Variations in the peak growing season NDVI in the Mongolian permafrost zones

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Abstract. The main purpose of this study is to clarify the long-term changes in vegetation and the relationship between NDVI and climate parameters in three different areas of the permafrost zones of Mongolia. We selected a total of 135 study sites in Munkhkhairkhan, Ulaanbaatar, and Bayanzurkh in the permafrost zones and conducted field measurements of CO_2 in 2022. In this study a total of 19 satellite images were used, with an interval of two years between 2010 and 2022. Landsat-5 TM, Landsat-8, 9 (OLI/TIRS), and Sentinel-2A MSI satellite data were acquired with the cloud cover range of 0-10% during the peak growing season in June, July, and August. There were significant positive correlations between total precipitation and NDVI in the summer season for Munkhkhairkhan ($R = 0.48$ in total area, $R = 0.43$ in peat sites), Ulaanbaatar ($R = 0.30$ in total area, $R = 0.26$ in peat sites), and Bayanzurkh ($R = 0.50$ in total area, $R = 0.39$ in peat sites), compared to the spring season. Despite the estimated negativity for Munkhkhairkhan, the correlation between mean annual air and NDVI was positive for Ulaanbaatar and Bayanzurkh. In addition, the NDVI fluctuation patterns, particularly for the total area and the peat sites, corresponded to precipitation in the summer season. As shown in the results, there were significant positive correlations between NDVI and total precipitation for all study areas. The impact on climate of the effects of temperature and precipitation at the same time and in the same time also varied strongly between biomes and months.

Keywords: NDVI, vegetation dynamics, peat, permafrost, climate parameters

1 Introduction

The permafrost region accounts for approximately 22% of the exposed land area in the Northern Hemisphere, along with a continuous, discontinuous, sporadic and isolated distribution [1]. In Mongolia, approximately 63% of the territory was sublaid by permafrost in 1971, while it is now approximately 29.3%, according to the 2016

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result, primarily distributed in the Altai, Khangai, Khuvsgul and Khentii mountains [2]. It has decreased by 50% in the last 45 years.

Organic-rich permafrost peat stores approximately 277 Pg of carbon [3], equivalent to 14% of the global carbon storage in the soil [4]. In recent years, climate warming has led to widespread increases in soil temperature and permafrost thaw in peatlands [5], easing environmental restrictions on decomposition. This can substantially release carbon dioxide (CO_2) and methane (CH_4) into the atmosphere [6], resulting in extensive and positive feedback to climate change. In addition to altering the carbon dynamics of the peatland, permafrost thaw also leads to landscape-scale changes, directly and indirectly influencing the composition of the plant community and functional traits [7]. Peatlands occur in tropical and subtropical regions but are also common in permafrost at high latitudes. Peatlands are found mainly in areas with permafrost regions in Mongolia. Peatlands occur in tropical and subtropical regions but are also common in permafrost at high latitudes. Peatlands are found mainly in areas with permafrost regions in Mongolia. Peatlands cover 27,000 km^2 or more than 1.7% of the country. In the last 30 years, it has decreased by 60% to 80%, depending on the region [8].

Vegetation is essential in the regulation of climate by exchanging energy, water vapour, and momentum between the land surface and the atmosphere [9]. Vegetation dynamics is often measured using satellite data, where metrics such as the Normalized Difference Vegetation Index (NDVI) can be used as proxies for chlorophyll activity. Therefore, they can indicate plant productivity [10]. Variations in vegetation activity have been linked to climate change [11]. Investigating the interannual variations of NDVI and their relationship with climate is critical to understanding the mechanisms of climate-derived variations in vegetation activity, carbon and hydrological cycles, and the dynamics of vegetation structures [12].

Mongolia lies in a transition zone from the Gobi Desert in central Asia in the southwest to the Siberian Taiga Forest in the north. Most of Mongolian territory is characterized by arid and semi-arid climates, and more than 70% of Mongolia is covered by high-quality steppe grasslands with high sensitivity to global climate change [13]. As in other semi-arid regions, precipitation is the primary climatic control of vegetation activity on a national scale [14].

