Desertification and land degradation problems in soums in different natural regions of Mongolia

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ABSTRACT

Desertification and land degradation represent some of the most pressing and complex environmental challenges facing Mongolia today. According to desertification assessments, approximately 77.8% of the country's total territory shows signs of land degradation to varying degrees. The manifestation of desertification and degradation differs across natural zones and is influenced by multiple factors, including climate change, human activity, overgrazing, and water scarcity. For instance, in the forest steppe zone, major contributors include deforestation, intensive agriculture, and pasture overload; in the dry steppe zone, vegetation cover reduction and overgrazing are prevalent; while in the desert steppe, increasing wind erosion and sand movement, along with deteriorating vegetation, are common indicators.This study investigates the changes in land cover associated with drought, desertification, and land degradation between 1985 to 2022 in three representative soums across Mongolia's forest steppe, dry steppe, and desert steppe zones. The research methodology was developed in accordance with international standards and adapted to the specific environmental context of Mongolia. It integrates satellite remote sensing data, ground-based observations, and socio-economic indicators to conduct spatiotemporal analysis. Key indicators used in the assessment include drought intensity and frequency, wind and water erosion, vegetation cover change, and the population and livestock density. The results reveal significant spatial disparities in land degradation across the studied regions. The case studies of Orkhon soum (Darkhan-Uul province), Rashaant soum (Bulgan province), and Govi-Sumber aimag highlight strong interrelations between drought variability, land cover change, vegetation degradation, socio-economic factors, and overall land degradation. The findings show that 83.9% of Orkhon soum, 49.8%, of Rashaant soum, and 99.02% of Govi-Sumber aimag have been affected to varying degrees by fluctuating and desertification and land degradation to some extent. This research is significant in that it focuses on the soum level representing localized areas within distinct ecological zones offering valuable insights for targeted policy and land management interventions. Since implementation of mitigation strategies at the soum level falls under a single administrative authority, the potential for effective decision-making and action is considerably enhanced.

Keywords: Drought, Desertification, Land degradation, Vegetation cover

Монгол орны байгалийн ялгаатай бүсүүд дэх сумдын цөлжилт, газрын доройтлын асуудал

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ХУРААНГУЙ

Монгол улсад өнөөдөр хамгийн ноцтойгоор илэрч байгаа хүрээлэн буй орчны асуудлуудын нэг нь цөлжилт ба газрын доройтол юм. Цөлжилтийн үнэлгээгээр нийт нутаг дэвсгэрийн ойролцоогоор 77.8 хувьд ямар нэг хэмжээгээр газрын доройтол илэрч байна. Иймээс цөлжилт газрын доройтол нь байгалийн бүсүүдэд харилцан адилгүй бөгөөд уур амьсгалын өөрчлөлт болон хүний үйл ажиллагаа, мал аж ахуйн хэт ачаалал, усны хомсдол зэрэг олон хүчин зүйлээс шалтгаалж ялгаатай шинжээр илэрч байна. Жишээ нь хангайн бүсэд газар тариалан, ойн хомсдол, бэлчээрийн ачаалал их байхад хээрийн бүсэд ургамлан нөмрөг багсаж, бэлчээрийн даац хэтрэх, говийн бүсэд салхи шуурганы давтамж нэмэгдэж элсний нүүлт нэмэгдэх ургамлан нөмрөг муудах гэх мэт олон шинжээр илэрч байна. Энэхүү судалгаа нь Монгол орны байгалийн бүсүүд болох ойт хээр, хуурай хээр, цөлөрхөг хээрийн бүсийг төлөөлүүлэн 3 сумдын газар нутгийн 1985-2022 оны хоорондох ган, цөлжилт ба газрын доройтол газрын бүрхэвчийн өөрчлөлтийг судалж дүн шинжилгээ хийв. Судалгааны арга зүйг олон улсын стандартын дагуу Монгол орны онцлогт тохируулан боловсруулж, хиймэл дагуулын болон газрын мэдээлэл, нийгэм эдийн засгийн үзүүлэлт дээр үндэслэн цаг хугацаа, орон зайн дүн шинжилгээг хийсэн. Үнэлгээнд гангийн эрчим, давтамж, салхи усаар элэгдэх хөрсний эвдрэл, ургамлын бүрхэвчийн өөрчлөлт, хүн ам болон малын нягтшил зэрэг олон үзүүлэлтүүд багтсан. Судалгааны үр дүнд газрын доройтол бүс нутгийн хэмжээнд эрс ялгаатай байгааг харуулж байна. Дархан-Уул аймгийн Орхон сум, Булган аймгийн Рашаант сум, Говьсүмбэр аймгийн жишээ судалгаанууд нь гангийн хэлбэлзэл, газрын бүрхэвчийн өөрчлөлт болон ургамлан бүрхэвч, нийгэм эдийн засгийн үзүүлэлтүүд, газрын доройтол хоорондын хүчтэй уялдаа холбоог илэрхийлж байна. Нэгдсэн үр дүнгээр Орхон сумын нийт нутаг дэвсгэрийн 83.9%, Рашаант сумын 49.8%, Говьсүмбэр аймаг 99.02% тус бүр ямар нэг хэмжээгээр хэлбэлзэлтэй буюу цөлжилт газрын доройтол илэрсэн байна. Энэхүү судалгааны ажил нь Монгол орны хэмжээнд бус сумын түвшинд бүр тодруулбал ялгаатай бүсүүдэд нэг нэг сумын хэмжээнд авч судалснаараа ач холбогдолтой. Тус судалгааны үр дүнгээс хамаарч авч хэрэгжүүлэх арга хэмжээ нь сумын түвшинд учраас өөрөөр хэлбэл Монгол орны засаг захиргааны нэгжийн хувьд нэг удирдлагатай учир шийдвэр гаргах, хэрэгжүүлэх боломж өндөр юм.

