Characterization of Soil Properties in Mongolia's Permafrost Regions

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Abstract

The distribution of permafrost in Mongolia is sporadic and discontinuous, and it varies depending on factors such as location, landscape, and temperature. Furthermore, the soil cover in these regions exhibits diverse patterns and characteristics. The objective of this study was to investigate and analyze these variations and differences by examining the soil cover within the permafrost regions.

To accomplish this, we divided the permafrost regions into four distinct areas: Mongolian-Altai, Gobi-Altai, Khangai, and Khuvsgul. We proceeded by collecting soil samples from 164 fixed depths (0-5 cm, 5-15 cm, 15-30 cm, and 30-60 cm) in 41 soil profiles surrounding permafrost monitoring boreholes.

This study provides important insights into the characteristics of soil cover in the permafrost regions of Mongolia. The findings reveal that the soil cover in Mongolia is diverse and influenced by various factors such as location, climate, and temperature. The dominant soils in the studied regions are Kastanozems and Chernozems, with Aridic Kastanozems being more prevalent in Mongolian-Altai and Gobi-Altai. The study also highlights differences in soil pH, carbonate content, organic matter, available phosphorus, and potassium among the regions. Soil texture is distributed evenly across the regions, while gravel content varies depending on the region. Overall, the study contributes to our understanding of soil characteristics in Mongolia's permafrost regions.

Overall, the results of this study provide useful information for those who are interested in understanding the soil cover in Mongolia and its distribution across different regions. The information can be used for various purposes such as agriculture, ecology, and environmental studies.

Keywords: Mongolian soil, permafrost soil, Soil organic carbon

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1 Introduction

Permafrost covers approximately 21.8% of the northern hemisphere's land area [1] and plays a crucial role in global climate, water circulation, and ecosystems. In our country, permafrost distribution varies across different locations, landscapes, and temperatures. Permafrost has been identified to cover approximately 29.3% of the total land area of Mongolia in a continuous, discontinuous and isolated extent [2].

Permafrost acts as a natural storehouse for large amounts of carbon in the form of frozen organic matter. As permafrost thaws due to climate change, this stored carbon can be released into the atmosphere as greenhouse gases, contributing to global warming.

Beyond these general characteristics, specific features and properties of permafrost can vary. The Altai and Khangai mountain ranges exhibit distinct topographical characteristics influenced by tectonic forces and altitude, while the Khuvsgul and Hentii mountain regions feature rugged relief, diverse landforms, and varying degrees of slope processes.

Mongol-Altai, Gobi-Altai, Khangai, and Khuvsgul are distinct areas within the permafrost regions of our country. We have conducted a comprehensive study on the characteristics of permafrost, its formation, properties, and engineering considerations, [3], [4]. Our research aims to examine the variations in permafrost soil characteristics in different regions of Mongolia and determine if there are any significant differences.

The study of organic carbon in permafrost, which plays a crucial role in permafrost stability, characteristics, climate, and ecosystem, requires comprehensive research and understanding. Therefore, in this study, we aim to investigate the links between organic carbon and permafrost and provide insights into their interactions. Permafrost regions globally contain approximately 1307 Pg of organic carbon, which is three times more than the carbon stored in the atmosphere, indicating its significant role in the global carbon cycle [5]. In the northern permafrost regions, organic carbon accounts for 30-40% of the top three meters of the soil, representing 15-20% of the total terrestrial carbon on Earth [5], [6]. This suggests that areas with permafrost have a higher carbon storage potential. Recent research has also been investigating the changes and impacts of permafrost thawing and degradation [7], [8], [9]. A study focusing on permafrost organic carbon has been conducted in the Khuvsgul Province [3]. With the increasing effects of climate change, understanding the dynamics of permafrost organic carbon in Mongolia becomes crucial. It is essential to study the characteristics of soil and the composition of organic carbon in different regions.

Due to the significance of permafrost, it is crucial to conduct studies on the soils within that area.

