Preliminary Results of Estimating Erodibility and Erosivity over the Lake Valley, Mongolia

Dai Matsushima[1*], Ulgiichimeg Ganzorig[2] and Ochirbat Batkhishig[2]

[1]Department of Civil and Environmental Engineering, Chiba Institute of Technology, Chiba, Japan
[2]Institute of Geography and Geoecology, Mongolian Academy of Sciences Mongolia, Ulaanbaatar, Mongolia
[*]Corresponding author: matsushima.dai@it-chiba.ac.jp

Abstract. Gobi Lakes Valley is located in central Mongolia which is considered to be one of the regions where dust storms occur most frequently in Mongolia. We are planning to clarify both erodibility and erosivity in the valley. To accomplish this objective, we have started field observations of meteorology, soil thermal and moisture properties, and dust concentrations at two locations in the valley. In addition, we are estimating the spatio-temporal distribution of soil moisture and vegetation indices, and the meteorological conditions at times when dust storms occurred over the valley and the surroundings. Results of the above analyses will be validated using the observational data and open-to-public satellite and meteorological data such as the Global change observation mission-C/Second generation global imager (GCOM-C/SGLI) and the SYNOP (Synoptic surface observation). Some preliminary results of this study have been obtained so far. One is the threshold wind speeds as a function of soil moisture at multiple locations in the Gobi Lakes Valley and the surroundings are almost the same as those of Tsogtovoo, Umnugobi, which were estimated in a previous study. The other is that occurrences of strong wind accompanying dust storms correspond to frequent cold-air advection coming from the northwest side covering the valley. We will finally estimate erodibility and erosivity over the Gobi Lakes Valley comprehensively as a goal.

Keywords: dust storm, Gobi Lakes Valley, thermal inertia-derived soil moisture, threshold wind speed.

1 Introduction

Dust storms are frequently observed in Mongolia in late winter and spring after thawing, which is induced over a loose surface prone to wind erosion [1]. Dust storms are closely related to drought conditions [2], which are often caused by extremely little rainfall in spring and summer in Mongolia *e. g.* in years 2009 and 2010, in relationship with severe disasters (dzuds) [3]. A recent study shows the frequency of drought condition occurrences in the last two decades by 2015 was significantly larger than the

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previous two decades by 1995 [4]. Dust storms are considered to increase as the land conditions proceed to desertification due to consecutive droughts [2], and it has been discussed whether the grassland in Mongolia is faced with a tipping point to widespread desertification [5, 6].

Dust storm occurrences increase as the erodibility and the erosivity get strong. Recently integrated erodibility is investigated in overall Mongolia [7] and East Asia [8]. [9] show both the erodibility and erosivity in East Asia using the synoptic surface observation (SYNOP) data. It has been noted that the valley is considered one of the most frequent occurrences of dust storms [10]. Focusing on the valley, [11] conducted a remote sensing study that reveals the rate of aeolian surface erosion. The sediment in the valley can be an important source of dust particles. Some studies are focusing on sediment brought from the mountains on both sides of the Gobi Lakes Valley, which is important for dust storm climatology. [12] show the characteristics of lake sediment in the valley concerning climate trends and fluctuation in the last five decades. Shrinking water bodies enhance dried sedimental areas adjacent to the water bodies, which is likely to cause more dust storms [13], and the area of the lakes in the Gobi Lakes Valley has been shrinking [14].

Important quantities that characterize each dust storm phenomenon are the threshold friction velocity/wind speed and the dust particle (PM_{10}) concentration and flux. [15] show precise quantities of them over the Gobi Desert. Two of the authors have investigated the threshold wind speed as a function of surface soil moisture using thermal inertia-derived soil moisture that is retrieved from the model and the SYNOP data in Tsogtovoo, which is near the eastern end of the valley, and shows the relationship between the threshold wind speed and soil moisture is formulated using an existing relationship proposed by [16, 17]. However, the above relationship of threshold wind speed to soil moisture has not been investigated at locations other than Tsogtovoo. In addition, the rapid climate and geomorphological changes have undergone in recent decades, but there have not been a sufficient number of dust storm-related studies combining field and remote sensing observations. Our objective is to clarify both erodibility and erosivity in the Gobi Lakes Valley and the surroundings.

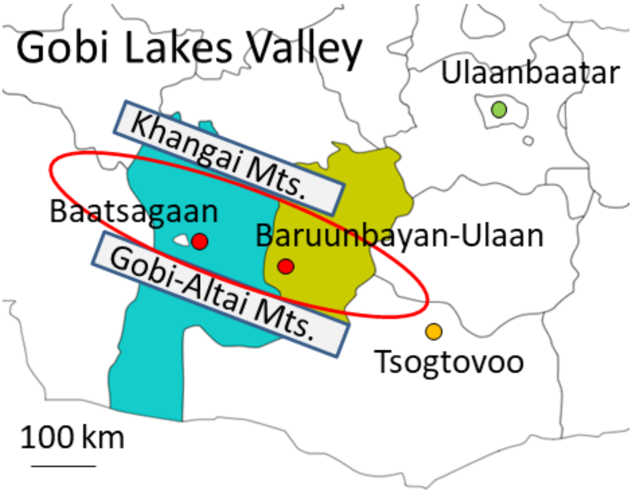

Fig. 1. Schematic of the Gobi Lakes Valley (mostly inside the red eclipse) and the surroundings. Red symbols denote the field observation sites (see text).