Түлхүүр үг: Цөлжилт, Газрын доройтол, NDVI, Ган

1. INTRODUCTION

Desertification and land degradation have become critical challenges worldwide, posing threats to food security, human health, and socio-economic stability [1]. According to the United Nations Convention to Combat Desertification (UNCCD), desertification is defined as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" [2]. Mongolia, characterized by its vast territory spanning multiple ecological zones, is particularly vulnerable to desertification processes. Recent studies have shown that approximately 77.8% of the country's total land area is already affected to some degree by land degradation and desertification [3].

These processes are driven by both climatic factors such as prolonged droughts and precipitation variability and anthropogenic pressures, including overgrazing, unsustainable land use, and expansion of settlements. Given the ecological diversity of Mongolia, assessing the spatial extent and severity of desertification requires regionally adapted methodologies. This study aims to evaluate the patterns and driving factors of land degradation in selected soums across different natural zones using a newly developed assessment framework that integrates remote sensing and multi-criteria analysis. The results of this research are intended to contribute to evidence-based decision-making for sustainable land management in Mongolia.

2. METHODS AND DATA

This study employed a multi-criteria assessment approach to evaluate the state of desertification and land degradation in selected soums across different ecological zones in Mongolia. The methodology was based on the national framework established under the "National Action Program to Combat Desertification 2010–2020" approved by the Government of Mongolia. Building on this framework, the fourth nationwide desertification assessment was conducted with support from the Swiss Agency for Development and Cooperation (SDC) between 2011 and 2013.

To ensure spatially and temporally accurate assessment, remote sensing techniques were combined with updated theoretical definitions and international reference methodologies adapted to Mongolia's specific natural and socio-economic conditions.

In accordance with the newly developed methodology, over 50 criteria indicators were initially considered for evaluation. However, some indicators were deemed not yet suitable for assessment at the present time. Therefore,

based on the available data and the capacity of these indicators, a refined set was selected to evaluate the status of desertification and land degradation, as well as to produce related mapping. The following types of criteria indicators were used for this purpose:

- Drought Normalized Index Intensity (NDII);
- Frequency of drought events during the study period;
- Soil erosion by water (tons/ha/year);
- Soil erosion by wind (tons/ha/year)
- Vegetation cover change (based on NDVI dynamics);

Trend of vegetation degradation (NDVI slope analysis);

- Livestock density;
- Human population density.

Each indicator was categorized into five severity levels using critical threshold values, and a composite desertification index was calculated for each soum based on the average of these scores.