This transition zone would be intriguing to shed more light on the vegetation dynamics and NDVI of peat and nonpeat sites in the permafrost zones. The main purpose of this study is to clarify the long-term changes in vegetation and the relationship between NDVI and climate parameters in three different areas of the permafrost zones of Mongolia.

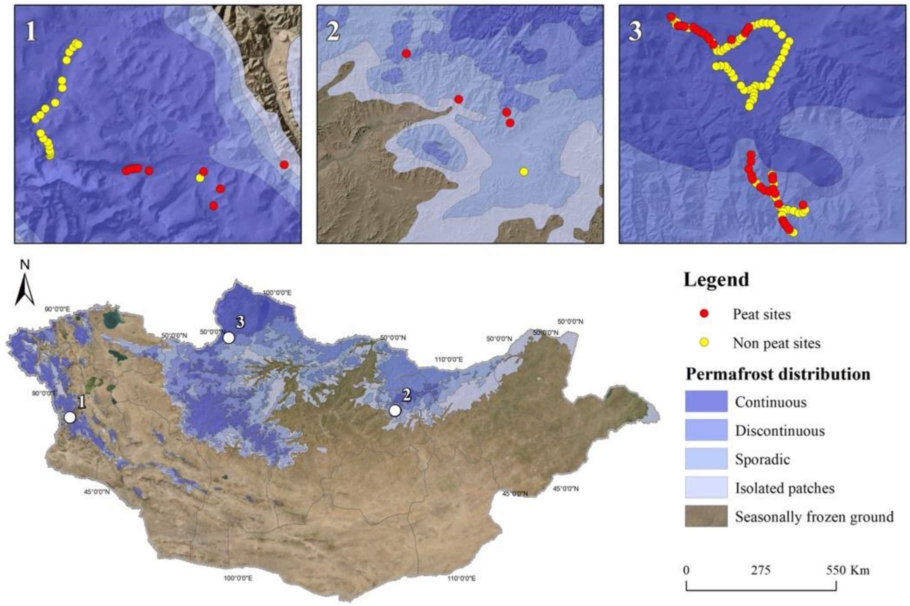

Fig. 1. Location of the study areas in the permafrost zones: 1) Munkhkhairkhan; 2) Ulaanbaatar area; 3) Bayanzurkh.

2 Study Area

We selected a total of 135 study sites in three different areas in Mongolia's permafrost zones (see Fig. 1) where we conducted an expedition and took field measurements of CO2 in 2022. Therefore, we used measurement data, especially the locations of peat sites. The data were identified by soil samples at the sites; thus, it clearly shows the peat and nonpeat sites.

Munkhkhairkhan mountain is located in Khovd province in the western part of Mongolia. The average air temperature in the coldest month, January, fluctuates from -30°C to -34°C, and the average air temperature in the warmest month, July, ranges from 15 ° C to 10° C. Total annual precipitation ranges between 300 and 400 mm [15]. The Munkhkhairkhan's highest peak, Noyon, rests at an elevation of 4362 metres in the Mongol-Altai range. The features of the mountain are glaciers and snowfields in the continuous and sporadic permafrost zones. Furthermore, 16 phytogeographical regions of Mongolia were determined by [16]. We describe the three different study areas in the context of the 16 regions. Munkhkhairkhan Mountain belongs to the Mongolian Altai Mountain Steppe region and is located in the high mountain belt. The belt is characterized by unique vegetation with short herbaceous plants and thickets of shrubs, lichens, and mosses. There are dominated by *Carex redowskiana, Kobresia bellardii, Festuca lenensis, Poa attenuata,* and *Festuca kryloviana* [17-20].

The Ulaanbaatar area is located in the northeast of Mongolia with sporadic to isolated permafrost zones. In July, the average temperature reaches 16.9°C; in January it drops to -22.3°C. The total annual precipitation ranges between 200 mm and 300 mm [15]. The Ulaanbaatar area belongs to the Khentii Mountain Taiga region in the phytogeographical regions of Mongolia. A total of 1276 species of vascular plants are spread in this region, the main representatives being the eastern Siberian taiga, the Daurian forest, and the high mountain flora, which are dominated by *Carex acuta, Carex williamsii, Poa kenteica, Equisetum arvense, Larix sibirica, Betula platyphylla* and *Pinus sylvestrisare* [17-19].

