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Greenhouse gas (GHG) emission in the permafrost regions of western Mongolia: case area in the Munkhkhairkhan mountain

Batzorig Batbold¹, Saruulzaya Adiya^{1*} and Tsogt-Erdene Gansukh¹

¹Institute of Geography and Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

*Corresponding author: saruulzayaa@mas.ac.mn

Abstract. Permafrost thaws accelerate the rates of carbon released by the soil into the atmosphere and cause significant positive climate-change feedback. We selected Munkhkhairkhan mountain as the study area. The main purpose of this study is to estimate GHG emissions and to calculate the emission factor (EF) at the study sites in Doloon Nuur and Shuurkhai in Munkhkhairkhan. This study is conducted in summer 2022 and carbon dioxide (CO₂) emissions were measured using the EGM-4 instrument. Soil samples were collected at depths of 0-5 cm, 5-10 cm, and 10-15 cm at the sites. We have determined the soil organic carbon content (SOC) at peat and nonpeat in both sites. According to the results, CO₂ fluxes ranged between 0.1 and 18.5 $\mu\text{mol}/\text{m}^{-2} \text{ s}^{-1}$ in the Doloon Nuur and Shuurkhai. Furthermore, EF at all sites on Munkhkhairkhan mountain (\pm standard error) was 112.3 g [CO₂] m⁻² yr⁻¹ (\pm 18.2), 5.9 g [CH₄] m⁻² yr⁻¹ (\pm 1.0). SOC content was 10.5% in 0-5 cm, 14.2% in 5-10 cm, and 11.4% in 10-15 cm at the study sites in Shuurkhai. The SOC content at the sites in Doloon Nuur ranges from 3.1% in 0-5 cm, 2.3% in 10-15 cm and 1.7% in 10-15 cm. This study is conducted with a year measurement; therefore, further research should extend the time period and can be used as a baseline study.

Keywords: Greenhouse gas, emission factor, organic carbon in the soil, permafrost

1 Introduction

In recent decades, the degradation of permafrost that accompany climate warming has been widely detected in mountain permafrost regions, as well as in high-latitude Arctic regions [1]. This degradation is evident from the deepening of the active layer thickness [2, 3], increases in ground temperature [4, 5], and formations of thermokarsts in the terrain [6]. A large amount of organic carbon from the soil is stored in mountain permafrost regions, and the carbon pools in these regions are very sensitive to increasing temperature [7, 8].

Approximately 1,700 Pg of carbon is stored in permafrost soil, approximately twice the amount of carbon that is currently in the atmosphere [9]. This is the remnant of plants, animals, and microbes that have accumulated in permafrost soils over hundreds of thousands of years [10]. CO₂ and CH₄ will accelerate the global increase in temperature and have a positive effect on terrestrial ecosystems [11].

Most previous studies have investigated GHG emissions and their long-term trends in permafrost regions of the northern hemisphere [11-15]. In Mongolia, some research on greenhouse gas emissions has been carried out in recent years [16-18]. For example, Saruulzaya et al. (2021) investigated CO₂ and CH₄ concentrations in Mongolian permafrost regions between 2010 and 2020 using GOSAT satellite data. Their results showed that CO₂ increased by 2.24 ppm / year and 7.29 ppb / year during the study period. However, they calculated seasonal variations of CO₂ concentrations and showed different patterns in four permafrost zones: Continuous and discontinuous permafrost zones had lower near-surface CO₂ concentrations in summer and autumn, and sporadic and isolated permafrost zones had higher near-surface CO₂ concentrations in winter and spring. Sainbayar et al. (2022) studied seasonal fluctuations of CO₂ in the atmosphere in Mongolia. CO₂ concentration has seasonal fluctuations, while vegetation cover plays an important role in the emission and absorption of natural carbon, and is the main factor in seasonal fluctuations of terrestrial CO₂. Furthermore, Saruulzaya et al. (2022) calculated the emission factors CO₂ and CH₄ in wetlands, peatland, and cropland in Ulaanbaatar City and the Khurkh river valley in Khentii province of Mongolia. GHG emissions were determined to have higher values in peatlands than in wetland and croplands.