The critical values of the indicators are mentioned in the methodology section, and the indicators will be categorized according to the following table (**Table 1**). The calculations were performed using ArcGIS software.

Table 1. Integrated criteria for desertification assessment. Nd-No drought, Sd-Slight drought, Md-Moderate drought, D-Drought, Sd-Severe drought

Indicator	0 Non degraded	1 Slight	2 Moderate	3 Severe	4 Very severe
1. Basic climate condition (Mezentsev,s humidity coefficient)	>1	0.4-1	0.3-0.4	0.2-0.3	0.2>
2. Normalized index of drought intensity	Nd	Sd	Md	D	Sd
3. Normalized index of drought frequency (year)	0.2<	3-4	5-6	7-8	9-11
4. Soil degradation by water erosion (%)	<20	20-40	40-60	60-80	80<
5. Change in wind erosion (%)	<20	20-40	40-60	60-80	80<
6. Change vegetation cover (%)	<20	20-40	40-60	60-80	80<
7. Trend in vegetation cover change (Mann – Kendall test)	<0.1	0.2-0.89	0.9-1.89	1.89-2.89	2.9>
8. Change livestock number (%)	<100	101-200	201-300	301-400	401<
9. Change population number (%)	<100	101-200	201-300	301-400	401<

Since land cover undergoes long-term changes driven by both natural and anthropogenic factors, we based our study on high-resolution, temporally continuous satellite data that allows for the detection of long-term trends. Specifically, we utilized the GLC_FCS30D dataset, a fine-scale global land cover product with 30-meter

resolution and consistent temporal coverage from 1985 onward.

GLC_FCS30D is a satellite-derived product that classifies land cover into 35 detailed categories at 30-meter resolution, making it one of the most accurate and long-term datasets available for detecting land cover change globally. It was developed by the Aerospace Information Research Institute of the Chinese Academy of Sciences by integrating Landsat imagery from 1985 to 2022 [4].

In mapping the land cover of Mongolia, we adopted the nomenclature from the global classification scheme developed by the International Geosphere-Biosphere Programme (IGBP), adjusting it as necessary to suit the context of Mongolia. This approach was particularly suitable given the use of medium- to low-resolution satellite imagery commonly employed in regional-scale studies.

3. RESULTS

3.1 Desertification and Land Degradation in Orkhon Soum, Darkhan-Uul Province
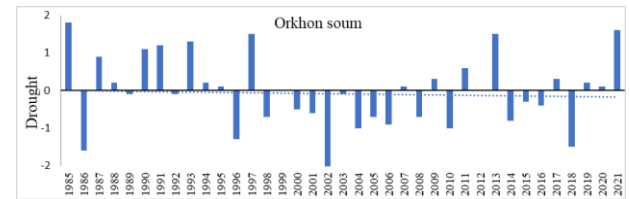
Orkhon soum of Darkhan-Uul province is located in the Mongolian forest-steppe zone. This study identified changes in land cover, drought conditions, and land degradation in the area between 1985 and 2022. As a result, Orkhon soum was classified into eight land cover categories (**Table 2**).

Table 2. Changes in Land Cover Classification of Orkhon Soum (1985–2022)

Land Cover Classification	1985 Proportion (%	2005 Proportion (%	2015 Proportion (%	2022 Proportion (%	Change (ha)	Change (%)
Forest	8.1	7.1	7.5	8.0	-40.9	0.1
Shrubland/Sparse Vegetation	15.3	16.1	12.1	9.2	-2749.4	6.1
Steppe/Grassland	64.8	67.3	66.1	69.5	+2105.8	-4.7
Meadow and River Valley	0.5	0.5	0.5	0.5	-14.0	0.0
Urban and Built-up Area	0.2	0.3	0.3	0.3	+36.5	-0.1
Cropland/Agricultural Land	10.1	8.0	12.6	11.6	+654.0	-1.5
Sand/Sandy Area	0.1	0.1	0.1	0.1	+1.8	0.0
Water Bodies	0.8	0.7	0.7	0.8	+7.0	0.0

