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Original Article

Climate change impact of land cover changes in the Kharhiraa-Turgen mountain region

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ABSTRACT

The study region experiences marked seasonal climatic contrasts, primarily influenced by the Central Asian anticyclone during winter and the South Asian continental depression in summer. The Mongolian Altai Mountains serve as a significant orographic barrier, further shaping local climatic patterns. Although spatial variability in precipitation is relatively limited, the steady increase in temperature-exacerbated in recent decades by global climate change - has intensified climatic differentiation across the region. This warming trend contributes to growing heterogeneity in environmental conditions and landscape processes, underscoring the area's heightened sensitivity to ongoing climatic shifts. The aim was to illustrate climate and land cover shifts in the Kharkhiraa-Turgen mountain region using Landsat satellite data at a spatial scale. Temporally, changes were assessed between 2002 and 2021 at five-year intervals. By 2021, grassland coverage dominated the landscape, occupying 46.1% of the land cover, an increase of 1.9% from 2015. Conversely, bare land decreased from 37.2% in 2000 to 30.2% in 2021, while wetlands along riverbeds expanded from 14.35% in 2000 to 17.5% in 2021. In January 2000, the average air temperature was -20.5°C, compared to -18°C in January 2021, reflecting a 2.5°C increase. July temperatures rose from 16.2°C in 2000 to 17.4°C in 2021, a 1.19°C change. Summer precipitation in 2021 (151 mm) surpassed that of 2015 (70.1 mm), 2010 (118.3 mm), 2005 (106.9 mm), and 2000 (96.5 mm), indicating a relative increase in precipitation in the area. The prevalence of bare soil in the region is closely associated with the mountainous terrain, steep slopes, and patterns of soil erosion. Harsh climatic conditions further exacerbate rock exposure and hinder soil stabilization. Rainfall predominantly runs off the surface rather than infiltrating, which, in turn, facilitates the development of wetlands and water bodies in certain areas.

Keywords: grassland, bare soil, wetland, precipitation, temperature

INTRODUCTION

Changes in land use and land cover occur as a consequence of the intricate interplay between natural processes and human socio-economic activities (Johnson and Lewis, 2007). These dynamics evolve as a function of the synergistic impacts arising from natural determinants and anthropogenic interventions (Perminova et al., 2016). Due to global warming and climate change, we observe a rapid change in land cover. Land use changes also affect surface temperatures through non-radiative processes, particularly through the hydrological cycle. These processes are less well known and are difficult to quantify but tend to offset the impact of albedo changes. As a consequence, there is low agreement on the sign of the net change in global mean temperature as a result of land use change (Jia et al., 2019; Hartmann et al., 2013). According to the AR5 report, the repercussions of recent climate-induced extreme occurrences underscore the heightened susceptibility of specific ecosystems to ongoing climate shifts. The consequences of these climate-related extremes encompass transformations within ecosystems, disturbances in food production and water provisions, impairment of infrastructure and habitation, and implications for health, mortality, psychological well-being, and overall human welfare. Moreover, it should be noted that land-use alterations, which are non-radioactive, also exert an influence on surface temperature through distinct processes. Consequently, there exists a consensus regarding the direction of the net change in global mean temperature due to land-use modifications, as indicated by previous research (Burkett et al., 2014; Duyck et al., 2012).

As global climate change intensifies, distinguishing between human-induced land degradation and climate-induced land degradation becomes crucial, particularly when the latter is beyond the influence or control of land users (Vlek et al, 2010).

According to the physical geography of Mongolia, the research area is included in the Kharhiraa-Turgen mountains and depression sub-region of the Altai-Soyon region of Mongolia (Dash, 2009; Tsedevdorj, 2019).

At the north-eastern end of the Mongolian Altai mountain range are the Kharhiraa and Turgen mountains, which are part of the Mongolian Altai mountain system. These mountains are separated from the main mountains of the Mongolian Altai by the large tectonic depression of Lake Achit, but have a similar

Fig. 1. Landscape of the Kharkhiraa-Turgen Mountains. a. High peaks of the Turgen Mountains. b, c. Formation of thermokarst lakes in mountainous areas, attributed to global warming. d. General view of the Turgen Mountains, showing evidence of both Quaternary and modern glaciation (Photos by Bayar Balgantseren and Ser-Od Tsedevdorj)

length (Enkhbold et al., 2024). The watershed of the Kharhiraa and Turgen mountains generally runs from northwest to southeast, and the highest peak is Mount Turgen (3,965 m), which is permanently covered with snow (Fig. 1). This district has many rocks and boulders as well as steep slopes and is largely deserted from the edge, which is a result of the valleys surrounding it (Dash, 2015).

The Tsagaanshuvuut mountains (3,496 m) run north-west to south-east, east of the Kharhiraa and Turgen mountains. Between these ridges is the isolated depression of Lake Uureg. The ridges isolate Lake Uureg, which is located in the depression in the middle of the ridges. In appearance, these mountains resemble the Mongolian Altai Mountains, with sharp peaks, steep flanks and relatively great absolute and relative heights.

The extension of the Kharhiraa and Turgen mountains is Altan Khukhii Mountain, which is located on the north side of the Khovd River (Dash, 2015). The mountain peaks and ridges are largely flat, and the flanks are quite steep or were generally uplifted during the late geological period of the former flat surface. The topography of a mountain system is varied, with uniformly elevated surfaces and erosion-defined ridges, depositional valleys and intermountain depressions, and this variation has a particular impact on landscape composition (Doljin and Yembuu, 2021). For example, in mountain systems with altitudes of 3,500 to 4,000 meters or more, snow and ice landscapes are widespread due to altitude and climatic conditions, while the peripheral areas of the mountain system are surrounded by troughs and depressions.