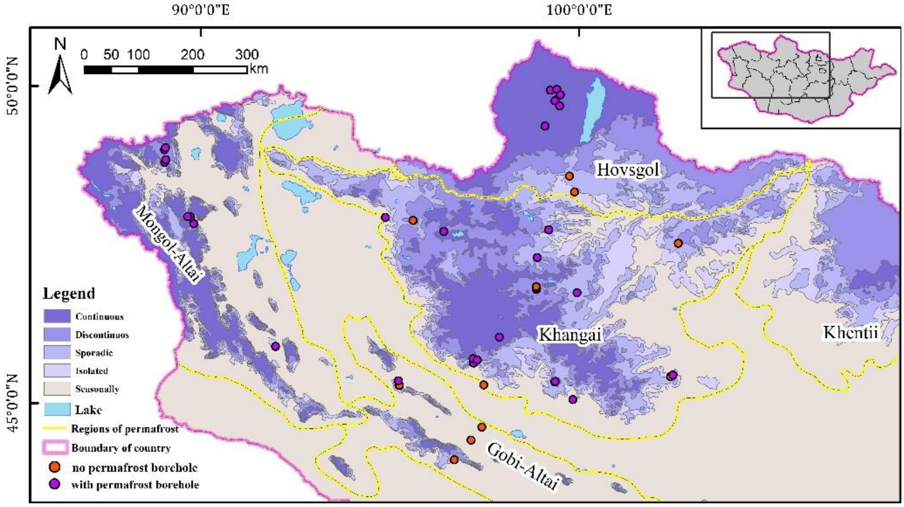
2 Study area and methods

2.1 Study area

The study was conducted to conduct a comprehensive assessment of permafrost soil conditions in specific monitoring sites across several provinces in Mongolia. The fieldwork was carried out in July and August 2021 and June 2022, focusing on the following provinces: Khuvsgul, Bulgan, Arkhangai, Zavkhan, Uvs, Khovd, Govi-Altai, Bayankhongor, and Uvurkhangai.

During this period, a total of 41 monitoring sites were selected, and soil samples were collected at each site. These samples were labeled and transported to the Soil science laboratory at the Institute of Geography and Geoecology, where further analysis was conducted. In total, 164 soil samples were processed and analyzed in the laboratory.

The study area includes six permafrost regions in Mongolia: Mongol-Altai, Govi-Altai, Khangai, Khuvsgul, Hentii, and Khangai Mountains. These regions are important in terms of soil characteristics, landscape, and physical geography [2]. Soil sampling locations were selected within these regions, specifically in Mongol-Altai, Govi-Altai, Khangai, and Khuvsgul regions. These regions were further subdivided to represent the diverse outcomes. The geographical distribution of the sampled soil sites is illustrated in (Figure 1).



2.2 Laboratory analysis

For laboratory analysis, the collected soil samples were divided into different layers: 0-5 cm, 5-15 cm, 15-30 cm, and 30-60 cm. The bulk density of the soil samples was also determined. In the laboratory, soil samples were air-dried and passed through a 2-mm sieve to remove coarse fragments. pH and electrical conductivity (EC) measurements were conducted using a pH meter (Orion 5 star). Soil moisture content was determined using the gravimetric method, while available phosphorus and potassium contents were analyzed using the Machigin method. Soil carbonates were calculated using a volumetric calcimeter, bulk density and moisture contents were determined using the weight and volumetric method. Additionally, the soil gravel size was assessed for particles larger than 2 mm. Statistical analysis was performed using Microsoft Excel and SPSS Statistics 23.

Fig 1. Soil sampling and permafrost borehole location

3 Results

The soil type varies significantly across the study area, which was extensively sampled in large areas. From *Cryic Umbrisols* to various types of soils, including *Calcisols*, there is a wide range of soil characteristics (Table 1).

In the Khuvsgul and Khangai regions, the dominant soil types were Kastanozems and Chernozems, while Aridic Kastanozems soils were more prevalent in the Mongol-Altai and Gobi-Altai regions. This soil variation contributes to regional differences. Additionally, when classifying the boreholes based on region, there were 30 boreholes with permafrost and 11 boreholes without permafrost.

Table 1. Soil types

Soil type name	Soil profile (n)	Elevation, msl (m)
Aridic Kastanozems	9	2219
Follic Phaeozems	1	2170
Fluvisols	1	2075
Leptic Kastanozems	12	2060
Salic Solonetz	4	2024
Calcic Umbrisols	3	1742
Calcic Kastanozems	6	1722
Chernozems	4	1676
Calcisols	1	1506

The distribution of Aridic Kastanozems and Leptic Kastanozems soils dominates in permafrost regions. A diverse range of soil types is present, including Follic Phaeozems and Calcisols. Additionally, sampling points range in altitude from 1506 to 2219 meters, covering various natural zones with different types of soil cover. When examining these soil sections based on their permafrost distribution, there are 8 points in the continuous zone, 8 in the discontinuous zone, 13 in the sporadic zone, 4 in the isolated zone, and 8 in the seasonal zone.

