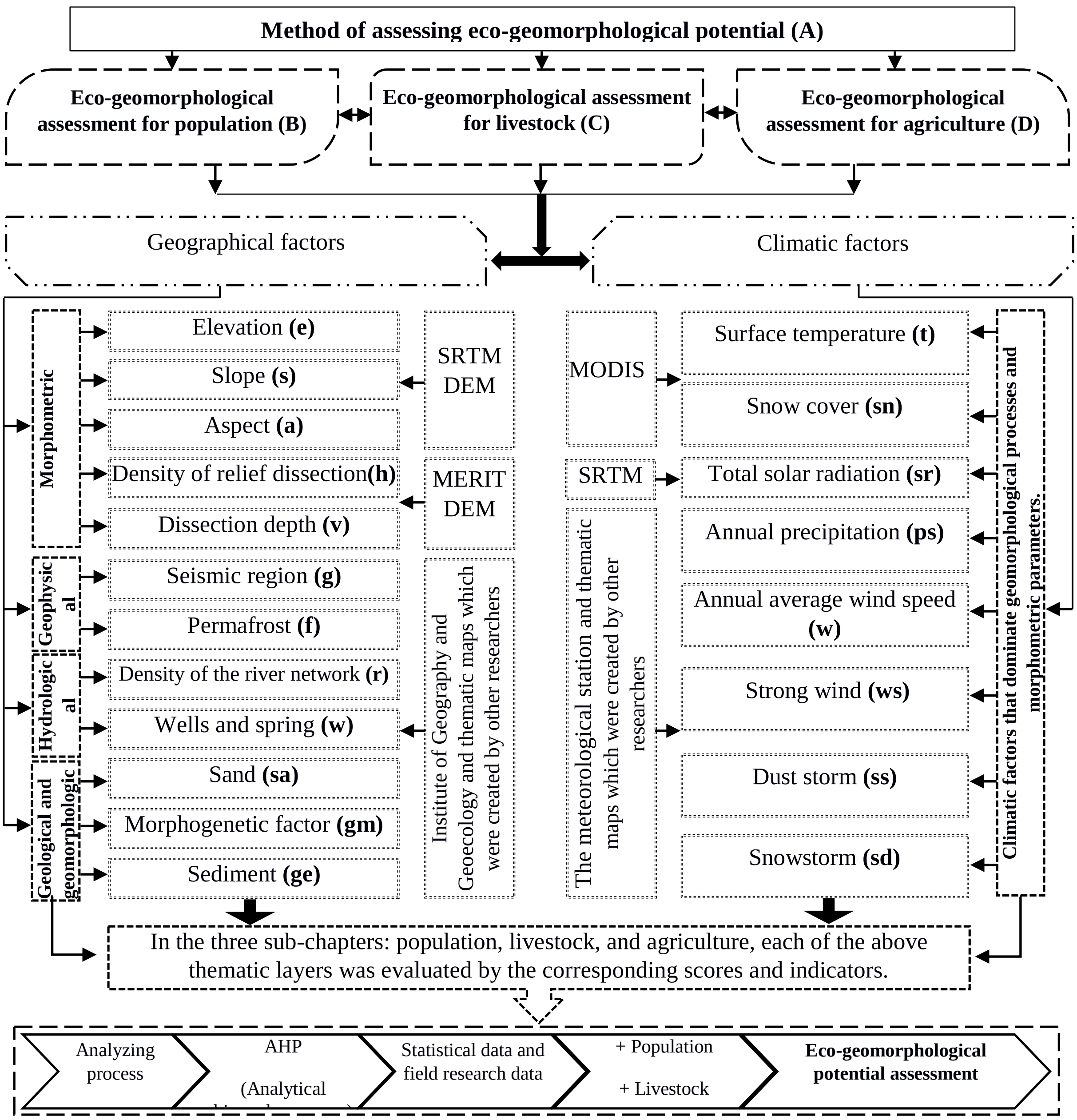
$$\boldsymbol{D} = e + s + a + h + v + f + r + w + sa + t + sn + sr + ps + w + ws \quad (3)$$

$$\boldsymbol{A} = \mathbf{B} * 0.5 + \mathbf{C} * 0.35 + \mathbf{D} * 0.15 \quad (4)$$

Assessment of eco-geomorphological potential - A
Eco-geomorphological assessment for population - B
Eco-geomorphological assessment for livestock - C
Eco-geomorphological assessment for agriculture - D

*** The selected indicators were ranked according to population, livestock, and agriculture and multiplied by different weighted values for each assessment.*
**** The eco-geomorphological assessment for livestock was evaluated for each of the 5 head of livestock and the results were summarized.*
***** see other letter notation in (Figure 3).*

Figure 3. Method of assessing eco-geomorphological potential



RESULTS AND DISCUSSION

Assessment of eco-geomorphological potential for the population. There is no detailed study in our country determining the surface of a comfortable living environment and construction work. In order to consider relief in a building, it is first necessary to determine the dynamic changes in the surface and the morphometric parameters [10]. In order to detect the favorable and negative conditions of geomorphological conditions in human habitat, the methodology of ecological and geomorphological assessment of the urban population was first evaluated based on the studies of [11-13]. Another important indicator in urban and residential environment is the issue of engineering infrastructures, such as roads and networks. In order to assess the ecological and geomorphological capacity of the population, it is necessary to conduct geomorphological surveys by road and infrastructure engineers.

Table 2. Eco-geomorphological potential for the population

Eco-geomorphological potential for population		*Area*	
		sq.km	*%*
1	*(Very low)*	*69723.24*	*4.5*
2	*(Low)*	*92880.79*	*5.9*
3	*(Moderate)*	*760858.3*	*48.6*
4	*(High)*	*374424.4*	*23.9*
5	*(Very high)*	*266229.3*	*17.0*