In the highlands of the Mongolian Altai, continental air movement is predominant in the temperate zone, dry continental air prevails all year round and the air masses mainly flow in from the north and northwest (Yembuu, 2021). In the warm season, warm, dry air penetrates from the warm southwest and the cyclone effect is activated, while in the cold season, arctic and extremely cold air currents are at work. In the high mountains of the Mongolian Altai, however, milder climatic conditions prevail in winter than in the neighboring valleys, and the air temperature rises. Thus, researchers discovered for the first time the formation of temperature inversions associated with the characteristics of humid areas at the foot of the mountains. The reason for this is that cold air collects at the bottom of the depression in winter (Tsegmid, 1969; Yembuu, 2021).

DATA AND METHODOLOGY

Study area. According to the administrative division, the Kharkhiraa-Turgen mountain region belongs to Ulgii, Umnugovi, Turgen, Sagil, Bukhmurun, Hovd soums in Uvs

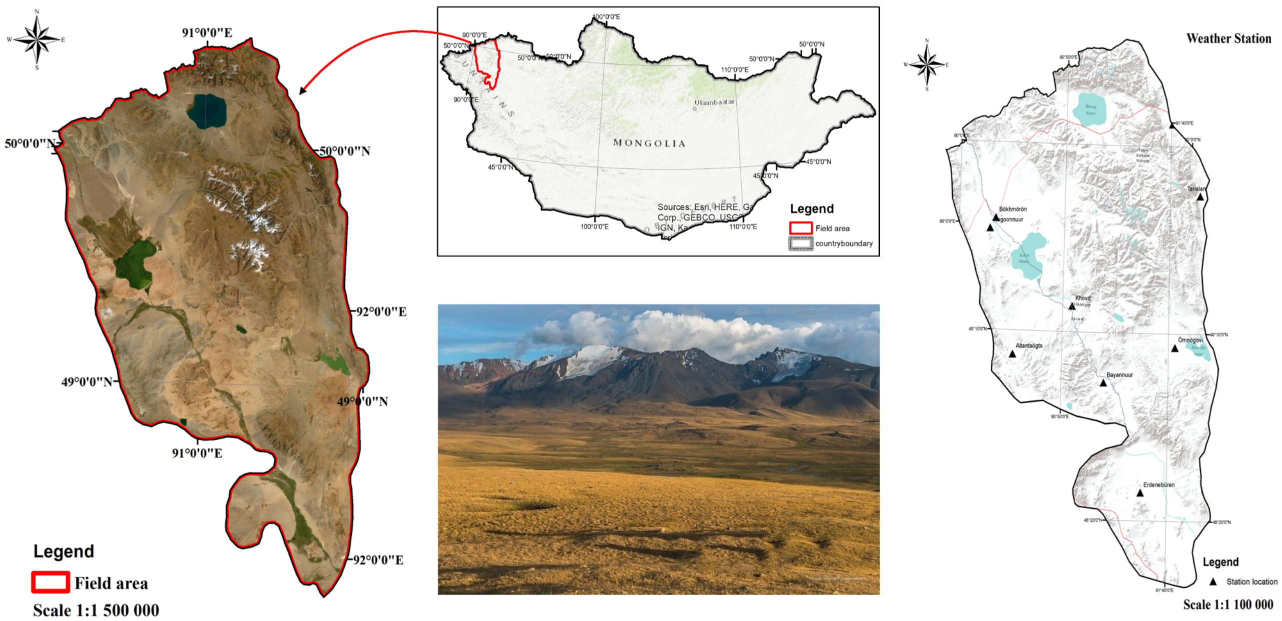

Fig. 2. Kharkhiraa-Turgen mountainous region and weather station location

province, Nogoonnuur, Altantsugts in Bayan-Ulgii province and Myangad in Hovd province (Fig. 2). As far as the general geographical structure is concerned, it is divided into main parts of mountain ranges and depressions within them. The desert and grassland landscapes of this region are very extensive compared with those of the Mongolian Altai, which is explained by the fact that the landscapes of the Uureg depressions, Lake Achit and the Khovd river basin extend over a vast territory. The region's highest peaks are Must Uul, the main peak of the Kharkhiraa mountain range, at 4,037 meters above sea level, and Deglii Tsagaan, at 3,978 meters, the main peak of the Turgen mountain range. These mountains were covered by glaciers in ancient times, and their traces are often visible in today's landscape (Tsedevdorj, 2021).

The Buural, Turgen, and Jivertei rivers span a total area of approximately 145,000 hectares, situated east of the Tsagaan Deglii Mountains. These rivers trace the ridgelines of the mountain ranges from which they originate. The Turgen Mountains encompass a diverse range of natural zones and vegetation belts, including high mountain tundra, forest, taiga, and mountain steppe. This area presents a unique landscape characterized by the striking beauty of permanent snow and ice, complemented by waterfalls, glacial cirques, caves, and dramatic cliffs. The mountains are predominantly rocky with steep, rugged slopes and are sparsely vegetated, a condition influenced by the arid depressions surrounding Lakes Uureg and Achit (Tsedevdorj, 2019).

In the Kharkhiraa-Turgen mountains, the Kharkhiraa, Turgen, Tsagaanshuvuut and Altan Khukhii mountains, which make up this sub-province, as well as the Uureg, Achit and Olon Lakes depressions, form part of the inter-mountain and inland depressions (Tsedevdorj, 2021). Apart from glaciers and permanent snow plains in the Turgen mountains, the mountains of the southern side, such as Yamaat Uul and Turgen Range, are 3,000-4,000 m high, and the mountains in the eastern part, such as Khukh Deest, Zeegtiin Shil, and Ulaan Davaa, are 2,500-3,000 m high. On the other hand, the northern side facing the Uureg Lake plain is lower and the altitude is 2,000-2,500 meters. The main ridge rises from west to east, and the mountains with numerous small lakes in the south separate it from the mountains of the inland depression Kharkhiraa. In this area, the peaks are characterized by steep slopes, and traces from the Quaternary Ice Age are well-preserved. Modern glaciers extend along the crests of the main ridges. The surface features steep, jagged sides, and numerous cracks are present. The mountain slopes, particularly in the valleys, are often covered with rubble and sparse vegetation (Fig. 2).