The average soil chemical properties are presented in Table 2. As observed from the table, there is a transition in the reaction medium from neutral to weakly alkaline with an increase in soil depth, while the carbonate content varies from low to moderately carbonated. Following a general trend, the levels of organic matter, available phosphorus, and potassium decrease as the depth of the soil layer decreases. The table 2 displays the average values of soil chemical properties.

Table 2. The average values of soil chemical properties

Depth, cm	n	pH	$CaCO_3$	SOM	EC	P_2O_5	K_2O
0-5	41	7.2	2.6	4.3	0.31	3.1	47.3
5-15	41	7.3	4.3	3.0	0.22	1.8	21.3
15-30	41	7.5	7.4	1.8	0.55	1.3	15.7
30-60	41	7.7	6.7	0.9	0.75	1.6	11.7

As shown in (Figure 2), the chemical properties of the soil are represented by the indicators (max, min, median). The values exhibit a wide range of variability: pH ranging from 5.28 to 9.21, carbonate content from 0.0% to 36.3 %, organic matter content from 0.11 % to 11.39 %, EC from 0.02 to 6.43, available phosphorus from 0.12 to 15.30, and potassium from 0.68 to 354.78.

The higher carbonate values observed in the sections of the Darkhad Hotgor can be attributed to the geological characteristics of that particular area. It is important to note that these values were not excluded from the overall analysis, and the results were calculated based on all samples. Furthermore, it is interesting to highlight sample number twenty-four, known as Hujirt Uvur, which exhibited exceptionally high levels of available potassium and phosphorus. This indicates that there is no permafrost, but the soil is rich in fertility indicators.

Additionally, points 28 and 34 display high electrical conductivity (EC) values and share the common characteristic of being in close proximity to a salt lake. This suggests a possible influence of salinity in these areas. Conducting a detailed study of soil geochemistry and salinity at these points would be of great interest to gain a deeper understanding of their unique characteristics.

Table 3. The average values of soil physical properties

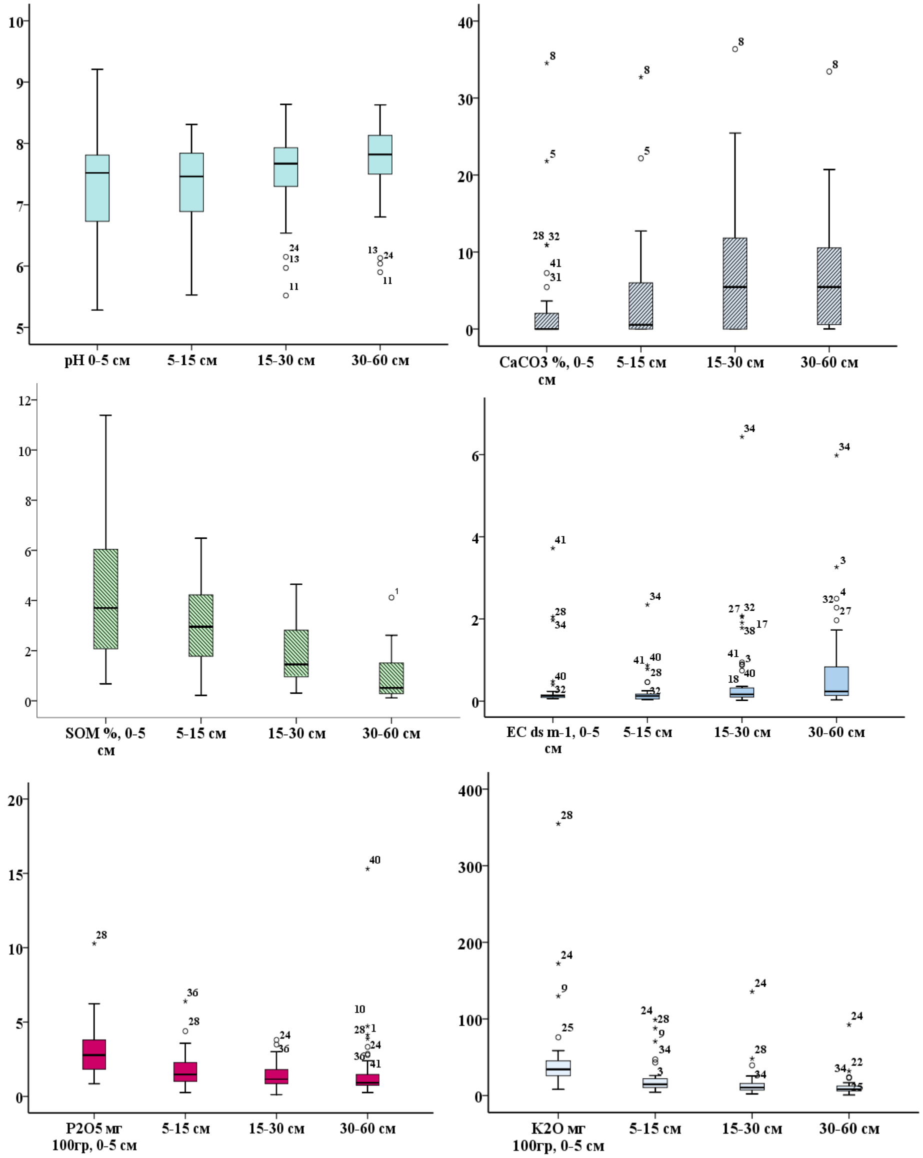
Depth, cm	n	Sand	Silt	Clay	Coarse >2 mm, %	Bulk density gr/cm^3	Moisture, %	Particle density, gr/cm^3	Porosity, %
0-5	41	58.7	27.5	13.8	16.7	1.22	9.68	2.56	51.61
5-15	41	60.4	26.4	13.2	27.0	1.32	9.32	2.51	47.46
15-30	41	60.5	26.0	13.4	32.0	1.32	9.86	2.53	47.77
30-60	41	59.2	27.3	13.4	34.1	1.35	9.04	2.53	46.43