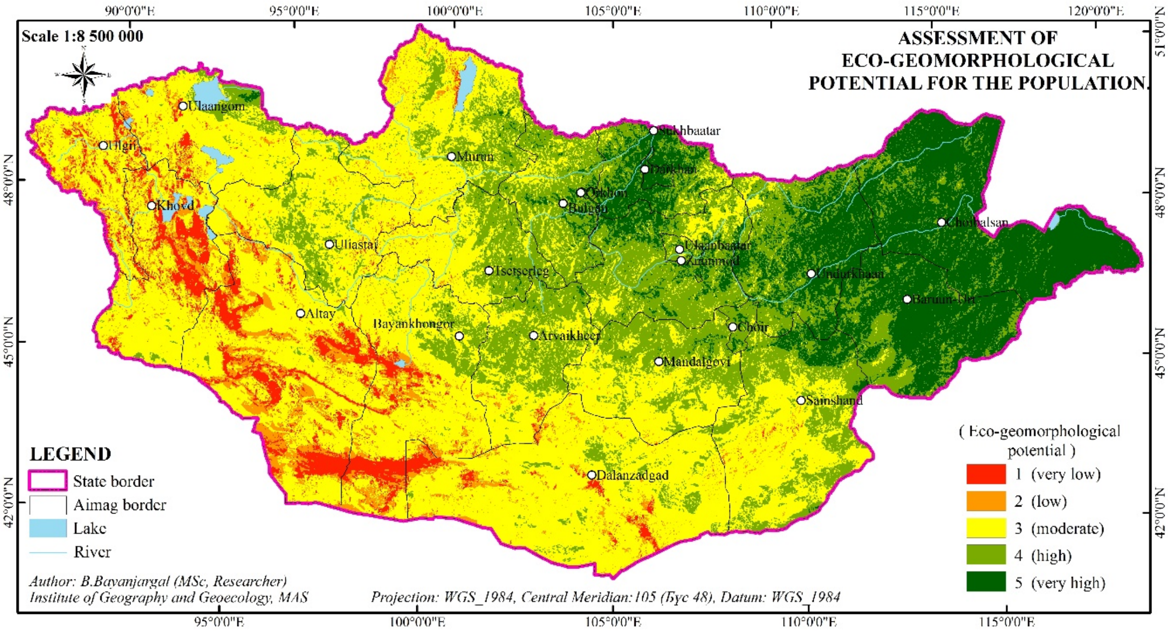


Figure 4. Assessment of eco-geomorphological potential for the population

Vol. 60 No 03 (235) 2020
DOI: https://doi.org/10.5564/pmas.v60i3.1418

Table 3. Eco-geomorphological potential for the population, (by natural belts and zones)

Natural belts and zones	Area of natural belts and zones, sq.km	Of which: Area for each evaluation level, in percentage					Total % of high and very high	Level of potential
		Very low	Low	Moderate	High	Very high		
Result of eco-geomorphological potential for the population								
Alpine	*55351.5*	*10.4*	*15.0*	*73.3*	*1.3*	*0.0*	*1.3*	***6***
Mountain taiga	*70894.3*	*0.5*	*1.6*	*55.0*	*39.7*	*3.2*	*42.9*	***3***
Forest steppe zone	*236013.0*	*0.2*	*1.2*	*41.6*	*38.8*	*18.1*	*56.9*	***2***
Steppe zone	*540835.6*	*2.1*	*2.4*	*25.9*	*30.2*	*39.3*	*69.5*	***1***
Gobi zone	*358568.5*	*6.9*	*8.2*	*60.5*	*21.8*	*2.6*	*24.4*	***4***
Desert zone	*302453.2*	*8.9*	*12.5*	*74.4*	*4.3*	*0.0*	*4.3*	***5***

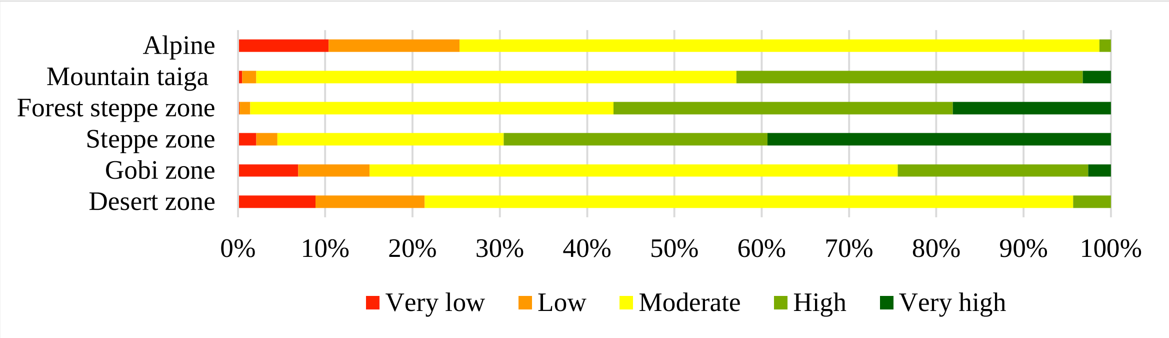


Figure 5. Eco-geomorphological potential for population (by natural belts and zones)

Comparing the assessment of eco-geomorphological potential for population by provinces and provincial municipalities: According to the statistical information of the National Statistical Office of Mongolia, the urban population category includes 2,197,970 people, which is roughly equivalent to 70 per cent of the total population of the country. The term urban population refers to all the population and households living in the capital city, provincial centers, and villages [14-15]. This category does not include the population of rural settlements or soum centers. According to this indicator, there are about 300,000 people are living in 315 soum centers, and in total, 77 per cent of Mongolia's population, or 2.5 million people, live in province and soum centers, cities, and villages.

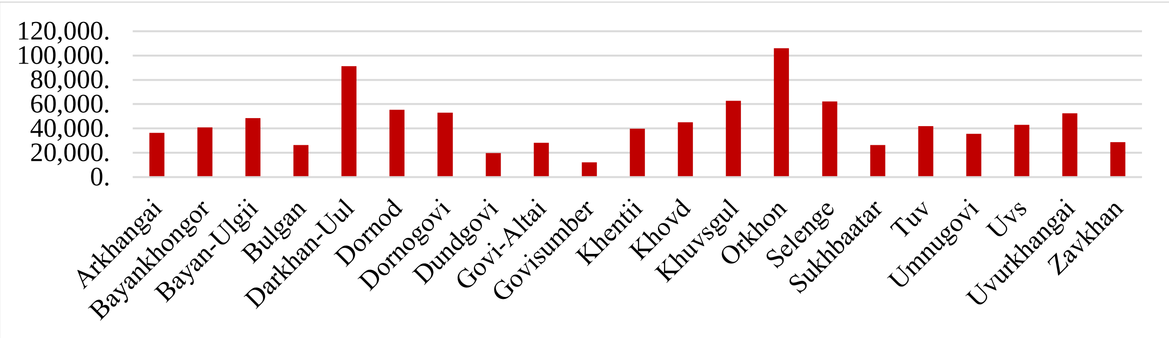


Figure 6. Number of residents in the settled areas, by aimags (provinces)

After Ulaanbaatar, Orkhon, Darkhan-Uul, Selenge, Khuvsgul, and Dornod aimags lead in the number of residents of settled area and Orkhon, Darkhan-Uul, Tuv, Selenge, and Bulgan aimags lead in terms of the number of migrants from 1983 to 2018.

Such inland migration, on the one hand, has been due primarily to the attractivness of the market and, secondly, temporary migration to areas with high ecological potential or favorable habitats. On the other hand, the number of migrants in the western regions such

Vol. 60 No 03 (235) 2020
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as Bayan-Ulgii, Zavkhan, Uvs, and Khovd aimags has been relatively high during these years. According to Sh. Oniki and B.Batbuyan's herder migration survey carried out in Bulgan aimag, 84 of the 124 households were herder households from Uvs aimag, and 95 per cent of all herders from Uvs aimag had settled in the forest-steppe and steppe zones of Selenge, Darkhan-Uul, Tuv and Bulgan aimags in the central region [16] of the country.