According to the climatic regions of Mongolia, the research region belongs to 3 regions: regions with humid cold summers with harsh winters, humid cold summers with harsh winters, and dry cool summers with harsh winters (Namkhaijantsan, 2009).

The humid and cold zone includes the regions with harsh winters, and here the high mountain belt of the Altai Mountains with an altitude of 1,800 m or more is included. In winter, the air temperature is colder than -25°C, and in summer it is cooler than +15°C. The total temperature of the soil surface above 10°C is less than 1,500°C, and the air temperature does not reach 10,000°C. The difference in the sum of plus and minus temperatures of the year ranges from 500°C to 1,000°C (Yembuu, 2021). A dryness degree of less than 1.0 is generally considered humid. In winter, there is a snow cover of more than 20 cm. The snow cover will form early and disappear late. During the winter, snowstorms occur an average of 6-7 times a year, including 5-10% of 11-15 m/s, 15-20% of 6-10 m/s, and 60% of 2-5 m/s. -70% probability.

In addition to conducting a forest survey to study the origin and age structure of blackwood forests in the Kharkhiraa and Turgen mountains, a soil survey was conducted, and a comprehensive soil survey was conducted from the peak of Khukh Deest Mountain (2905 m) to the Uvs Lake (759 m) in the Kharkhiraa mountains (Batkhishig, 2016).

In terms of soil and plants, the brown soil of the mountain meadows occurs at the beginning of the Zavkhan river, where there is permanent snow and ice. Dark brown soil is common in the back of Kharkhiraa and Turgen mountains, in the middle of the foothills and sloping plains, and light brown soil is common and forms an independent soil zone. Black trees and willows grow exclusively below the peak of Turgen mountain, and larch forests grow mainly on the sides of the mountains. 368 species of plants grow in this region, 12 of which are rare.

Data sourse

Our classification for land cover uses the common international land cover classification system (LCCS) introduced by the Food and Agriculture Organization of the United Nations (FAO) and follows the United Nations Conventions Guidance Document for the 2018 UNCCD reporting No.7 when classifying land cover (Lars, 2007; Minelli, 2018).

This study used 6 of the 7 reclassified categories from the 2018 UNCCD report. Cropland was excluded because the region is not suitable for mountain farming (Table. 1), (Table. 2), (Fig. 3).

1."Tree-covered areas", 2. "Grassland", 3. "Wetland", 4. Bare soil, 5. Snow cover, 6. Water bodies'.

Table 1. Data source description

	Data type	Time	Data sources	Data website address
Image data	Landsat 7 (ETM) Landsat 8-9 (OLI) DEM Land use/cover	2000-2012 2013-2022 2000 2000-2020	USGS USGS NASA Globeland30	https://earthexplorer.usgs.gov/ https://glovis.usgs.gov/ https://srtm.csi.cgiar.org/srtmdata/ http://www.globallandcover.com/
Basic geographic data	Land use/ cover area	1990-2021	Mongolian Statistical Yearbook, CAS Mongolian Environment Database Climate Service System	https://www.1212.mn/mn/statistic/statcate/573072/table-view/DT_NSO_2400_022V2 https://eic.mn/land/ http://icc.mn/index.php?menuitem=5&datatype=lst

Table 2. Satellite-data

Time	Landsat7 ETM / Landsat8-9 OLI	Spatial resolution (meters)
2000	LT05_L1TP_142026_20000918_20200906_02_T1 LT05_L1TP_142027_20000918_20200906_02_T1 LT05_L1TP_141026_20000725_20200906_02_T1	30
2005	LE07_L1TP_141026_20040829_20200915_02_T1 LE07_L1TP_142025_20040905_20200915_02_T1 LE07_L1TP_142026_20040905_20200915_02_T1	30
2010	LE07_L2SP_141026_20100814_20200911_02_T1 LE07_L2SP_142025_20100821_20200910_02_T1 LE07_L2SP_142026_20100821_20200910_02_T1	30
2015	LE07_L1TP_141026_20150812_20200903_02_T1 LE07_L2SP_142025_20150819_20200904_02_T1 LE07_L2SP_142026_20150819_20200904_02_T1	30
2021	LC08_L2SP_141025_20210905_20210910_02_T1 LC08_L2SP_142025_20210912_20210916_02_T1 LC08_L2SP_142026_20210912_20210916_02_T1	30