The third study area in Bayanzurkh Soum is located in Khuvsgul province in the continuous and discontinuous permafrost zones. There are peatlands concentrated in the surrounding area of Bayanzurkh soum. The average temperature in January fluctuates between -30°C and -35°C, and the average temperature in July ranges from 15°C to 10°C. The total annual precipitation varies between 250 and 300 mm [15]. Bayanzurkh soum belongs to the Khuvsgul mountain taiga region in the phytogeographical regions of Mongolia. There are a total of 1081 species of vascular plants spread throughout this region. The main representatives of this area, the Sayan and Altai-Sayan Mountain flora, are dominated by *Festuca hubsugulica, Pinus sibirica, Larix sibirica, Equisetum variegatum*, and *Trollius sajanensis* [17-19].

3 Methods and Materials

3.1 Image analysis and NDVI calculation

In this study, 19 satellite images were used, with an interval of two years between 2010 and 2022. These satellite data were acquired with a cloud cover range of 0-10% during the peak growing season in June, July, and August. Landsat-5 TM, Landsat-8, 9 (OLI/TIRS), and Sentinel-2A MSI satellite data were obtained from the US Geological Survey database and the European Space Agency's Copernicus Data Hub. All datasets are registered in UTM coordinate system zones 46N, 47N, and 48N, and the elevation was referenced from the WGS 1984 datum.

Then we calculated NDVI and developed thematic maps of changes in vegetation cover in three different study areas, using ArcGIS 10.8 and Snap software to clarify long-term changes in vegetation and the relationship between NDVI and climate parameters. For mapping analyses, NDVI values were calculated by uploading Sentinel images to the NDVI Processer tool in the Snap program. Also, Landsat satellite images were analyzed using the Map Algebra tool in ArcGIS 10.8 software. All images analyzed from 2010-2022 were combined using the Image Analysis tool. In the end, the NDVI pixel values of the study sites were extracted from the total area and processed using the spatial analyst tool. The fundamental values of NDVI were calculated using 'Equation (1)'. NDVI always generates a value between -1 and +1 [21]. We classified NDVI pixel values as water, snow body (<0), bare soil (0-0.03), sparse vegetation (0.03-0.3), moderate vegetation (0.3-0.5), and dense vegetation (0.5<).

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

NIR, near infrared, RED, visible red.

3.2 ERA5 reanalysis data

This study used data sets from the atmospheric reanalysis of the fifth generation European Centre for Medium-Range Weather Forecasts (ECMWF) (ERA5). ERA5 provides hourly data with 0.25° spatial resolution of 0.25 ° from 1979 to near-real-time and is easy to access from the Climate Data Store [22]. Air temperature and precipitation data between January 2010 and December 2022 were obtained from ERA5. We calculate the mean annual air temperature and total precipitations; temperature and precipitation in spring (March, April, and May); the temperature and precipitation in summer (June, July, and August) respectively. Fig. 2 shows the long-term climate parameters in three different study areas from 2010 to 2022.

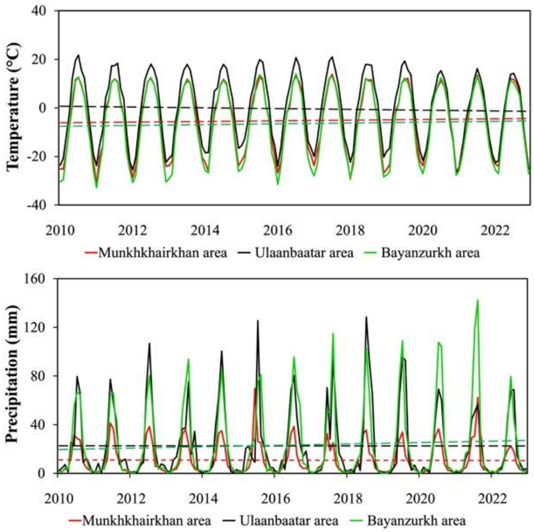

Fig. 2. Long-term trends in temperature and total precipitation in the Munkhkhairkhan, Ulaanbaatar, and Bayanzurkh areas.