Table 4. Eco-geomorphological potential for the population (by aimags)

Aimags (Provinces), and Capital city	Area of aimags and capital city sq.km	Of which: Area for each evaluation level, in percent					Total % of high and very high	Level of potential
		Very low	Low	Moderate	High	Very high		
Result of eco-geomorphological potential for population								
Arkhangai	*55313.8*	*0.3*	*1.6*	*54.4*	*42.7*	*1.1*	*43.7*	***13***
Bayankhongor	*115977.8*	*9.9*	*12.7*	*67.7*	*9.6*	*0.0*	*9.6*	***18***
Bayan-Ulgii	*45704.9*	*15.6*	*17.7*	*66.0*	*0.8*	*0.0*	*0.8*	***21***
Bulgan	*48733.0*	*0.0*	*0.1*	*22.8*	*67.4*	*9.7*	*77.1*	***10***
Darkhan-Uul	*3275.0*	*0.0*	*0.0*	*0.1*	*13.4*	*86.5*	*99.9*	***1***
Dornod	*123597.4*	*0.0*	*0.0*	*0.1*	*11.3*	*88.5*	*99.9*	***2***
Dornogovi	*109472.3*	*0.3*	*1.3*	*55.3*	*35.6*	*7.5*	*43.1*	***14***
Dundgovi	*74690.3*	*0.0*	*0.5*	*54.2*	*44.3*	*1.0*	*45.3*	***12***
Govi-Altai	*141447.7*	*17.8*	*21.1*	*60.4*	*0.7*	*0.0*	*0.7*	***22***
Govisumber	*5541.8*	*0.0*	*0.0*	*5.1*	*79.6*	*15.3*	*94.9*	***6***
Khentii	*80325.1*	*0.0*	*0.0*	*5.0*	*42.3*	*52.6*	*95.0*	***5***
Khovd	*76060.4*	*18.3*	*17.6*	*62.8*	*1.2*	*0.0*	*1.2*	***20***
Khuvsgul	*100628.8*	*0.8*	*3.5*	*70.7*	*24.4*	*0.6*	*25.0*	***15***
Orkhon	*844.0*	*0.0*	*0.0*	*1.2*	*48.8*	*50.1*	*98.8*	***4***
Selenge	*41152.6*	*0.0*	*0.0*	*8.9*	*42.7*	*48.4*	*91.1*	***7***
Sukhbaatar	*82287.2*	*0.0*	*0.0*	*0.9*	*25.8*	*73.3*	*99.1*	***3***
Tuv	*74042.4*	*0.0*	*0.1*	*17.4*	*64.7*	*17.8*	*82.6*	***9***
Ulaanbaatar	*4704.4*	*0.0*	*0.0*	*13.3*	*74.7*	*12.0*	*86.7*	***8***
Umnugovi	*165380.5*	*3.7*	*6.7*	*83.7*	*6.0*	*0.0*	*6.0*	***19***
Uvs	*69585.4*	*4.1*	*6.7*	*76.0*	*12.3*	*0.8*	*13.2*	***17***
Uvurkhangai	*62895.3*	*0.6*	*1.9*	*46.7*	*50.0*	*0.8*	*50.8*	***11***
Zavkhan	*82455.7*	*1.0*	*3.8*	*76.2*	*19.0*	*0.0*	*19.0*	***16***

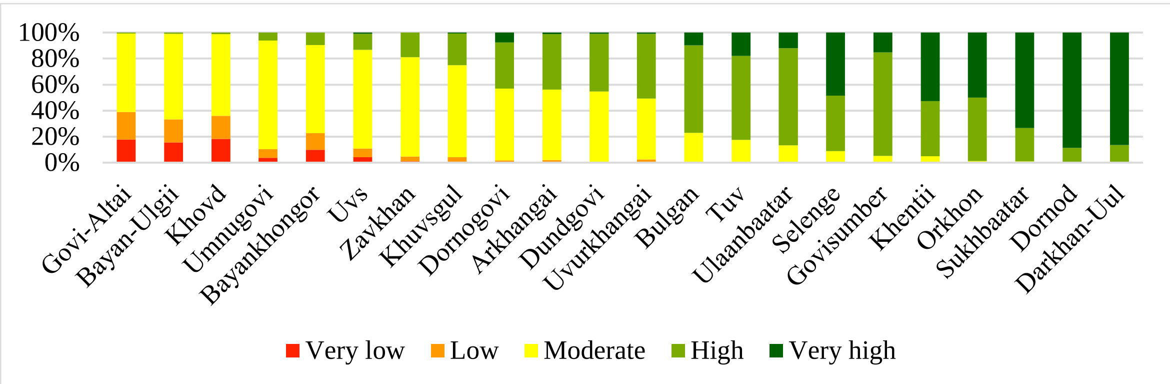

Figure 7. Eco-geomorphological potential for population (by aimags)

Assessment of eco-geomorphological potential for livestock: Eco-geomorphological potential and evaluation criteria were set differently for each of the types of livestock in the spatial distribution map of landscape, and the results were summarized. In this study, we estimated that 3.8 per cent of the area had low (2) potential, 64.6 per cent had moderate (3) potential, and 31.6 per cent had high (4) potential, while there were no areas with very low (1) and very high (5) potentials since the location of the type of livestock and the

Vol. 60 No 03 (235) 2020
DOI: https://doi.org/10.5564/pmas.v60i3.1418

ecological favorable areas did not condition each other's location. This means that it is not possible to raise five heads of livestock in one unit of land, one household, and on only one pasture land. On the one hand, assessment of the eco-geomorphological potential for livestock has the advantage of complementing assessment of the eco-geomorphological potential for the population because more than 20 per cent of our population are engaged in nomadic livestock breeding. Evaluation criteria were calculated based on studies by [12,17-19].

Table 5. Eco-geomorphological potential for livestock

Eco-geomorphological potential for livestock		*Area*	
		sq.km	*%*
2	*(Low)*	*59453.18*	*3.8*
3	*(Moderate)*	*1009867*	*64.6*
4	*(High)*	*494795.9*	*31.6*