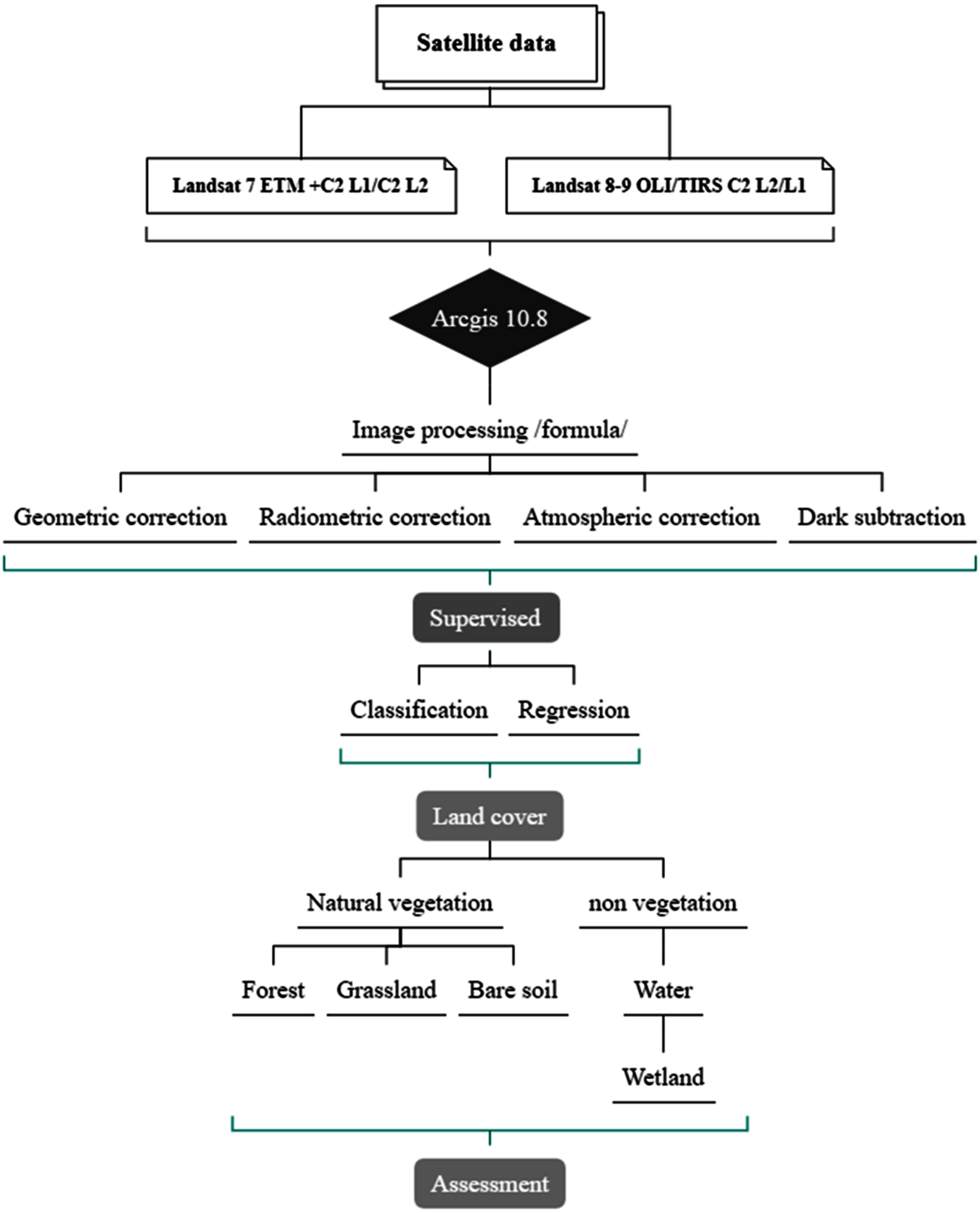

Fig. 3. Protocol used for supervised classification of land cover in the study area

RESULT

"Climate and land cover changes in the mountainous region of Kharkhiraa-Turgen between 2000 and 2021 were used. The average was calculated using data from 7 Soum climate stations (Power.larc.nasa.gov) and NASA weather data included in the study area. In doing so, the average data from 1 to 12 months of each year is included in the table, taken at intervals of five years" (Table. 3)

The average air temperature in January was -20.51°C in 2000, and decreased by 2°C to -18.05°C in 2021. July temperature increased

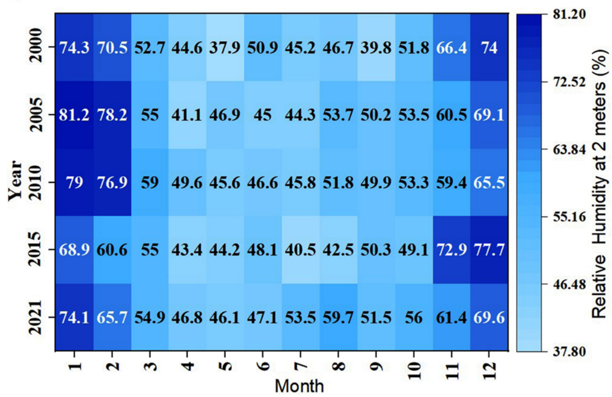

Fig. 4. Indicator of relative humidity of the study area (Power.larc.nasa.gov, 2000-2021)

Table 3. Historical monthly weather data of seven soums (Erdeneburen soum of Khovd province, Tarialan, Khovd, Umnugovi soum of Uvs province, Nogoonnuur, Altantsugts, Bayannuur soum of Bayan-Ulgii province)