3.3 Statistical analysis

Last year, we conducted an expedition and took CO2 field measurements in these study areas, which clarified whether these sites contained peat or non-peat. We extracted NDVI pixel values from each study site and then identified the difference between the values of the sites containing peat and the total study area. To test whether there are links between variability in climate parameters and the peak growing season NDVI, we performed statistical analyses using multiple linear regression (MLR) and correlation.

4 Results and Discussion

4.1 NDVI in study areas from 2010 to 2022

In this study, we have calculated the NDVI of 135 study sites in three different study areas, such as Munkhkhairkhan, Ulaanbaatar, and Bayanzurkh in the permafrost zones, from continuous to isolated. Figures 3, 4, and 5 show the NDVI maps from 2010 to 2022 in each study area.

For the Munkhkhairkhan mountain area, the maximum value of the peak growing season NDVI was 0.78 in 2018, and the minimum value was 0.0 in 2010 (see Fig. 3). Peat was found in nine sites of a total of 30 sites in this area. The mean pixel value of the NDVI in total sites was 0.21 to 0.51 between 2010 and 2022. The mean value of NDVI at the peat sites is between 0.19 and 0.49. According to the NDVI pixel classification, Munkhkhairkhan belongs to “bare soil to moderate vegetation”.

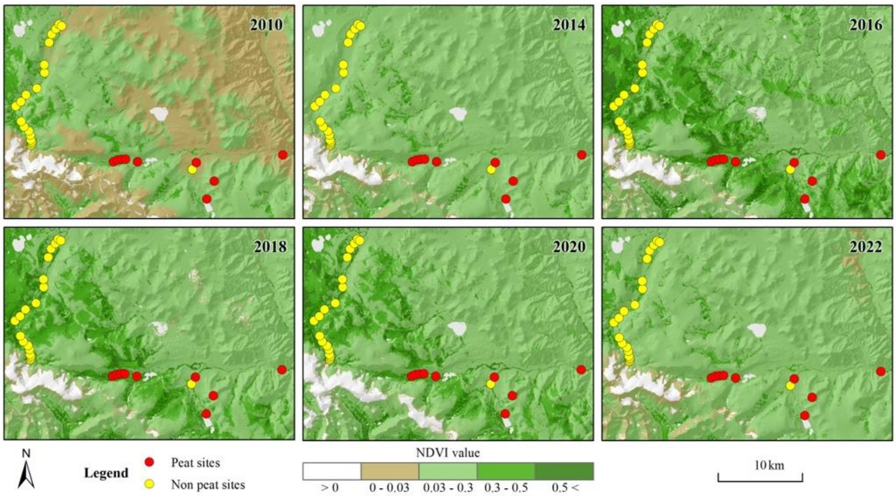

Fig. 3. Variations in the NDVI peak growth season for the Munkhkhairkhan mountain area.

For the Ulaanbaatar area, the maximum value of NDVI was 0.66 in 2016, and the minimum value was 0.25 in 2020 (see Fig. 4). Peat was found in four out of five sites. The mean pixel value of NDVI at all sites ranges from 0.35 to 0.56 between 2010 and 2022. The mean value of this index at the peat sites ranges between 0.37 and 0.60. As a result, the Ulaanbaatar area belongs to “sparse to dense vegetation” in the NDVI pixel value classification.

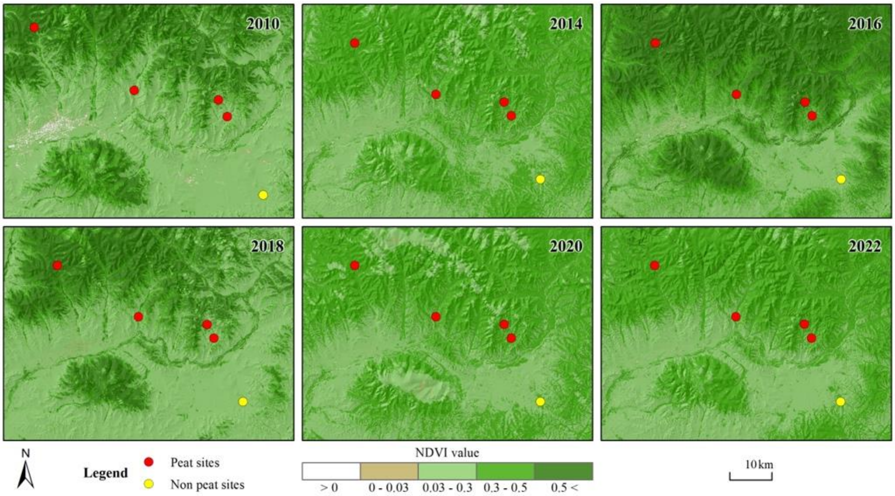

Fig. 4. Variations in the peak growing season NDVI for the Ulaanbaatar area.