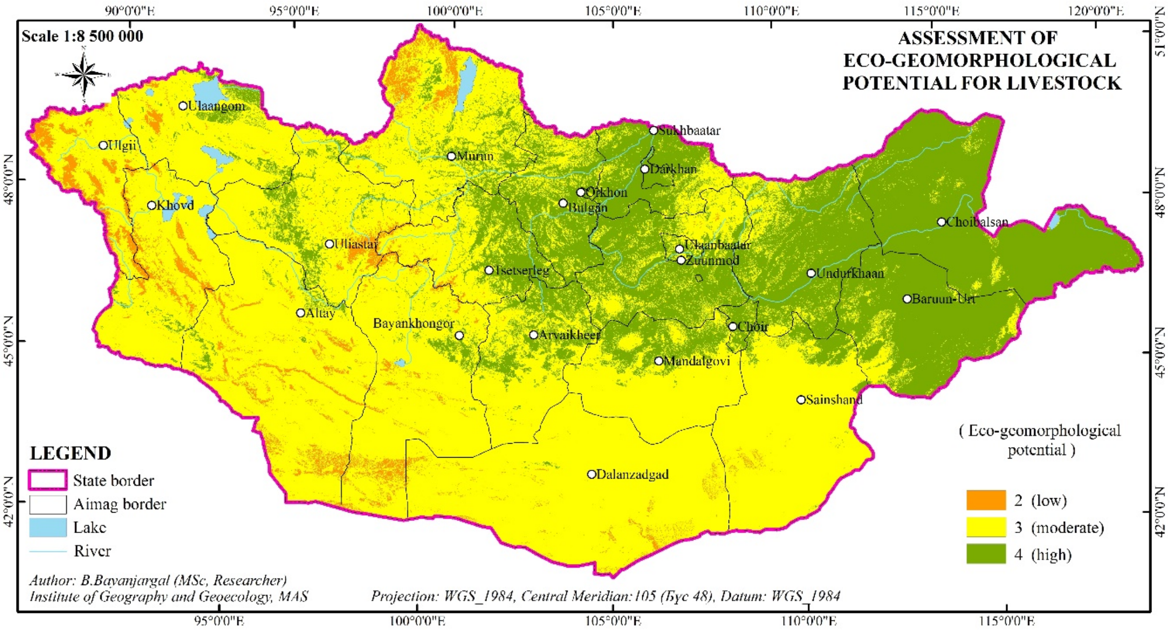

Figure 8. Assessment of eco-geomorphological potential for livestock

Table 6. Eco-geomorphological potential for livestock, (by natural belts and zones)

Natural belts and zones	Area of natural belts and zones, sq.km	Of which: Area for each evaluation level, in percent					Total % of high and very high	Level of potential
		Very low	Low	Moderate	High	Very high		
Result of eco-geomorphological potential for the livestock								
Alpine	*55351.5*	*0*	*45.8*	*54.1*	*0.1*	*0*	*0.1*	***6***
Mountain taiga	*70894.3*	*0*	*4.0*	*78.3*	*17.7*	*0*	*17.7*	***3***
Forest steppe zone	*236013.0*	*0*	*0.8*	*52.4*	*46.8*	*0*	*46.8*	***2***
Steppe zone	*540835.6*	*0*	*1.7*	*35.4*	*62.8*	*0*	*62.8*	***1***
Gobi zone	*358568.5*	*0*	*1.2*	*89.8*	*8.9*	*0*	*8.9*	***4***
Desert zone	*302453.2*	*0*	*5.1*	*94.5*	*0.4*	*0*	*0.4*	***5***

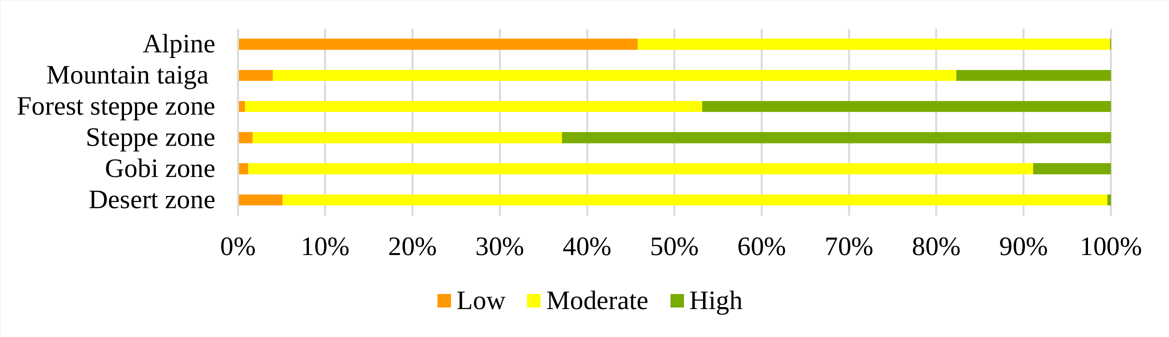

Figure 9. Eco-geomorphological potential for livestock, (by natural belts and zones)

Table 7. Eco-geomorphological potential for livestock, (by aimags)

Aimags (Provinces), and Capital city	Area of aimags and capital city sq.km	Of which: Area for each evaluation level, in percent					Total % of high and very high	Level of potential
		Very low	Low	Mod erate	High	Very high		
Result of eco-geomorphological potential for livestock								
Arkhangai	*55313.8*	*0.0*	*3.4*	*57.6*	*39.1*	*0.0*	*39.1*	***11***
Bayankhongor	*115977.8*	*0.0*	*6.4*	*89.7*	*3.9*	*0.0*	*3.9*	***18***
Bayan-Ulgii	*45704.9*	*0.0*	*27.6*	*72.1*	*0.3*	*0.0*	*0.3*	***21***
Bulgan	*48733.0*	*0.0*	*0.0*	*32.3*	*67.7*	*0.0*	*67.7*	***8***
Darkhan-Uul	*3275.0*	*0.0*	*0.0*	*4.3*	*95.7*	*0.0*	*95.7*	***2***
Dornod	*123597.4*	*0.0*	*0.0*	*2.8*	*97.2*	*0.0*	*97.2*	***1***
Dornogovi	*109472.3*	*0.0*	*0.6*	*91.5*	*7.9*	*0.0*	*7.9*	***17***
Dundgovi	*74690.3*	*0.0*	*0.0*	*76.3*	*23.7*	*0.0*	*23.7*	***13***
Govi-Altai	*141447.7*	*0.0*	*7.8*	*90.1*	*2.1*	*0.0*	*2.1*	***19***
Govisumber	*5541.8*	*0.0*	*0.0*	*21.0*	*79.0*	*0.0*	*79.0*	***6***
Khentii	*80325.1*	*0.0*	*0.0*	*19.3*	*80.7*	*0.0*	*80.7*	***5***
Khovd	*76060.4*	*0.0*	*9.1*	*89.1*	*1.7*	*0.0*	*1.7*	***20***
Khuvsgul	*100628.8*	*0.0*	*8.8*	*75.3*	*15.8*	*0.0*	*15.8*	***14***
Orkhon	*844.0*	*0.0*	*0.0*	*14.2*	*85.8*	*0.0*	*85.8*	***4***
Selenge	*41152.6*	*0.0*	*0.0*	*24.1*	*75.9*	*0.0*	*75.9*	***7***
Sukhbaatar	*82287.2*	*0.0*	*0.0*	*11.9*	*88.1*	*0.0*	*88.1*	***3***
Tuv	*74042.4*	*0.0*	*0.1*	*32.8*	*67.1*	*0.0*	*67.1*	***9***
Ulaanbaatar	*4704.4*	*0.0*	*0.0*	*42.1*	*57.9*	*0.0*	*57.9*	***10***
Umnugovi	*165380.5*	*0.0*	*2.3*	*97.5*	*0.1*	*0.0*	*0.1*	***22***
Uvs	*69585.4*	*0.0*	*2.6*	*86.2*	*11.2*	*0.0*	*11.2*	***16***
Uvurkhangai	*62895.3*	*0.0*	*0.2*	*67.5*	*32.3*	*0.0*	*32.3*	***12***
Zavkhan	*82455.7*	*0.0*	*4.7*	*81.5*	*13.8*	*0.0*	*13.8*	***15***