	Year/ month	1	2	3	4	5	6	7	8	9	10	11	12
Precipitation	2000	0	0	0	9.8	15.1	52	15.8	13.6	2.3	3	0	0
	2005	0	0	0	4.5	25.6	11.3	7.5	62.5	9.8	0.8	0	0
	2010	0	0	0	3.8	9.8	39.2	16.6	52.7	15.8	12.8	0.8	0
	2015	0	0	6	3	14.3	39.2	3.8	12.8	11.3	5.3	4.5	0
	2021	0	0	0.8	18.3	21.4	33.5	45.2	51.2	8.5	4	1.7	3.7
Presure Kpa	2000	81.4	81.4	81.5	81.4	81.2	81.2	81.2	81.2	81.6	81.5	81.4	81.2
	2005	81.4	81.3	81.7	81.4	81.2	81.1	81.2	81.2	81.6	81.8	81.6	82.0
	2010	81.3	80.9	81.3	81.6	81.1	81.3	81.2	81.5	81.7	81.8	81.3	81.2
	2015	81.4	81.4	81.4	81.5	81.3	81.3	81.2	81.5	81.6	81.8	81.3	81.5
	2021	81.5	81.2	81.2	81.6	81.4	81.2	81.1	81.4	81.4	81.9	81.6	81.8
Temperature at 2 Meters (C)	2000	-20.5	-14.5	-7.2	2.5	9.7	14.1	16.2	14.3	7.9	-4.3	-13.5	-15.6
	2005	-20.5	-21.6	-6.3	2.6	7.0	13.4	17.3	13.9	7.4	0.6	-9.1	-17.2
	2010	-20.7	-20.5	-12.2	-2.4	6.3	14.7	16.5	12.7	7.3	0.2	-7.2	-16.9
	2015	-16.3	-14.0	-8.2	2.3	8.4	14.0	17.7	15.2	5.2	0.2	-10.1	-14.4
	2021	-18.0	-11.0	-6.2	0.5	7.9	12.3	17.4	12.9	7.2	-1.0	-9.2	-13.5
Maximum (C)	2000	-9.5	-1.0	13.5	18.0	24.4	28.0	28.0	29.5	22.8	9.5	-1.4	-5.0
	2005	-8.7	-5.9	12.8	22.5	20.1	28.8	29.3	29.0	22.0	12.0	2.8	-7.4
	2010	-7.0	-5.1	5.8	19.2	22.4	29.7	27.8	27.4	25.6	17.9	5.8	-0.7
	2015	-4.9	0.7	11.5	21.8	22.4	27.5	31.5	29.8	23.3	15.8	7.1	-2.7
	2021	-4.0	3.9	8.6	21.5	24.6	25.3	29.7	25.9	23.0	8.6	3.1	-1.8
Minimum (C)	2000	-32.1	-24.5	-20.5	-10.5	-4.3	0.7	5.5	-1.3	-5.1	-19.2	-24.8	-27.7
	2005	-34.1	-32.5	-22.1	-12.9	-8.3	0.0	6.1	-0.5	-4.4	-8.2	-19.9	-25.6
	2010	-34.9	-33.8	-29.4	-21.9	-5.4	0.2	1.7	-0.3	-3.7	-11.3	-21.0	-27.5
	2015	-24.0	-24.1	-20.8	-13.1	-4.1	0.1	2.3	0.2	-5.4	-10.8	-19.5	-23.0
	2021	-30.2	-25.5	-19.6	-10.2	-6.0	-0.9	5.2	-2.4	-6.5	-8.7	-21.9	-23.6

by 1.19°C from 16.25°C in 2000 to 17.44°C in 2021. The temperature in October, November, and December decreased by 1-3°C, respectively. This shows that climate change is affecting it (Fig. 5). Air humidity ranges from 45-59.7% in June-August to 65-74% in January and February. It is relatively high in the months with high precipitation and decreased by 5-20% in the months with low precipitation (Fig. 4). Air pressure is a constant 81.3 kPa between 2000 and 2021 (Fig. 6). In terms of wind direction, in 2000, it was 2.5 m/s from the northwest, and

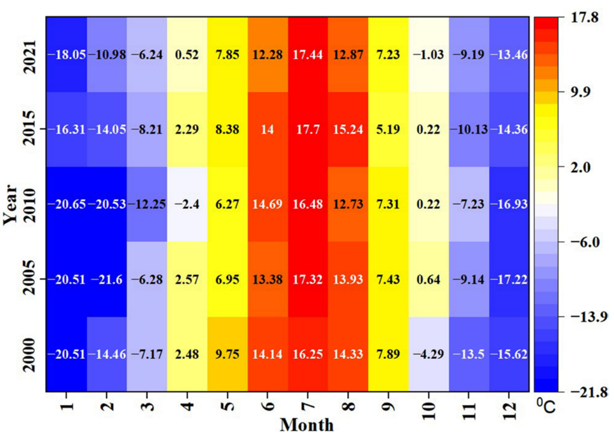

Fig. 5. Air temperature of the study area (Power.larc.nasa.gov, 2000-2021)

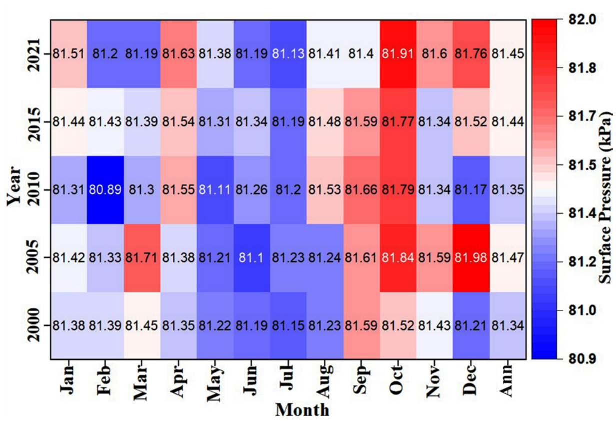

Fig. 6. Air pressure of the study area (Power.larc.nasa.gov, 2000-2021)

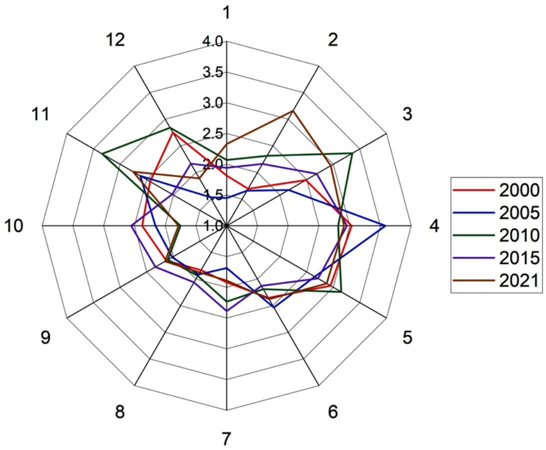

Fig. 7. Wind of the study area, A. 1.0-4.0 indicates wind speed (m/sec). B. 1-12 indicates month (Power.larc.nasa.gov, 2000-2021)