Much research has been done on climate change, glaciation, and permafrost changes in the Munkhkhairkhan glacier mountain [19-23]. Although this environmental gradient would be interesting for a comprehensive analysis of the factors that control CO₂ flux and SOC, EF has not been determined in the mountain so far. The main purpose of this study is to estimate the GHG emissions in the Doloon Nuur and Shuurkhai of Munkhkhairkhan Mountain.

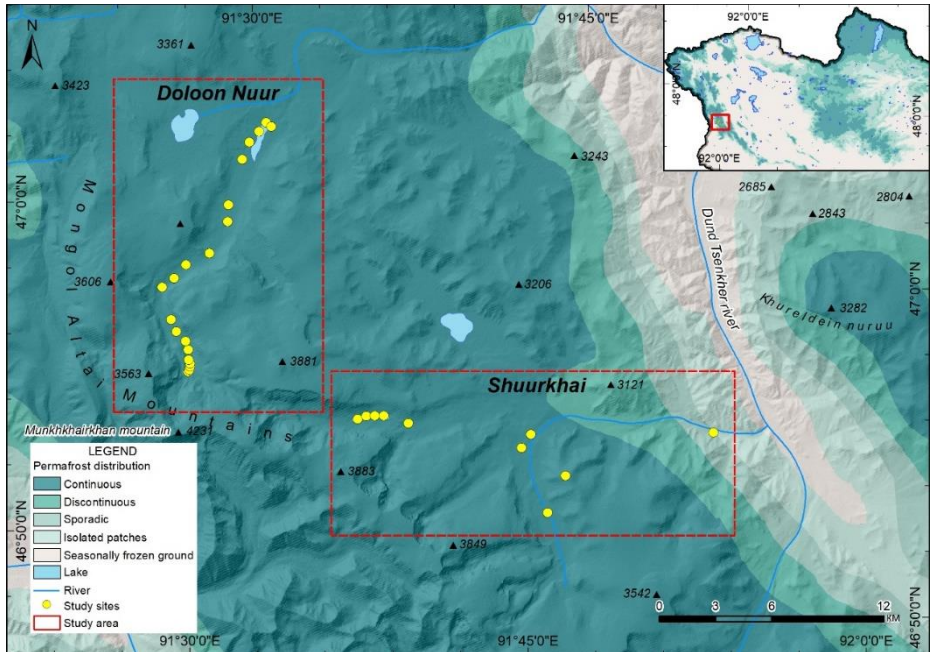


Fig.1. Location of the Munkhkhairkhan mountain and study sites in Doloon Nuur and Shuurkhai. (Jambaljav et al., 2016)

2 Study area

The Munkhkhairkhan mountain with a glacier is located in Khovd province in the western part of the Mongolian permafrost zone. The average air temperature in the coldest month of January fluctuates from 30°C to 34°C , and the average air temperature in July the warmest month ranges from $+15$ to $+10^{\circ}\text{C}$. The mean annual total precipitation ranges between 300 and 400 mm [24]. Most of the study area is covered by alpine vegetation. In this study, we selected several sites in the Munkhkhairkhan glacier mountain that is located in sporadic, continuous permafrost zones (Fig.1).

3 Methods and Materials

3.1 Soil sample

According to fieldwork, soil samples were collected at 30 sites in Doloon Nuur and Shuurkhai in August 2022. A total of 10 sites are located in Shuurkhai and 20 sites in Doloon Nuur. There are peat soils more concentrated at sites in Shuurkhai, whereas nonpeat soils were in Doloon Nuur. We collected a total of 90 soil samples at sites with depths of 0-5 cm, 5-10 cm, and 10-15 cm, respectively. These soil samples were

analyzed in the soil laboratory of the Institute of Geography and Geoecology of the Mongolian Academy of Sciences to determine the contents of SOC (percent volume, %).

3.2 CO₂ flux measurements

The EGM-4 (Environmental Gas Monitor for CO₂) instrument was used to measure the CO₂ concentration at 30 sites in Doloon Nuur and Shuurkhai in the Munkhkhairkhan mountain. Before starting the measurements, cuttings of plants were taken from the study area, roots were collected, and the chamber was tightly sealed. Connect the well-sealed chamber to the CO₂ analyzer.