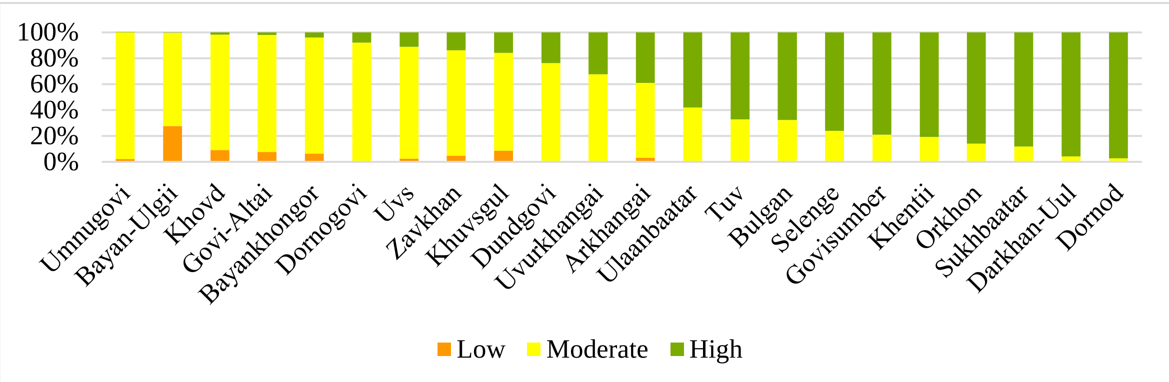

Figure 10. Eco-geomorphological potential for livestock, (by aimags)

Vol. 60 No 03 (235) 2020
DOI: https://doi.org/10.5564/pmas.v60i3.1418

Assessment of eco-geomorphological potential for agriculture: The rugged nature of Mongolia's mountains and depressions has a different effect on agriculture. The impact of relief on agriculture should be considered primarily in relation to surface slope, surface obstacle, mountain slopes, absolute altitude, and micro-features of relief. Relief has a significant effect on the natural resources indispensable for agriculture, such as precipitation, solar radiation, fertile soils, and surface and groundwater distribution. For example, there are thick forests and foliage at the back side of a mountain, but there are no forests in the front part. This is directly related to the micro-differences in the relief. Therefore, the yield per hectare of two farms in the same geographical area appears to be different. The evaluation criteria of Munkhdulam (2017) were followed since it was difficult to develop criteria for this sub-topic [20].

Table 8. Eco-geomorphological potential for agriculture

Eco-geomorphological potential for agriculture		*Area*	
		sq.km	*%*
1	*(Very low)*	*11106.11*	*0.7*
2	*(Low)*	*112862.2*	*7.2*
3	*(Moderate)*	*609494*	*39.0*
4	*(High)*	*555316.3*	*35.5*
5	*(Very high)*	*275337.3*	*17.6*

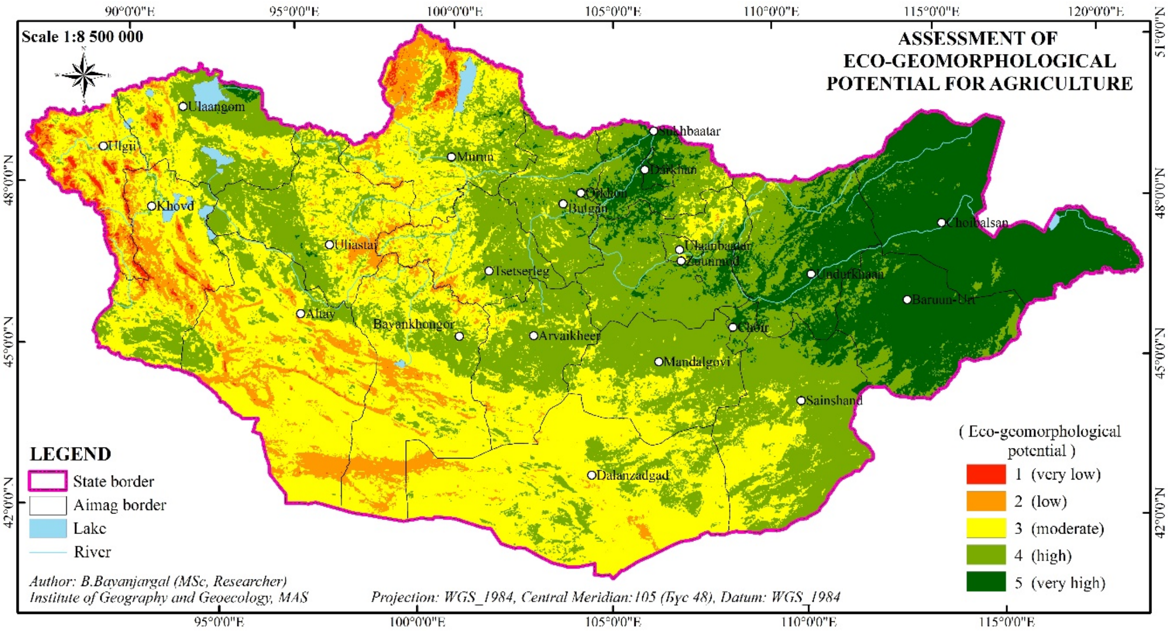

Figure 11. Assessment of eco-geomorphological potential for agriculture

Table 9. Eco-geomorphological potential for agriculture, (by natural belts and zones)

Natural belts and zones	Area of natural belts and zones, sq.km	Of which: Area for each evaluation level, in percent					Total % of high and very high	Level of potential
		Very low	Low	Moderate	High	Very high		
Result of eco-geomorphological potential for the agriculture								
Alpine	*55351.5*	*7.6*	*40.1*	*51.5*	*0.8*	*0.0*	*0.8*	***6***
Mountain taiga	*70894.3*	*0.2*	*3.4*	*54.7*	*39.6*	*2.1*	*41.7*	***3***
Forest steppe zone	*236013.0*	*0.0*	*2.1*	*37.1*	*47.6*	*13.2*	*60.8*	***2***
Steppe zone	*540835.6*	*0.5*	*5.1*	*19.5*	*46.5*	*28.4*	*75.0*	***1***
Gobi zone	*358568.5*	*0.4*	*16.1*	*43.0*	*37.8*	*2.8*	*40.6*	***4***
Desert zone	*302453.2*	*1.2*	*22.5*	*63.6*	*12.8*	*0.0*	*12.8*	***5***