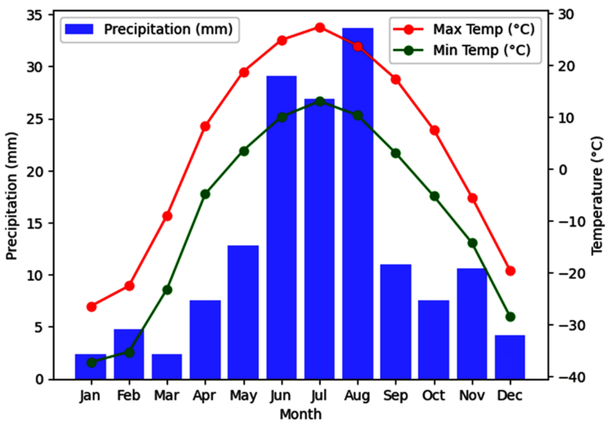

Fig. 8. Monthly precipitation and maximum and minimum temperatures of the study area (Power.larc.nasa.gov, 2000-2021)

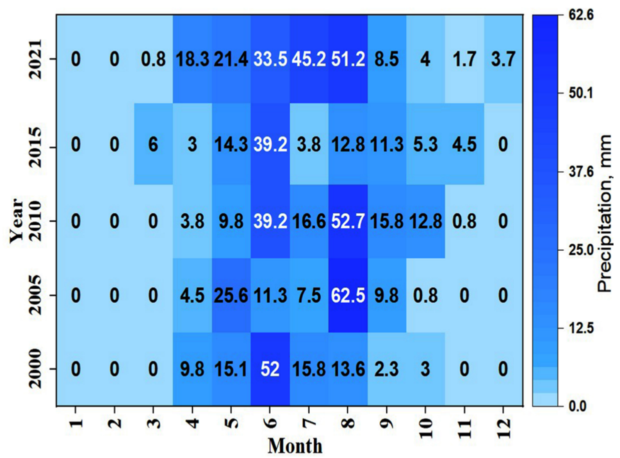

Fig. 9. Monthly precipitation of study area (Power.larc.nasa.gov, 2000-2021)

in 2021, it was 2-3.2 m/s from east to north and southeast (Fig. 7).

The total rainfall in the region was 111.6 mm in 2000, 122.5 mm in 2005, 151.5 mm in 2010, 100.2 mm in 2015, and 188.3 mm in 2021. In this region, August has the most precipitation (50-62 mm) compared to other months. In August 2005, the maximum rainfall was 62 mm. Very little precipitation falls from December to March. A total of 70.1 mm of precipitation fell in May between August 2015, while 155 mm fell in May between August 2021. Depending on the distribution of precipitation, changes in land cover categories vary (Fig. 8), (Fig. 9).

Using Landsat satellite data, this analysis showcases changes in land cover classification across several categories: grassland, bare soil, wetland, tree-covered, water, and snow-cover (Fig. 10). In 2021, grassland covers the largest area at 46.1%, up from 43.3% in 2015, indicating a 1.9% increase. Conversely, bare land decreased by 7% from 37.2% in 2000 to 30.2% in 2021, while wetlands expanded from 14.35% in 2000 to 17.5% in 2021, influenced by varying annual rainfall (Table. 4), (Fig. 11), (Fig. 12).

Snow cover ranged from a maximum of 2.7% in 2021 to a minimum of 1.95% in 2000. Other categories, such as forest cover and water, increased to 2.3% and 1.2%, respectively, in 2021. Each land cover category experienced an increase in area compared to previous years, possibly attributed to the higher total summer precipitation in 2021 (151 mm) compared to 2015 (70.1 mm), 2010 (118.3 mm), 2005 (106.9 mm), and 2000 (96.5 mm) (Fig. 9).

Compared to other mountain systems in Mongolia such as Khangai, Khentii, and Khuvsgul, the study area exhibits lower total precipitation and significant annual temperature fluctuations. This characteristic is influenced by the geographical positioning of the mountain system and its proximity to surrounding desert and dry depressions. The prevalence of bare soil in the land cover category is attributed to the elevation of the mountain system, its slopes, and the course of soil erosion. The harsh climate contributes to the abundance of rocks on the mountains' surfaces and steep slopes, limiting soil stabilization possibilities. Consequently, rainfall primarily fosters soil and plant growth by running off the surface and collecting in lakes within depressions and hollows, rather than providing direct moisture. As a result, the size of wetlands and water areas has increased.