The duration of the measurement of CO₂ concentration is 5 minutes and we have measured CO₂ at the study sites three times. Then we calculate the CO₂ fluxes using the following equation (Equation 1).

3.3 Emission factor (EF)

An EF is defined as the average emission rate of a given CO₂ for a given source relative to units of activity. We used the IPCC method [25] 'Equation (1)'.

$$EF = \frac{W}{A \cdot t} \quad (1)$$

EF – Emission factor [g CO₂/CH₄ m⁻² year⁻¹], *W* – total weight of GHG [g CO₂/CH₄], *A* – area [m²], *t* – period [years].

4 Results and Discussion

In this study, we have estimated CO₂ fluxes at the study sites in Doloon Nuur and Shuurkhai of the Munkhkhairkhan mountain in the continuous and sporadic permafrost zones. As shown in the results, CO₂ fluxes ranged between 0.1 and 18.5 μmol/m² s⁻¹ in Doloon Nuur and Shuurkhai. The average flux of CO₂ at all sites was 6.0 μmol/m² s⁻¹ in Shuurkhai and Doloon Nuur (Fig.2a). Fig.2b shows that CO₂ fluxes depend on several environmental factors such as sunlight, vegetation cover, soil temperature, and humidity. The highest values of CO₂ fluxes were recorded between 12:00 pm and 3:00 pm, which was more related to temperature and the effects of sunlight (Fig.2b).

Based on the analysis of the soil samples, the SOC content was 10.5% in 0-5 cm, 14.2% in 5-10 cm and 11.4% in 10-15 cm at the study sites in Shuurkhai. However, the SOC contents at the Doloon Nuur sites range from 3.1% in 0-5 cm, 2.3% in 10-15 cm and 1.7% in 10-15 cm (Fig.2c). We found that the SOC at the study sites in Shuurkhai was higher than at the sites in Doloon Nuur. Fig.3 shows the relationships between CO₂ flux, SOC contents, photosynthetic active radiation (PAR), temperature, and assimilation rates in both Doloon Nuur and Shuurkhai. The relationship between CO₂ flux and SOC was weak in both Doloon Nuur and Shuurkhai (Fig.3a). However, the results of the relationship of CO₂ flux and temperature ($R^2 = 0.59$) were more significant

in Shuurkhai than in Doloon Nuur ($R^2 = 0.025$) (Fig.3b). The regression coefficient of the relationship between CO_2 flux and PAR was more significant in Shuurkhai than in Doloon Nuur (Fig.3c). The relationship between CO_2 flux and assimilation rates is more significant at both sites (Fig.3d).

The EF is calculated at all the sites in Doloon Nuur and Shuurkhai of the Munkhkhairkhan mountain. EF at all sites in the Munkhkhairkhan mountain (\pm standard error) was $112.3 \text{ g } [\text{CO}_2] \text{ m}^{-2} \text{ yr}^{-1}$ (± 18.2), $5.9 \text{ g } [\text{CH}_4] \text{ m}^{-2} \text{ yr}^{-1}$ (± 1.0).

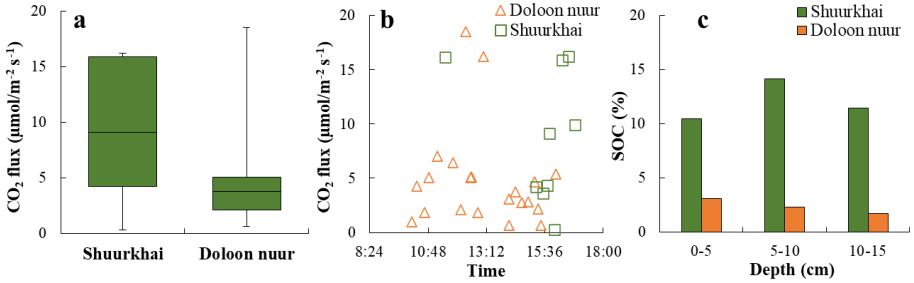


Fig.2. (a) CO_2 fluxes in the Doloon Nuur and Shuurkhai of the Munkhkhairkhan mountain; (b) CO_2 fluxes in different time periods; (c) SOC contents at different depths.