Vol. 60 No 03 (235) 2020
DOI: https://doi.org/10.5564/pmas.v60i3.1418

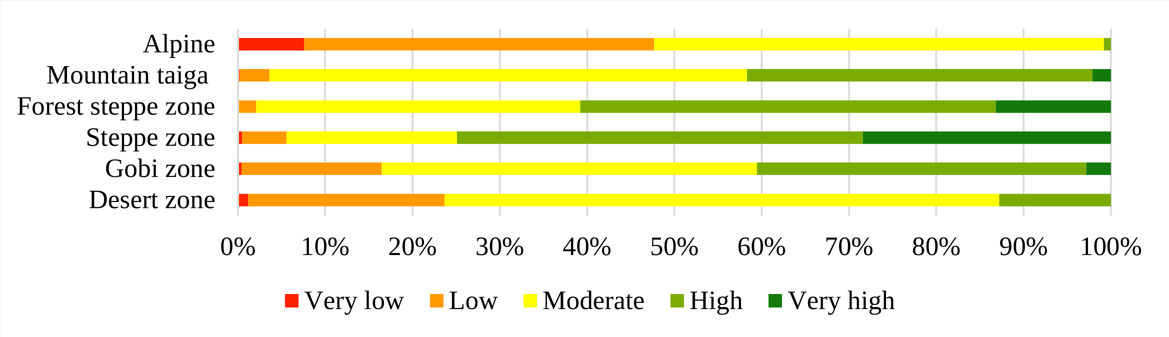

Figure 12. Eco-geomorphological potential for agriculture, (by natural belts and zones)

Table 10. Eco-geomorphological potential for agriculture, (by aimags)

Aimags (Provinces), and Capital city	Area of aimags and capital city sq.km	Of which: Area for each evaluation level, in percent					Total % of high and very high	Level of potential
		Very low	Low	Mod erate	High	Very high		
Result of eco-geomorphological potential for agriculture								
Arkhangai	*55313.8*	*0.1*	*6.2*	*40.0*	*53.2*	*0.5*	*53.7*	***14***
Bayankhongor	*115977.8*	*0.0*	*15.7*	*65.5*	*18.8*	*0.0*	*18.8*	***19***
Bayan-Ulgii	*45704.9*	*13.4*	*31.0*	*52.3*	*3.3*	*0.0*	*3.3*	***22***
Bulgan	*48733.0*	*0.0*	*0.0*	*11.3*	*84.8*	*3.9*	*88.7*	***10***
Darkhan-Uul	*3275.0*	*0.0*	*0.0*	*0.0*	*23.4*	*76.6*	*100.0*	***2***
Dornod	*123597.4*	*0.0*	*0.0*	*0.0*	*2.9*	*97.1*	*100.0*	***4***
Dornogovi	*109472.3*	*0.0*	*0.0*	*24.8*	*69.2*	*6.0*	*75.2*	***11***
Dundgovi	*74690.3*	*0.0*	*0.0*	*32.9*	*67.0*	*0.1*	*67.1*	***12***
Govi-Altai	*141447.7*	*0.3*	*19.3*	*68.3*	*12.2*	*0.0*	*12.2*	***21***
Govisumber	*5541.8*	*0.0*	*0.0*	*0.0*	*64.9*	*35.1*	*100.0*	***5***
Khentii	*80325.1*	*0.0*	*0.0*	*2.5*	*43.1*	*54.4*	*97.5*	***6***
Khovd	*76060.4*	*2.2*	*20.6*	*58.2*	*19.0*	*0.0*	*19.0*	***18***
Khuvsgul	*100628.8*	*2.2*	*17.7*	*52.2*	*27.5*	*0.4*	*27.9*	***17***
Orkhon	*844.0*	*0.0*	*0.0*	*0.0*	*67.1*	*32.9*	*100.0*	***2***
Selenge	*41152.6*	*0.0*	*0.0*	*6.5*	*55.8*	*37.7*	*93.5*	***7***
Sukhbaatar	*82287.2*	*0.0*	*0.0*	*0.0*	*15.1*	*84.9*	*100.0*	***1***
Tuv	*74042.4*	*0.0*	*0.1*	*9.0*	*78.4*	*12.5*	*90.9*	***8***
Ulaanbaatar	*4704.4*	*0.0*	*0.0*	*11.3*	*79.6*	*9.1*	*88.7*	***9***
Umnugovi	*165380.5*	*0.0*	*3.5*	*81.3*	*15.2*	*0.0*	*15.2*	***20***
Uvs	*69585.4*	*0.6*	*5.0*	*40.8*	*51.1*	*2.4*	*53.5*	***15***
Uvurkhangai	*62895.3*	*0.0*	*1.3*	*36.1*	*62.2*	*0.3*	*62.5*	***13***
Zavkhan	*82455.7*	*0.0*	*7.0*	*48.0*	*44.6*	*0.3*	*44.9*	***16***

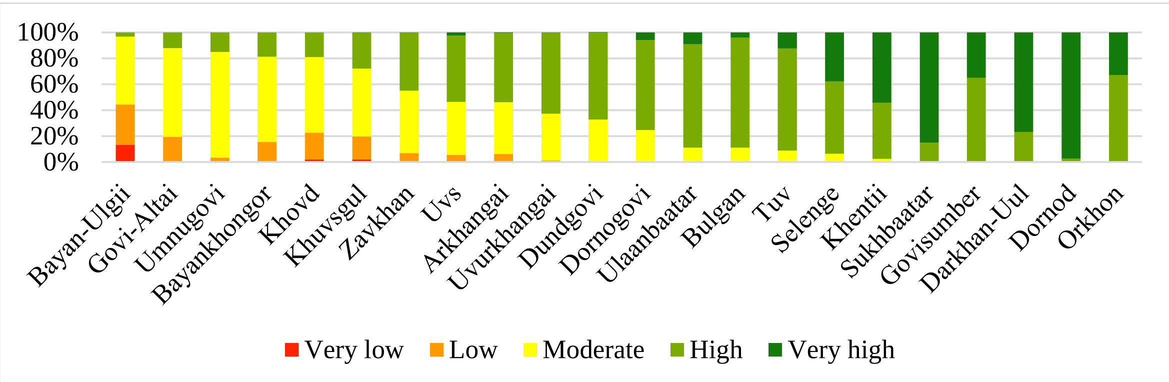

Figure 13. Eco-geomorphological potential for agriculture, (by aimags)

As of 2019, Mongolia was cultivating a total of 507,942.9 hectares of land, of which 85 per cent is in Selenge, Tuv, Bulgan, Dornod, Khentii, and Darkhan-Uul aimags [15]. According to our research, in Dornod, Orkhon, Sukhbaatar, Darkhan-Uul, Tuv, and Selenge aimags, the potential was "very high" in terms of eco-geomorphological assessment for agriculture.