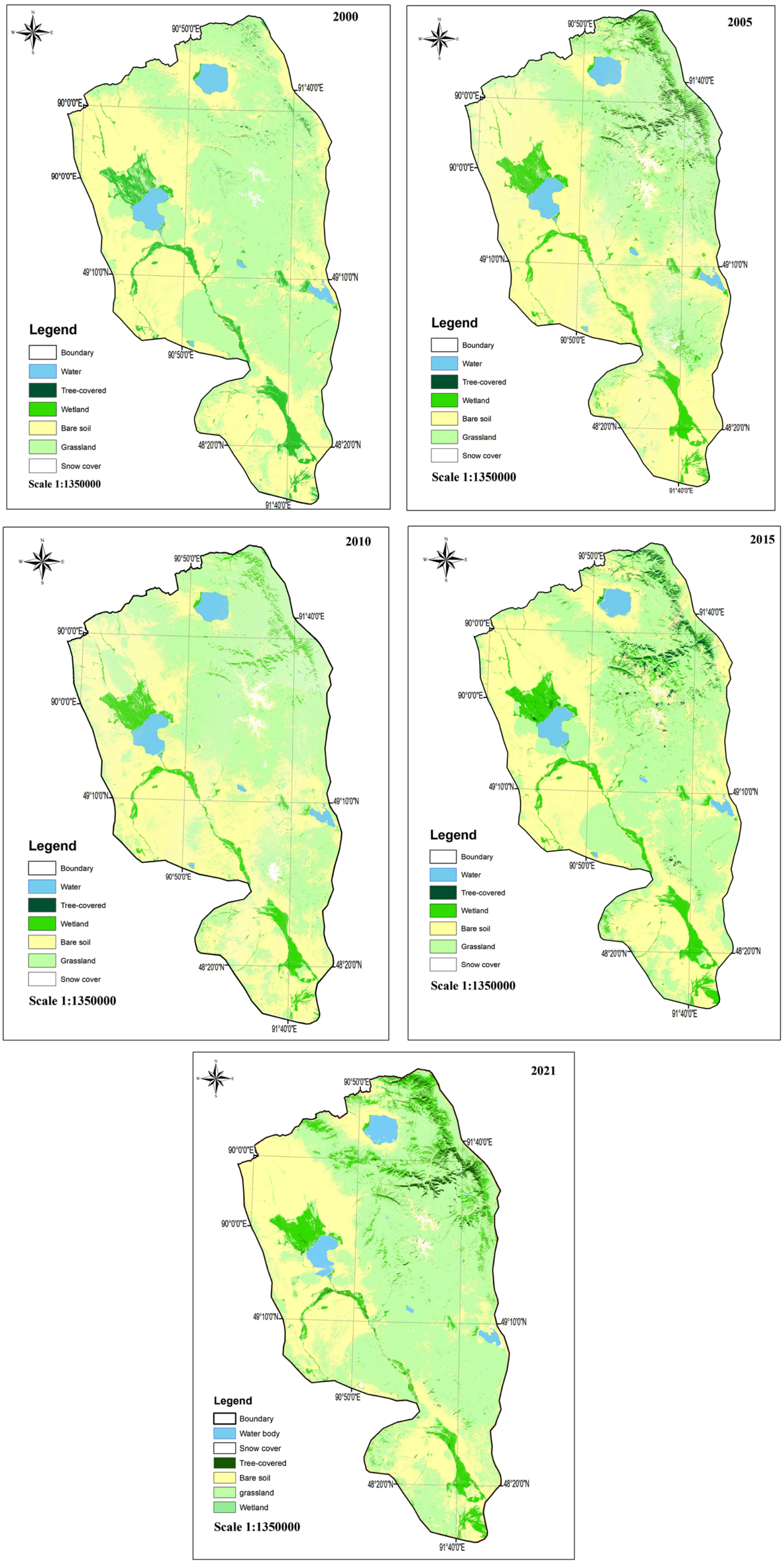

Fig. 10. The land cover changes of Kharhiraa-Turgen sub-province were taken at 5-year intervals. The changes were classified as bare soil, grassland, snow cover, tree covered, water, and wetland (2000-2021).

Table 4. Land area by type of land cover transition (sq.km)

Land classification	2000	2005	2010	2015	2021
	Change in the area (percent) %				
Bare soil	37.2	34.9	32	37.2	30.2
Grassland	44.2	43.75	45.8	43.3	46.1
Snow cover	1.95	2.25	2.32	2.4	2.7
Tree covered	1.8	2.7	2.07	1.9	2.3
Water	0.5	0.6	1.01	0.7	1.2
Wetland	14.35	15.8	16.8	14.5	17.5