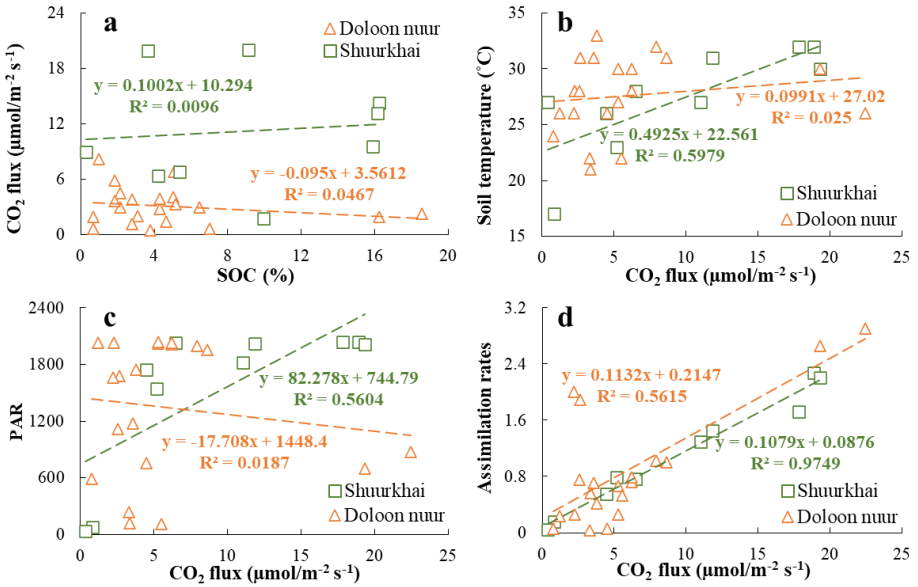


Fig.3. Relationship between CO_2 flux and SOC, soil temperature, PAR and assimilation rates.

Batkhisig et al., (2021) reported that soil organic content has decreased by 12.3% during the last 35 years. During this period, air temperature increased by $1.25 \text{ }^\circ\text{C}$,

precipitation decreased by 5 mm, and livestock increased 2.6 times [26]. Organic content, which is the main indicator of pasture soil fertility, has been decreasing in recent years due to the increase in the number of livestock [26].

Additionally, several reports have indicated that permafrost degradation has been detected in Mongolia, and these changes probably have had significant impacts on surface energy balances, local hydrological cycles, ecosystem services, and environmental changes in recent decades [27-31]. For example, based on in situ measurement data from 69 well sites in this region, it was found that ecosystem-driven permafrost is degrading in warm regions of Mongolia [31]. Our results are attributed to their results. For example, the number of livestock in Doloon Nuur was higher than that in Shuurkhai, which may have influenced the changes in SOCC. Future studies are required to address the spatial and temporal changes in CO₂ and CH₄ in the Munkhkhairkhan mountain.

5 Conclusions

This study estimates the first baseline information on CO₂ fluxes at 30 sites in the Munkhkhairkhan mountain in the continuous and sporadic permafrost zones. At the study sites, we collected a total of 90 soil samples in August 2022 with depths of 0-5 cm, 5-10 cm, and 10-15 cm, respectively. We used the EGM-4 instrument to measure CO₂ concentration at the study sites in Doloon Nuur and Shuurkhai. Then, we calculate the CO₂ flux and EF in this study area. We found that the CO₂ fluxes had different values in both areas. While the SOC content at the study sites in Shuurkhai was higher than at the sites in Doloon Nuur. The SOC content was highest in the peat sites concentrated in Shuurkhai. The results of CO₂ fluxes depend on several environmental factors, such as soil temperature, PAR, assimilation rates, and SOC content. We have concluded that the SOC content is higher in Shuurkhai than in Doloon Nuur, which is related to herders' camps and the number of livestock. This study was carried out with a year measurement, and with further research extending the time period, it can be used as a baseline study of the effects of climate change.

Acknowledgements

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