Assessment of the eco-geomorphological potential of Mongolia: The eco-geomorphological potential assessment map of Mongolia was produced using the above three thematic layers (eco-geomorphological potential assessment for population, livestock, and agriculture), which had been rated on a scale of 1-5, along with the weights calculated using the GIS-based Analytic Hierarchy Process (AHP).

Table 11. The Eco-geomorphological potential of Mongolia

Eco-geomorphological potential of Mongolia		*Area*	
		sq.km	*%*
1	*(Very low)*	*11954.5*	*0.8*
2	*(Low)*	*183001.8*	*11.7*
3	*(Moderate)*	*607763.7*	*38.9*
4	*(High)*	*565544.2*	*36.2*
5	*(Very high)*	*195851.8*	*12.5*

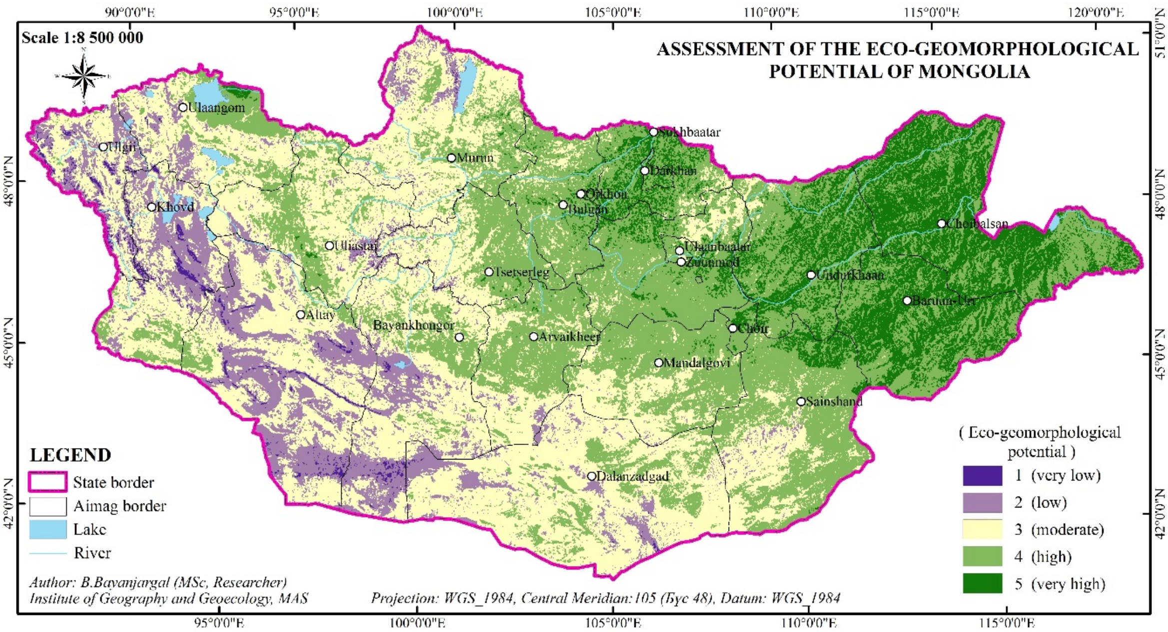

Figure 14. Assessment of the eco-geomorphological potential of Mongolia

Table 12. Assessment of the eco-geomorphological potential of Mongolia, (by natural belts and zones)

Natural belts and zones	Area of natural belts and zones, sq.km	Of which: Area for each evaluation level, in percent					Total % of high and very high	Level of potential
		Very low	Low	Moderate	High	Very high		
Result of eco-geomorphological potential of Mongolia								
Alpine	*55351.5*	*7.6*	*40.1*	*51.5*	*0.8*	*0.0*	*0.8*	***6***
Mountain taiga	*70894.3*	*0.2*	*3.4*	*54.7*	*39.6*	*2.1*	*41.7*	***3***
Forest steppe zone	*236013.0*	*0.0*	*2.1*	*37.1*	*47.6*	*13.2*	*60.8*	***2***
Steppe zone	*540835.6*	*0.5*	*5.1*	*19.5*	*46.5*	*28.4*	*75.0*	***1***
Gobi zone	*358568.5*	*0.4*	*16.1*	*43.0*	*37.8*	*2.8*	*40.6*	***4***
Desert zone	*302453.2*	*1.2*	*22.5*	*63.6*	*12.8*	*0.0*	*12.8*	***5***

Vol. 60 No 03 (235) 2020
DOI: https://doi.org/10.5564/pmas.v60i3.1418

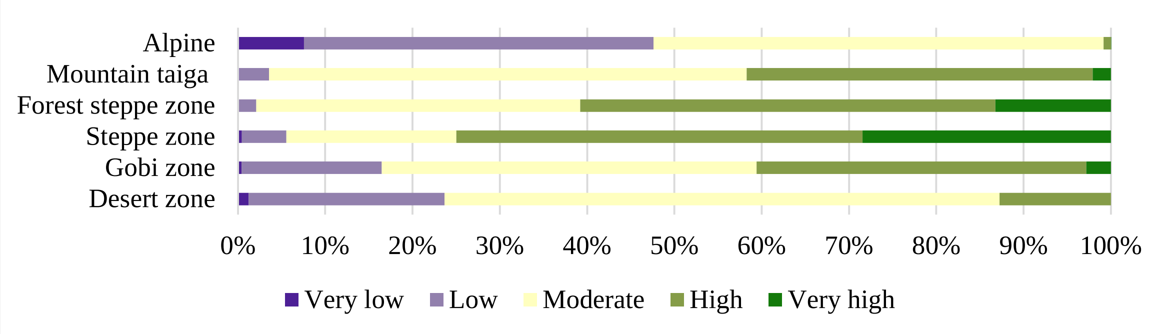

Figure 15. Assessment of the eco-geomorphological potential of Mongolia, (by natural belts and zones)

Following is a comparative result of the integrated assessment of eco-geomorphological potential of Mongolia by aimags and the capital city: In Darkhan-Uul, Orkhon, Dornod, Sukhbaatar, Govisumber, Khentii, Selenge, Tuv, Bulgan aimags and the capital city of Ulaanbaatar, the areas with very high or high ecological potential comprised of more than 85 per cent of the total territory of these aimags, while in Khuvsgul, Bayankhongor, Umnugovi, Khovd, Govi-Altai, and Bayan-Ulgii aimags, the areas with very high or high ecological potential accounted for less than 25 per cent of the total area of these aimags.