The soil properties of permafrost zones in Mongolia vary depending on factors such as location, climate, and temperature. These zones exhibit diverse patterns and characteristics in terms of soil cover. Some of the key soil properties investigated in permafrost regions include soil pH, carbonate content, organic matter, available phosphorus, potassium, soil texture, and gravel content. The dominant soils in these regions are Kastanozems and Chernozems, with variations observed across different areas such as Mongolian-Altai, Gobi-Altai, Khangai, and Khuvsgul. Understanding these soil properties is crucial for various purposes, including agriculture, ecology, and environmental studies.

Regarding the physical parameters of the soil, the average distribution of sand, silt, and clay particles was found to be uniform across all samples. The percentage of coarse larger than 2 mm and bulk density increased as the depth of the soil decreased. However, there was a slight decrease observed in terms of particle density and porosity. It should be noted that the averages may be skewed higher due to the absence of moisture sampling at depths of 15-30 cm and 30-60 cm in some samples, particularly in cases where moisture collection was challenging or difficult (as shown in Table 3).

This information suggests that the soil composition and physical characteristics vary with depth, and the absence of moisture sampling at certain depths may have influenced

Fig 2. Boxplot (max, min, median) of soil chemical properties



the overall average values. It highlights the importance of considering potential limitations and variations in data collection when interpreting the results.

On the other hand, in the Mongolia-Altai and Gobi-Altai regions, there was a strong positive correlation observed between coarse content, electrical conductivity (EC), and sand. This implies that these parameters tend to vary together and may be indicative of specific soil properties or environmental conditions in those regions. It's worth noting that these parameters were negatively correlated with the Khuvsgul region, suggesting differences in soil characteristics between these regions.

In the Khangai region, analysis revealed high levels of silt and available potassium and a low-reaction environment. This suggests that the soil in the Khangai region may have a higher concentration of silt particles and a higher availability of available potassium compared to the other regions studied. These results provide valuable insight into the specific soil properties and conditions in the Khangai region and highlight its unique composition compared to the other regions studied.

On the other hand, the Khangai region had the highest levels of available potassium at the depths of 5-15 cm and 15-30 cm. The Khuvsgul region had high organic matter and clay contents, while the Mongolia-Altai and Gobi-Altai regions had the highest contents of coarse, EC and reactants. At a depth of 30-60 cm, the Khuvsgul region had the highest sediment and carbonate contents, indicating significant carbonate accumulation in this region. In the Gobi-Altai region, carbonate, coarse fragments, reaction and EC contents were high, while in the Mongolia-Altai region, available phosphorus and clay contents were high. The Mongolia-Altai region had higher phosphorus contents compared to the Khuvsgul and Khangai regions, indicating different soil properties. However, the Khangai region consistently had high levels of available potassium, silt and organic matter. In the Khuvsgul region, on the other hand, clay content was highest in the upper layers and carbonate accumulation was elevated in all depth ranges (Figure 3).