According to **Table 2**, over the past 36 years, the areas covered by forest, shrubland, and meadow/river valleys have decreased, whereas the extent of sandy areas, water

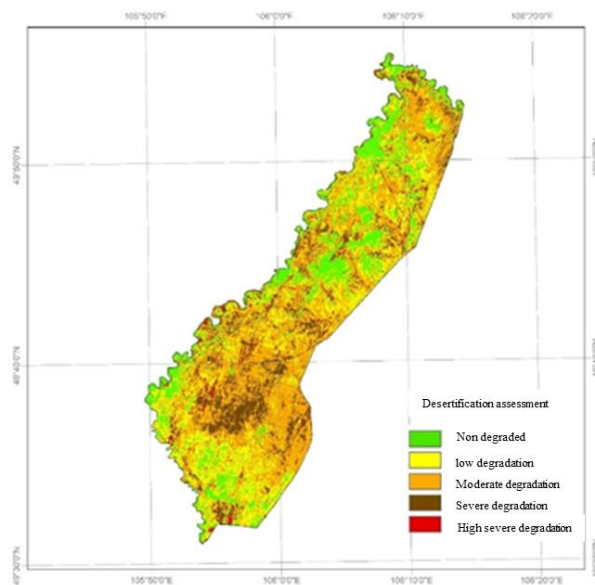bodies, croplands, steppe grasslands, and urban settlements has increased.

Figure 1. Changes in Drought Conditions in Orkhon Soum, Darkhan-Uul Province

Looking at the drought situation in the last 36 years, Orkhon soum has seen an increase in drought intensity since 1996. According to **Figure 1** Orkhon soum experienced some degree of drought in 1996, 1998, 2000-2002, 2004-2006, 2008, 2010, 2014-2016, and 2018. It was drought-free until 2022, meaning that the last few years have been relatively dry.

Therefore, when comparing the drought indicators with land cover changes, the most significant alterations in land cover occurred in 2005 and 2015, which corresponds to the period of high drought intensity from 2000 to 2016.

According to the changes in land cover and the assessment of land degradation, a total area of 20,615.7 hectares has shifted to lower categories of land cover and is considered degraded (**Figure 50**). In terms of land productivity, the normalized difference vegetation index (NDVI) was selected as the key indicator to evaluate changes. Based on this, 16.1% of the total area showed normal or improved conditions, 41.5% exhibited mild degradation, 14.4% showed moderate degradation, and 1.2% experienced severe degradation (**Figure 2**).

In Orkhon Soum, areas experiencing severe degradation include wetlands and riparian zones along the Kharaa River, areas surrounding agricultural lands, as well as grazing lands that are actively used.

Figure 2. Desertification and Land Degradation in Orkhon Soum, Darkhan-Uul Province

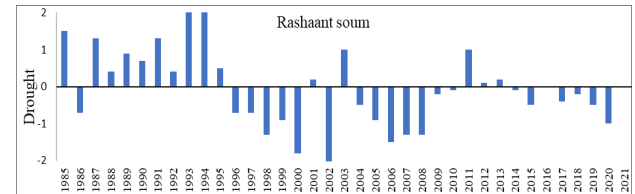## 3.2 Desertification and Land Degradation in Rashaant Soum, Bulgan Province

Place the table number and title on the same line at the top of the table. Numbering of the table (**Table 3**) with the description.

Table 3. Changes in Land Cover Classification in Rashaant Soum, Bulgan Province (1985–2022)