Table 13. Assessment of the eco-geomorphological potential of Mongolia, (by aimags)

Aimags (Provinces), and Capital city	Area of aimags and capital city sq.km	Of which: Area for each evaluation level, in percent					Total % of high and very high	Level of potential
		Very low	Low	Moderate	High	Very high		
Result of the eco-geomorphological potential of Mongolia								
Arkhangai	*55313.8*	*0.1*	*4.1*	*44.9*	*50.2*	*0.7*	*50.9*	***14***
Bayankhongor	*115977.8*	*1.2*	*24.8*	*57.6*	*16.4*	*0.0*	*16.4*	***18***
Bayan-Ulgii	*45704.9*	*7.5*	*39.0*	*52.3*	*1.2*	*0.0*	*1.2*	***22***
Bulgan	*48733.0*	*0.0*	*0.0*	*14.4*	*79.0*	*6.6*	*85.6*	***10***
Darkhan-Uul	*3275.0*	*0.0*	*0.0*	*0.0*	*57.4*	*42.6*	*100.0*	***1***
Dornod	*123597.4*	*0.0*	*0.0*	*0.0*	*38.1*	*61.9*	*100.0*	***1***
Dornogovi	*109472.3*	*0.0*	*2.0*	*29.7*	*61.5*	*6.7*	*68.3*	***11***
Dundgovi	*74690.3*	*0.0*	*0.6*	*35.2*	*63.5*	*0.7*	*64.1*	***12***
Govi-Altai	*141447.7*	*2.4*	*40.0*	*53.0*	*4.6*	*0.0*	*4.6*	***21***
Govisumber	*5541.8*	*0.0*	*0.0*	*0.5*	*68.7*	*30.8*	*99.5*	***5***
Khentii	*80325.1*	*0.0*	*0.0*	*3.1*	*55.8*	*41.1*	*96.9*	***6***
Khovd	*76060.4*	*3.4*	*37.7*	*49.6*	*9.4*	*0.0*	*9.4*	***20***
Khuvsgul	*100628.8*	*0.3*	*8.4*	*65.3*	*25.5*	*0.4*	*25.9*	***17***
Orkhon	*844.0*	*0.0*	*0.0*	*0.0*	*61.8*	*38.2*	*100.0*	***1***
Selenge	*41152.6*	*0.0*	*0.0*	*7.2*	*58.0*	*34.8*	*92.8*	***7***
Sukhbaatar	*82287.2*	*0.0*	*0.0*	*0.1*	*45.5*	*54.4*	*99.9*	***4***
Tuv	*74042.4*	*0.0*	*0.1*	*11.8*	*75.8*	*12.3*	*88.1*	***8***
Ulaanbaatar	*4704.4*	*0.0*	*0.0*	*13.8*	*72.9*	*13.3*	*86.2*	***9***
Umnugovi	*165380.5*	*0.2*	*11.8*	*73.2*	*14.8*	*0.0*	*14.8*	***19***
Uvs	*69585.4*	*0.2*	*13.0*	*52.8*	*32.1*	*1.9*	*34.0*	***15***
Uvurkhangai	*62895.3*	*0.0*	*3.1*	*37.2*	*59.2*	*0.5*	*59.7*	***13***
Zavkhan	*82455.7*	*0.2*	*7.5*	*63.4*	*28.5*	*0.4*	*28.9*	***16***

Vol. 60 No 03 (235) 2020
DOI: https://doi.org/10.5564/pmas.v60i3.1418

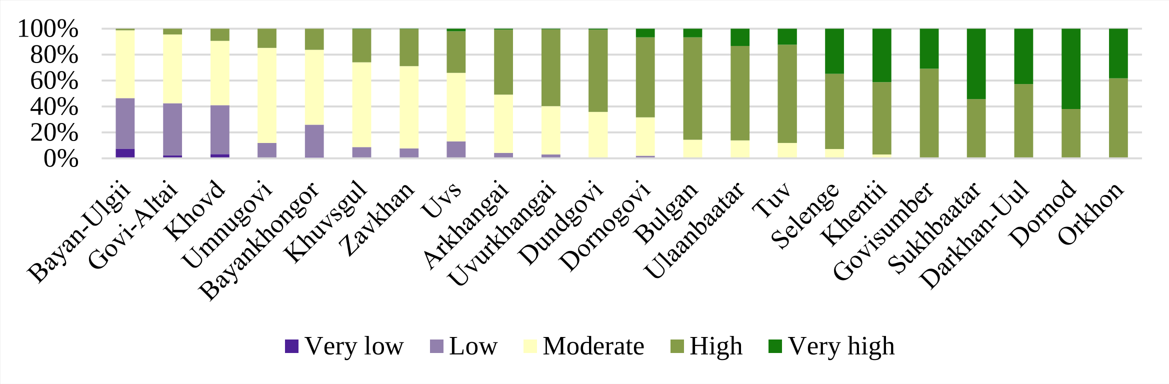

Figure 16. Assessment of eco-geomorphological potential of Mongolia, (by aimags)

CONCLUSIONS

The spatial resolutions of the thematic layers used as evaluation criteria by default in Mongolia were developed at 500 m, depending on the repeatability and availability of the data. In the eco-geomorphological assessment, the ecological potential was assessed as very low, low, moderate, high, very high, taking into account the population, livestock, and agriculture, also as a follower of the relief factors and the climatic factors that have the greatest influence on the surface changes and modern processes that take place on them. The relief plays various direct and indirect ecological roles. Rising elevation above the sea level creates microclimate zones, such as lower air pressure, oxygen deficiency, and reduction of air temperature, excessive solar radiation, and creation of strong winds, so relief factors have a significant impact on our daily lives.

In Mongolia, steppe and forest-steppe zones are high eco-geomorphological potential zones, whereas landscapes with low and very low eco-geomorphological potential are common in the high mountain belts, gobi, and desert zones. Landscape with very high and high eco-geomorphological potential cover more than 85 per cent of the total territory of Darkhan-Uul, Orkhon, Dornod, Sukhbaatar, Govi Sumber, Khentii, Selenge, Tuv, and Bulgan aimags and the capital city of Ulaanbaatar, which are located in the above-mentioned zones with high potential. Moreover, these aimags have a large population and urban concentration, and also these are the main regions for livestock and agriculture development. The findings of this study are significant by summarizing geomorphological or relief factors with climatic factors affecting them, and we recommend that further research work should concentrate on enhancing the resolution of climate data for doing large scale research in a smaller area. We have developed the map of eco-geomorphological potential in Mongolia by default, and the map can be applied as a basis for urban planning and agriculture, especially for the planning of livestock and agricultural areas.

Acknowledgments. This research work was carried out within the framework of research project “Assessment of the landscape-ecological potential of Mongolia natural zones” that was funded by the Science and Technology Foundation of Mongolia and implemented by the Institute of Geography and Geoecology, Mongolian Academy of Sciences during the years 2017-2019. We would like to thank the project leader, and all colleagues at the Division of Physical Geography, Institute of Geography and Geoecology, Mongolian Academy of Sciences, who provided direct and indirect assistance in the successful implementation of the research, and for the invaluable suggestions at the initial stage of the research

Vol. 60 No 03 (235) 2020
DOI: https://doi.org/10.5564/pmas.v60i3.1418

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