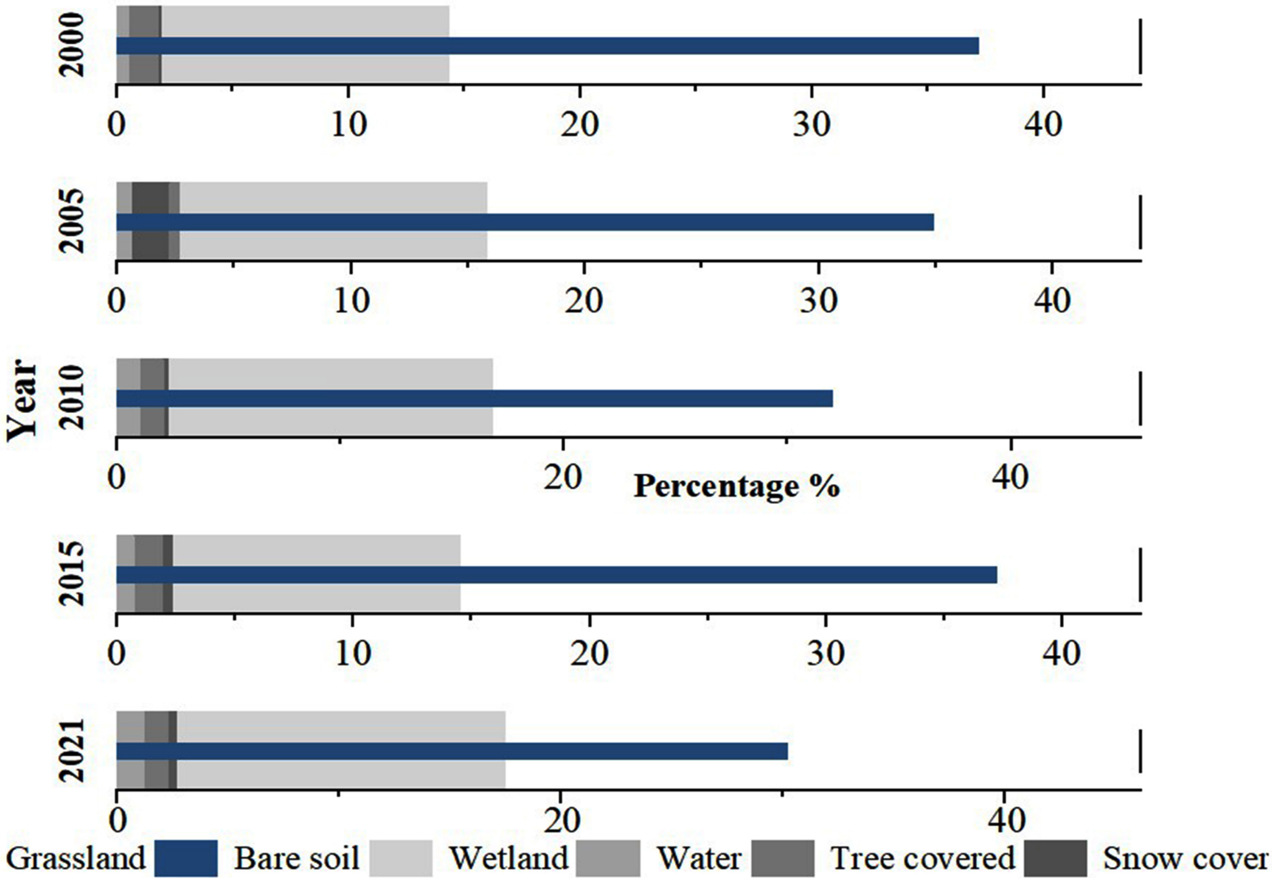

Fig. 11. Change in land classification area (Power.larc.nasa.gov, 2000-2021)

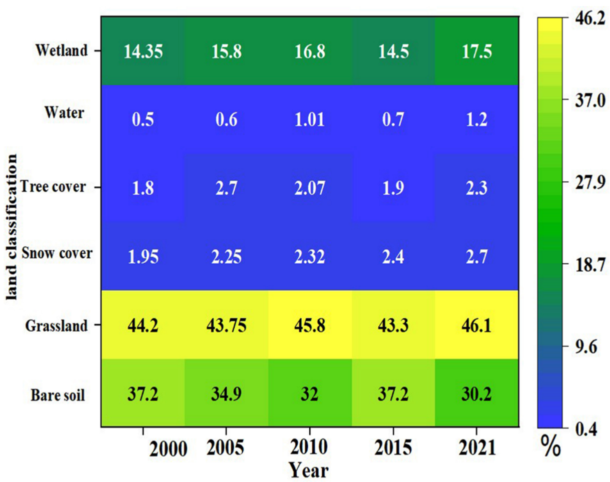

Fig. 12. Change in land classification over time (Power.larc.nasa.gov, 2000-2021)

The study was conducted at a spatial level and processed using Landsat satellite images with a resolution of 30x30 meters. Future research should incorporate high-resolution satellite images and field surveys to yield more comprehensive and comparative results.

DISCUSSION

The results of land cover research in the mountainous regions of our country are few. The Mongolian Desertification Atlas divides land cover into 18 categories and maps them for 2000 and 2010 (Tsogtbaatar and Khudulmur, 2013). Land cover changes in Mongolia were studied in

9 categories (Amarjargal et.al., 2017) comparing 2001 and 2015. The region we have chosen for study exhibits a unique climate, making it particularly susceptible to natural factors influencing land cover changes. During years of low rainfall, there is a noticeable decrease in the area of pastures, with a corresponding increase in bare land. However, in recent years, as both air temperature and precipitation have risen, the trend has reversed, with the area of bare land decreasing and the area of wetlands expanding. This shift indicates that the region's land cover is responding to changes in both temperature and precipitation patterns. In comparison, the Torngat Mountains in Canada, which are located at a similar latitude to our country, are also experiencing rising air temperatures and increased precipitation. These climatic changes are expected to continue, acting as significant drivers of environmental change in high-latitude mountain regions like the Torngat Mountains. Such areas are particularly sensitive to changes in glacial zones, permafrost, and the growing impact of tourism, which further exacerbates the environmental challenges they face (Davis et.al., 2020).

The LULCC evaluation starts from measuring the transformation of both the vegetation and non-vegetation cover at the same site, using aerial photographs, satellite images, or thematic cartography. Currently, remote sensing offers the possibility of describing some structural and functional aspects of ecological systems at different scales (Caballero et al., 2022; Cabello and Paruelo, 2009), given that spatial resolution offers new opportunities for.

We hope that the results of our study will serve as basic research material and help plan adaptation measures for livestock farming on a wider scale using high-resolution satellite data in the future.

CONCLUSION

Landsat satellite data were used to calculate land cover change in the Kharkhiraa-Turgen region (2000-2021). NASA climate data were calculated at 5-year intervals between 2000-2021. Land cover classification is categorized into six main classes to track area changes: 1. Grassland, 2. Bare soil, 3. Wetland, 4. Snow-cover, 5. Tree-covered, and 6. Water.

- In 2021, grassland covers the largest area (46.1%) within the land cover category, marking a 1.9% increase from 2015 (43.3%). Conversely, bare land decreased by 7% from 37.2% in 2000 to 30.2% in 2021, while wetlands expanded from 14.35% in 2000 to 17.5% in 2021.
- Also, the area covered by bare soil decreased from 37.2% in 2000 to 30.2% in 2021, while the area covered by wetlands increased from 14.3% in 2000 to 17.5% in 2021.
- Climate data reveals significant temperature fluctuations. In January 2000, the average air temperature was -20.5°C, compared to -18°C in January 2021, indicating a 2.5°C change. July temperatures rose from 16.2°C in 2000 to 17.4°C in 2021, marking a 1.19°C increase.
- Summer precipitation in 2021 (151 mm) surpassed that of 2015 (70.1 mm), 2010 (118.3 mm), 2005 (106.9 mm), and 2000 (96.5 mm), indicating a relative increase in precipitation in the region. No similar or drastic changes were observed in other months.
- The abundance of bare soil is linked to the mountain system's elevation, slope, and soil erosion patterns, influenced by the harsh climate and rocky terrain.
- Future research should incorporate high-resolution satellite images and detailed field surveys to provide comparative results.

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