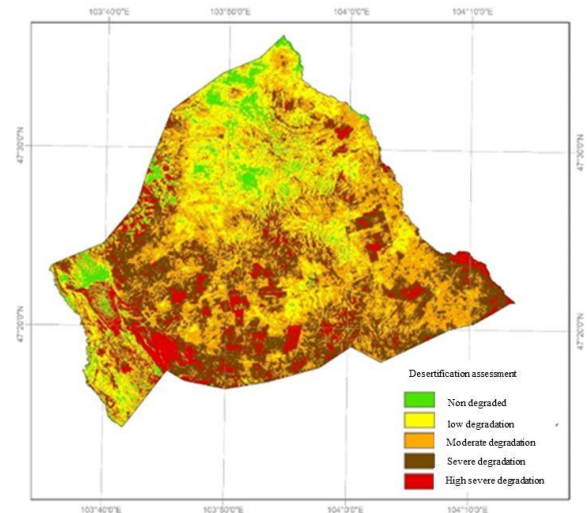| Over Classification	1985 Proportion (%)	2005 Proportion (%)	2015 Proportion (%)	2022 Proportion (%)	Change (ha)	Change (%)
Forest Steppe	1.0	0.9	0.8	0.7	-291.1	0.3
Grassland (Meadow Steppe)	20.1	16.1	16.5	18.2	-1848.3	1.9
Dry Steppe	72.6	78.1	78.0	77.3	4652.2	-4.8
Shrubland	0.0	0.0	0.0	0.0	-5.9	0.0
Wetlands and Marshes	0.0	0.2	0.2	0.2	124.3	-0.1
Urban Areas	0.0	0.0	0.0	0.0	0.0	0.0
Agricultural Land	5.1	3.5	3.1	2.2	-2919.4	3.0
Sand Area	1.1	1.2	1.3	1.4	289.1	-0.3
Water Bodies	0.0	0.0	0.0	0.0	4.0	0.0

Based on the changes in drought intensity over the past 36 years, the drought intensity in Rashaant Soum began to increase from 1996. According to the **Figure 3**, Rashaant Soum experienced some level of drought during the periods 1996-2002, 2004-2008, and 2017-2020. During the years with higher drought intensity, the areas of land cover classification such as meadow steppe and wetlands decreased significantly, while dry steppe areas became more dominant.

Figure 3. Changes in Drought Intensity During the Warm Seasons in Rashaant Soum (1985–2021)

Based on the changes in land cover, a total area of 6,629.9 hectares has shifted to lower categories of land cover and is considered degraded. In terms of land productivity, the normalized difference vegetation index (NDVI) was selected as the key indicator to evaluate changes. According to this assessment, 50.2% of the total area showed normal or improved conditions, 17.6% exhibited mild degradation, 14.2% showed moderate degradation, and 4.3% experienced severe degradation (**Figure 4**).

Figure 4. Desertification and Land Degradation in Rashaant Soum, Bulgan Province

According to the degradation map, the areas experiencing severe degradation include lands that were previously used for agriculture, dry steppe regions, areas surrounding sandy ecosystems, as well as wetlands and marshlands.
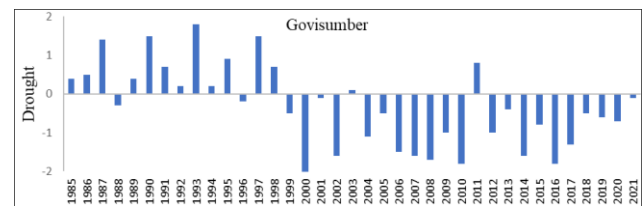
3.3. Desertification and Land Degradation in Govisümber Province

According to the changes in land cover in the province from 1985 to 2022, the area of dry steppe has decreased by 16,997.6 hectares, while the area of semi-desert steppe has increased by 23,488.1 hectares. Additionally, the area of bare land has increased by 3.9 hectares over the 36-year period, which has been classified as degraded or shifted to a lower land cover category. Furthermore, the area of urban settlements has increased by 138.6 hectares, and the area of wetlands has also grown in recent years. A trend has been observed where dry steppe is gradually transitioning to semi-desert steppe, and semi-desert steppe is slowly shifting to desert steppe (**Figure 4, Table 4**). This indicates that the region's ecosystems and landscape types are undergoing degradation, contributing to desertification and land degradation.