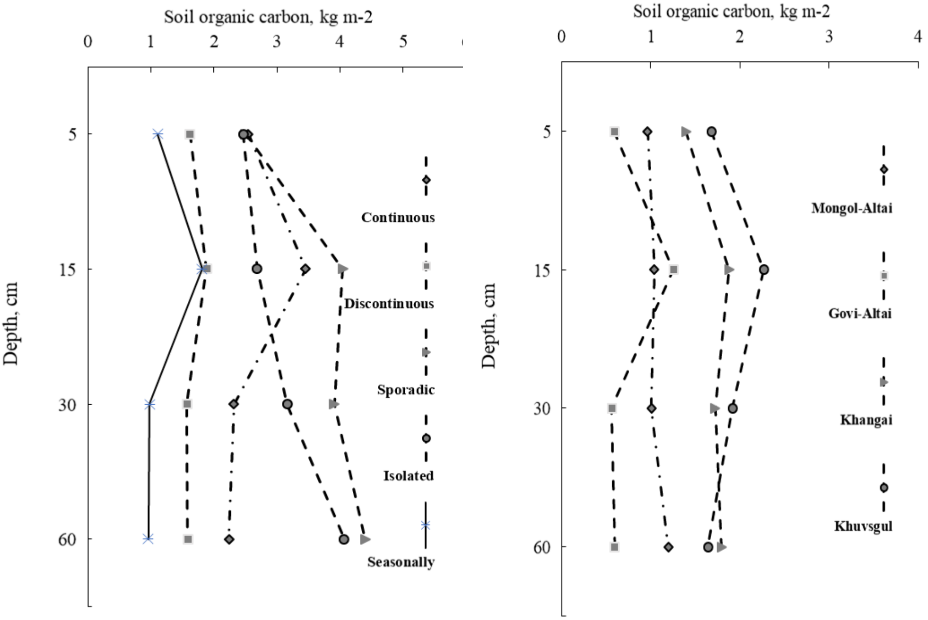


Fig 3. Distribution of soil organic carbon stock at various depths, regions, and permafrost distribution in Mongolia.

The organic carbon stock exhibited the lowest values in the seasonally distributed zone, with the highest stock observed in the sporadic zone. In terms of sequence, the distribution follows a gradient from more to less: sporadic, isolated, continuous, discontinuous, and seasonal.

The indicators are explained through the classification based on regions. Consequently, the reaction environment is weakly alkaline in the Khangai region and neutral in the other regions. The carbonate content exhibits the highest concentration, averaging at 10.2 %. Notably, the Govi region demonstrates a more pronounced carbonate concentration, while the Khuvsgul region surpasses the other regions in terms of carbonate content. This suggests a direct correlation with the geological composition of the region. The quality of electricity transmission is assessed as moderate in the Mongolia-Altai region, and low in the remaining regions. Regarding phosphorus levels, the Mongolia-Altai region exhibits the highest value, whereas the Gobi-Altai region showcases the lowest average. The content of coarse larger than 2 mm is most abundant in the Gobi-Altai region, comprising 49.7 % of the soil composition, while the Khuvsgul region demonstrates the lowest percentage at 10.9 %.

4 Discussion

Our research was based on permafrost monitoring boreholes in the Khangai, Khuvsgol, Mongolia-Altai and Gobi-Altai regions. The results show that the soil in these regions has different properties on a statistical level. The average values of sand, silt and clay in the soil samples ranged from 58.7-60.5%, 26.0-27.5% and 13.2-13.8%, respectively. The particle composition of the soil is evenly distributed.

However, there are significant differences in the coarse content between the different provinces. The gravel content follows a decreasing order from Govi-Altai, Mongolia-Altai, Khangai to Khuvsgul. Permafrost with boreholes have an average gravel content of 24.4% and are at an average elevation of 2001 m asl, while no permafrost boreholes have an average coarse content of 35.7% and an average elevation of 1887 m asl. These results indicate that boreholes with less gravel and located at higher elevations are more susceptible to permafrost.

In terms of fertility indicators and chemical properties, the order of Khangai, Khuvsgol, Mongolia-Altai and Gobi-Altai regions was observed. The focus was on soil organic carbon (SOC) as one of these indicators. In the study, the horizontal soil organic carbon stock (SOC) was calculated to be 4.2 kg m^{-2}, 3.0 kg m^{-2}, 6.8 kg m^{-2} and 7.5 kg m^{-2} for the depth of 0-60 cm in Mongolia-Altai, Gobi-Altai, Khangai and Khuvsgul regions, respectively. In Khuvsgul region, SOC was calculated to be 7.51 kg m^{-2} and 7.1 kg m^{-2} for the depth of 0-50 cm [10]. The calculated soil organic carbon (SOC) of 7.5 kg m^{-2} for the Khuvsgul region is in agreement with the research results.