As for Figure 5, the maximum value of NDVI in the Bayanzurkh area was 0.89 in 2020, and the minimum value was 0.04 in 2018. Peat was found in 34 sites out of a total of 100 sites. The mean pixel value of the total sites ranges from 0.34 to 0.64 between 2010 and 2022. The mean value of the peat sites is between 0.35 and 0.74. The area belongs to 'moderate to dense vegetation' in the NDVI pixel value classification.

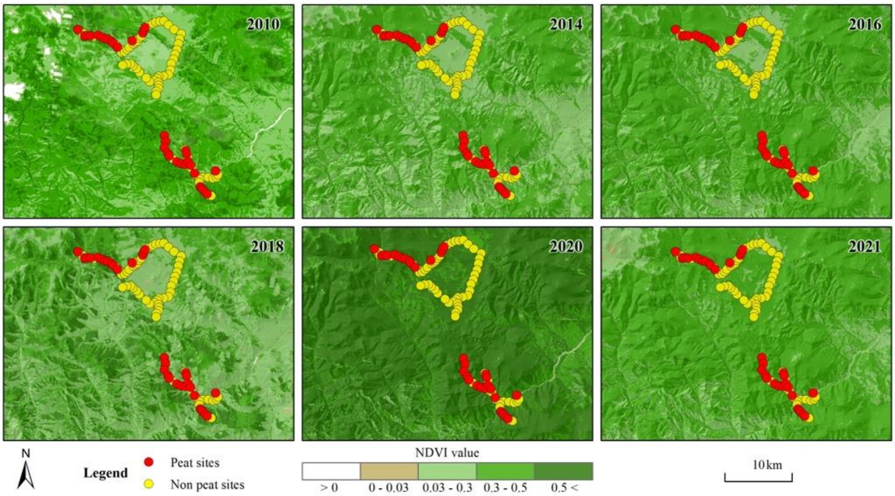

Fig. 5. Variations in the NDVI peak growth season for the Bayanzurkh area.

4.2 NDVI and Climate Variability

Multiple linear regression (MLR) analysis.
Figure 6 shows the MLR relation between NDVI and temperature; NDVI and precipitation, respectively. For Munkkhairkhan and Ulaanbaatar areas, the NDVI of the peak growing season was positively correlated with temperature in the spring season (R2 = 0.23,0.20 in total area, R2 = 0.32,0.18 at peat sites), but was significant for Bayanzurkh during the summer season (R2 = 0.21 in total area, R2 = 0.17 at peat sites). This study agrees with previous studies, suggesting that temperature is a decisive climatic factor for vegetation growth in high northern latitudes and an increase in temperature could improve vegetation growth by lengthening the growing period and enhancing photosynthesis [23]. On the other hand, the peak NDVI and precipitation were positively correlated in the summer season for Munkhkhairkhan (R2 = 0.23 in total area, R2 = 0.19 at peat sites) and Bayanzurkh (R2 = 0.25 in total area, R2 = 0.15 at peat sites), but there was no correlation between NDVI and precipitation for the Ulaanbaatar area (R2 = 0.09 in total area, R2 = 0.07 at peat sites). The results suggest that there is a relation between NDVI and precipitation in all study areas.