Table 4. Changes in Land Cover Classification in Govisümber Province (1985–2022)

Land Cover Classification	1985 Proportion (%)	2005 Proportion (%)	2015 Proportion (%)	2022 Proportion	Change (ha)	Change, (%)
Forest	0.011	0.0029	0.003	0.004	-34.1	0.0
Dry Steppe	69.1	68.8	65.6	66.0	-16997.6	3.1
Semi-desert Steppe	28.7	30.0	33.4	33.0	23488.1	-4.2
Desert Steppe	1.2	0.8	0.7	0.644	-3255.1	0.6
Meadow and Wetlands	0.032	0.1	0.2	0.141	603.1	-0.1
Urban Areas	0.1	0.1	0.1	0.117	138.6	0.0
Agricultural Land	0.8	0.1	0.031	0.045	-4049.4	0.7
Bare Land	0.0003	0.0001	0.0001	0.00019	3.9	0.0
Lake	0.03	0.0299	0.027	0.051	98.0	0.0

Looking at the drought conditions over the past 36 years, the intensity of drought in Govisümber Province increased significantly from 1999. According to the 68th chart, while the growing season was favorable from 1985 to 1998, the drought intensity was high from 1999 to 2017, and it fluctuated with mild drought conditions until 2021. The drought conditions between 1999 and 2017 may have contributed to the increase in semi-desert steppe areas.

Figure 5. Dynamic Changes in Drought Intensity in Govisümber Province from 1985 to 2021
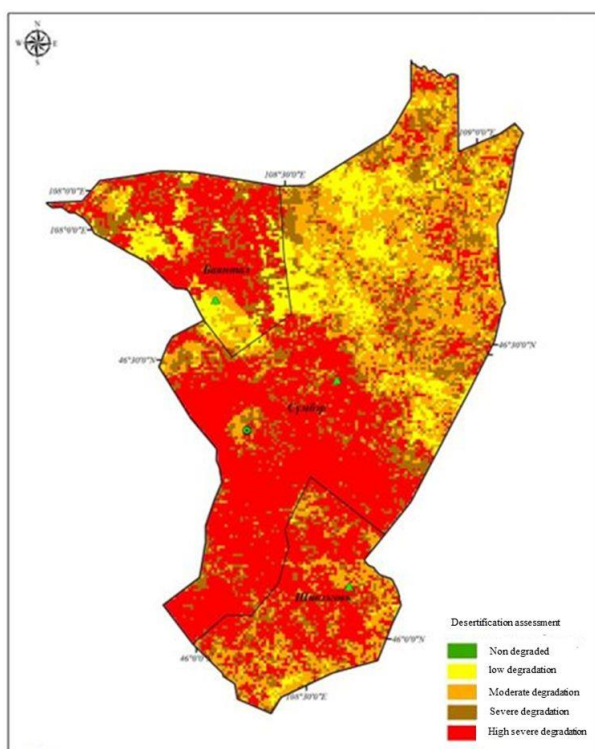
We have validated the land degradation and desertification maps through changes in the area of degraded vegetation cover, sandy land, the distribution of the normalized vegetation index, soil organic matter, and the degradation map. According to the research findings, when classifying the total area based on the level of desertification, 44.1% is categorized as extremely severe, 18.7% as severe, 25% as moderate, and 11.4% as mild, with 0.8% showing no signs of land degradation (**Figure 5, Table 4**).

Table 5. Status of Land Degradation by hectares /Province

№	Indicators	No Degradation	Mild	Moderate	Severe	Extremely Se
1	Area (ha)	44.3	631.5	1385.0	1036.0	2443.2
2	Proportion (%)	0.08	11.4	25.0	18.7	44.1

In this province, the area classified as "No Degradation" accounts for 0.08% of the total land area. This region shows stable fluctuations in NDVI values, which are highly likely to change depending on precipitation and seasonal conditions (**Table 5**).

Figure 6. Desertification and Land Degradation in Govisümber Province

Land degradation is strongly observed in 99.02% of the total area, with regions categorized as moderate or higher degradation levels. The dry steppe and desertified steppe zones in the Bayanthal, Sumber, and Shiveegov' sum areas are included in this category (**Figure 6**).

4. DISCUSSION

This study comprehensively examined desertification and land degradation trends across three ecologically distinct Mongolian regions Orkhon soum (forest-steppe zone), Rashaant soum (steppe zone), and Govisümber province (semi-desert and desert-steppe zones) over the period 1985 to 2022. The results clearly indicate an intensification of land degradation processes since the early 2000s, closely associated with increased drought frequency and severity.