Another study conducted in the Russian Arctic with sunny and peaty soils showed high SOC values of 7.9 kg m^{-2}, 15 kg m^{-2} and 24 kg m^{-2} for depths 0-10 cm, 0-30 cm and 0-100 cm, respectively [11]. In contrast, the Andean Mountains showed lower SOC values of 3.62 kg m^{-2} for the 0-100 cm depth [12]. It can be concluded that the SOC in the cold zone of our country is not at a low level compared to other regions.

In the context of soil groups in Mongolia, the forest-taiga group exhibits the highest organic carbon reserves, totaling 1510 Mg in the 0-30 cm surface soil layer. Additionally, soils in highlands, steppes, mountain steppes, and arid steppes display elevated levels of soil organic carbon stock. Furthermore, calculations have been conducted for each natural zone and soil type [13].

In addition, researchers have recently studied plant organic carbon resources in relation to the national distribution of soils and plants. It is important to study these aspects as well. In addition, looking at the continuous, discontinuous and isolated areas of the soil may reveal differences in soil properties that should be considered in future studies.

Due to the limited amount of soil research conducted in permafrost regions and high mountainous areas, there is a pressing need for further investigation and studies.

5 Conclusion

The soil investigations were carried out in the regions of Mongolia-Altai, Govi-Altai, Khangai and Khuvsgul in Mongolia using measuring points. Soil samples were collected from the depths of 0-5 cm, 5-15 cm, 15-30 cm and 30-60 cm and the results were analysed to determine the soil organic carbon content. The organic carbon stocks in the 0-60 cm depth range were 4.2 kg m^{-2}, 3.0 kg m^{-2}, 6.8 kg m^{-2} and 7.5 kg m^{-2} for Mongolia-Altai, Govi-Altai, Khangai and Khuvsgul, respectively. These results indicate significant differences in soil properties between the studied regions. Our investigations also indicate a relationship between soil properties and organic carbon content.

However, it is important to note that these results do not represent conclusive statistical correlations. Furthermore, variations in the physical properties of the soil, such as particle composition, showed a decreasing trend in coarse content. The boreholes without permafrost are situated at an average elevation of 1,887 meters, and the coarse content at a depth of 0-60 cm is 24.4%. In contrast, the boreholes with permafrost are found at an average elevation of 2,001 meters, with a coarse content of 35.7%. This indicates that more permafrost occurs in areas with lower coarse content and higher elevation.

When the statistical significance of these results was examined, no correlations were found either. When analysing the average values of all samples at constant depths, which are important parameters for permafrost soils, it was also found that the infiltration rate decreased slightly with depth. However, there were no significant differences in the composition of the shale between the four regions. On the other hand, the boreholes with permafrost had an average sand content of 57.7 %, while the boreholes without permafrost had a higher sand content of 65.3 %.

In addition, the carbonate content was found to be highest in the samples from the Khuvsgul region. These results provide valuable insights into the soil properties of the regions studied and highlight the importance of considering different parameters when assessing soil properties and their relationship to permafrost and organic carbon content.

The dominant soils, Aridic Kastanozems and leptic Kastanozems, display a varied distribution, with Aridic Kastanozems being more prevalent in Mongolian-Altai and Gobi-Altai. The study underscores differences in soil pH, carbonate content, organic matter, available phosphorus, and potassium among the regions. Notably, soil texture is uniformly distributed, while gravel content varies based on the region.

Altitude further contributes to the diversity of soil types, with sampling points ranging from 1506 to 2219 meters across different natural zones. The study identifies a wide array of soil types, from Follic Phaeozems to Calcisols, emphasizing the importance of understanding these variations.

Wetlands, a crucial ecological zone, demand specific attention due to their significance. The research highlights the imperative nature of studying soils in wetlands for a comprehensive understanding of their ecological role.

Furthermore, the examination of permafrost distribution reveals varying organic carbon stocks, with the seasonally distributed zone exhibiting the lowest and the sporadic zone displaying the highest stocks. These findings contribute significantly to our understanding of soil dynamics in Mongolia's permafrost regions.

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