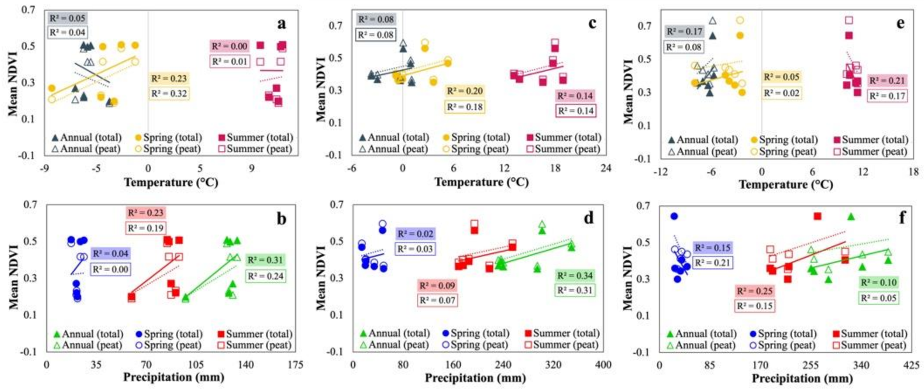

Fig. 6. Analysis of the relationship between NDVI and climate variability in Munkhkhairkhan (a; b), Ulaanbaatar (c; d), and Bayanzurkh (e; f)

Correlation analysis.
There were significant positive correlations between total precipitation and mean NDVI in the summer season for Munkhkhairkhan (R = 0.48 in total area, R = 0.43 in peat sites), Ulaanbaatar (R = 0.30 in total area, R = 0.26 in peat sites), and Bayanzurkh (R = 0.50 in total area, R = 0.39 in peat sites) than in the spring season. In contrast to the MLR analysis, all study areas had significant positive correlations between NDVI and total precipitation (see Table 2). Although negative correlations between NDVI and temperature were analyzed in the summer season, there were significant correlations between them in the spring season for Munkhkhairkhan (R = 0.48 in total area, R = 0.57 in peat sites), Ulaanbaatar (R = 0.44 in total area, R = 0.42 in peat sites), and Bayanzurkh (R = 0.23 in total area, R = 0.13 in peat sites). The mean annual air

temperature and the NDVI correlation were positive for Ulaanbaatar and Bayanzurkh, but negative for Munkhkhairkan (see Table 1). In addition, the NDVI fluctuation patterns, particularly for the total area and the peat sites, closely correlated with that of precipitation in the summer season.

Table 1. Correlations between NDVI of the peak growing season and Temperature

Study Area	Temperature					
	Annual		Spring		Summer	
	Total area	Peat Sites	Total area	Peat Sites	Total area	Peat Sites
Munkhkhairkhan	-0.23	-0.21	0.48	0.57	0.00	0.07
Ulaanbaatar	0.29	0.28	0.44	0.42	0.37	0.37
Bayanzurkh	0.41	0.28	0.23	0.13	-0.46	-0.41

Table 2. Correlations between peak growing season NDVI and Precipitation

Study Area	Precipitation					
	Annual		Spring		Summer	
	Total area	Peat Sites	Total area	Peat Sites	Total area	Peat Sites
Munkhkhairkhan	0.55	0.49	0.20	0.02	0.48	0.43
Ulaanbaatar	0.58	0.56	0.16	0.17	0.30	0.26
Bayanzurkh	0.32	0.21	-0.39	-0.45	0.50	0.39

5 Conclusions

This study clarified the correlation between the peak NDVI of the growing season and climate variability in three different study areas with permafrost zones between 2010 and 2022. This study provides baseline information on NDVI in these areas. As shown in the results, there were significant positive correlations between NDVI and total precipitation for all study areas. In 2016 and 2020, total annual precipitation had high values and was attributed to the peak NDVI growing season for Munkhkhairkhan, Ulaanbaatar and Bayanzurkh, and the classification results of the peak NDVI growing season were mostly moderate and dense. Based on the variations in the NDVI peak growing season, vegetation in all study areas belongs to the classification of 'sparse to dense vegetation' depending on total precipitation in the summer season. According to the results of the correlation and MLR analysis, the average temperature in spring and the total precipitation in summer affected the growth, evolution and productivity of vegetation and NDVI in study areas, such as Ulaanbaatar and Munkhkhairkhan. In contrast, temperature and total precipitation in the summer season were positively correlated with NDVI for Bayanzurkh. Variations in the NDVI during the peak growing season can be attributed mainly to trends in the monthly NDVI [24], and the monthly scale analysis can detect more detailed NDVI change signals and their contribution to the trends of the NDVI during the growing season. Furthermore, extending the time period and conducting an estimate statistical analysis can produce more detailed results.

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