Desertification and land degradation represent interrelated natural disasters confronting Mongolia, exerting significant impacts across diverse ecological zones. Studies have shown that approximately 77.8% of Mongolia's total land area is affected by varying degrees of desertification and land degradation [5]. This highlights the urgent need to assess desertification and land degradation risks at the provincial and soum levels, particularly within the dry and desert steppe regions. For example, data from 2000 to 2019 show that in Rashaant soum of Bulgan Province, forested land decreased by

498.1 ha, steppe area by 6085.2 ha, and cropland by 3025.9 ha, while arid shrubland increased by 747.2 ha and dry steppe by 5096.4 ha. Overall, land degradation was observed across 36,394.4 hectares of the soum's territory [6].

Extensive studies on desertification in Mongolia have been conducted by researchers such as L. Natsagdorj, J. Dulamsuren, Ts. Tsatsral [7], D. Dash, and N. Mandakh [8]. Additionally, between 2000 and 2018, an evaluation of land degradation in Bulgan Province indicated that 72.78% of the total area experienced some level of degradation [8]. Similarly, in Rashaant soum, increased drought intensity since 1996 coincides with marked declines in meadow steppe and wetlands, accompanied by expansion of dry steppe and sandy areas. Although half of the area remains in normal or improved condition, the 36% combined mild to severe degradation area signals emerging ecological stress in this region. The results suggest that dry steppe ecosystems, while generally more drought-tolerant, are not immune to degradation, especially where compounded by land use pressures such as agricultural expansion and grazing. In Govisümber province, a clear transition from dry steppe to semi-desert steppe and desert steppe landscapes was documented, reflecting progressive desertification under sustained drought conditions from 1999 to 2017. The high proportion of extremely severe degradation (44.1%) observed across this province aligns with this ecological shift and points to advanced desertification stages. This progression raises concerns about the resilience of semi-arid ecosystems and highlights the urgency for targeted land management interventions.

Across all study sites, the integration of remote sensing (NDVI and land cover classification) with drought records and socio-economic data enabled a nuanced understanding of how climatic variability and human activities synergistically drive desertification. Importantly, the study's scale analysing data at the soum level addresses a critical gap in desertification research in Mongolia, offering localized insights essential for effective policy-making and resource management.

Given the evidence of widespread land degradation affecting nearly 78% of Mongolia's territory, tailored mitigation strategies at the administrative unit level are imperative. These should incorporate sustainable grazing practices, reforestation, soil conservation, and water resource management adapted to the specific vulnerabilities of each ecological zone. This localized approach aligns well with Mongolia's governance structure, facilitating the design and implementation of adaptive land use policies that can mitigate desertification impacts and promote ecosystem resilience.

However, there is still a lack of localized studies at the soum level in Mongolia, despite their importance for decision-making and policy implementation. Conducting assessments at the lowest administrative units is crucial for developing effective strategies to combat desertification and for promoting sustainable land management at the local level.

5. CONCLUSION

Between 1985 and 2022, significant land cover changes and increasing drought intensity contributed to desertification and land degradation in the study areas.

In Orkhon Soum forest, shrubland, and meadow areas have decreased, while sandy lands, agricultural lands, steppe grasslands, and urban areas have expanded, 20,615.7 ha of land transitioned to lower land cover categories, with 83.9% of the area fluctuating and degraded and 1.2% severely degraded.

In Rashaant Soum intensified drought has led to reductions in meadow steppe and wetland areas, with dry steppe becoming more dominant., 6,629.9 ha were degraded, with 50.2% of land showing stable or improved conditions, with 49.8% of the area fluctuating and degraded and 4.3% was severely degraded.

In Govisümber Province dry steppe areas have decreased substantially while semi-desert steppe areas expanded, 16,997.6 ha of dry steppe was lost, while 23,488.1 ha of semi-desert steppe expanded. Degradation was found in 99.02% of the total land area, with 44.1% categorized as severely degraded.

These notable shifts in land cover are closely linked to increased aridity, recurrent drought events, and growing anthropogenic pressures, particularly overgrazing. Excessive livestock density and unsustainable grazing practices have accelerated vegetation loss, soil degradation, and desertification processes. These findings underscore the urgent need for targeted, location-specific land management and restoration strategies to mitigate the ongoing degradation and to enhance the resilience of Mongolia's vulnerable ecosystems.

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