Overall characteristics of dust storms in the valley should be investigated in terms of soil moisture and vegetation. We adopt the method of [17] incorporating novel precise remote sensing data to multiple locations in the valley and the surroundings to clarify the threshold wind speed of dust storms in the last two decades, as well as the climatology of strong channel wind characteristics (erosivity) in terms of the topography of the valley.

2 Method

Site description
Gobi Lakes Valley is located in Central Mongolia and extends in west-northwest and east-southeast directions ranging an area of 44-46°N in latitude and 98-105°E in longitude including several provinces such as Umnugobi, Uvurkhangai, and Bayankhongor. The valley is surrounded by two long mountain ranges (Khangai and Gobi-Altai mountains) on the north and south sides, respectively, which form a channel that can strengthen westerly wind (see Fig. 1). The altitude of the surface mostly ranges between 1100 m and 2000 m. Annual temperature and precipitation mostly range between 2 and 6°C, and 50 and 150 mm, respectively [18], which shows the valley is a relatively dry region in Mongolia. Thus, the overall vegetation in the valley is little except in the summer of some years with more rainfall than average.

Field observations
Field observations are being proceeded at two locations in the Gobi Lakes Valley to obtain data on surface meteorology, soil moisture and thermal properties, and dust concentration (PM_{10}). The observation sites are at Baruun-bayan Ulaan (45.18°N 101.41°E) and Baatsagaan (45.56°N 99.43°E) (denoted by red symbols in (see Fig. 1). At both sites, air temperature, humidity, pressure, and wind direction and speed are

observed using an integrated meteorological sensor (WS500, Lufft, Germany). Rainfall amount is observed using a rain gauge (6464M, Davis, USA). Soil moisture is observed using a set of soil moisture sensors and logger (SM150, Delta-T, UK and MIJ-12, Environmental Measurement Japan). Soil thermal properties (thermal conductivity and thermal diffusivity) are observed using a soil thermal sensor (TP01, Hukseflux, Netherlands). Dust concentration (PM_{10}) is observed using a portable dust sensor (HH300L and SH PM, Aeroqual, New Zealand). All data except soil moisture are sampled every 10 seconds, averaged every 10 minutes, and recorded into a data logger (SM300, Campbell, USA) on a 10-minute basis. Soil moisture is sampled and recorded on a 1-hour basis. The WS500 sensor is approximately 2.0 m above the surface, and the soil moisture and the soil thermal sensors are set 3 cm under the surface. The top of the rain gauge is approximately 0.5 m. All sensors are set in the yard of the meteorological stations and there are no significant obstacles in the surroundings of both sites. The observations started at the end of August 2022 and are ongoing.

Data

The surface temperature and the leaf area index data of the Global change observation mission-C/Second generation global imager (GCOM-C/SGLI) are used for retrieving thermal inertia in the soil moisture analysis. The GCOM-C is a polar orbit satellite managed by the Japan Aerospace Exploration Agency (JAXA), and the data are acquired twice a day (approximately 10:30 and 21:30 local time) at the same surface point [19]. The SGLI data can be obtained from the G-Portal website (https://gportal.jaxa.jp/). The geostationary satellite data (MTSAT-2) are also used for estimating insolation in a 0.05° resolution, which can be obtained from the website of Kochi University, Japan (https://weather.is.kochi-u.ac.jp/) [20]. The SYNOP data is used for the soil moisture analysis as well as finding the times of dust observation at each meteorological station, which are obtained from the hourly data archive of the Integrated Surface Database of the U.S. National Centers for Environmental Information (https://www.ncei.noaa.gov/ data/global-hourly/access/) [21]. The times of dust observations are identified using the codes 09, and 30-35 of the present weather.

Spatial estimation of soil moisture

Soil moisture is spatially estimated using thermal inertia, which is the square root of the multiplication of the volumetric heat capacity and the thermal conductivity, as a proxy variable. Thermal inertia is almost positively linear to soil moisture and is converted to the volumetric soil water content if the soil texture is known [22]. Thermal inertia is a coefficient of soil thermal properties of the heat budget model, and its value of it is retrieved through an optimizing procedure. The method is referred to [22] for details, but one significantly different point is that novel satellite data from GCOM-C/SGLI (250 m-resolution) are used in place of the Moderate-resolution imaging spectroradiometer (MODIS)

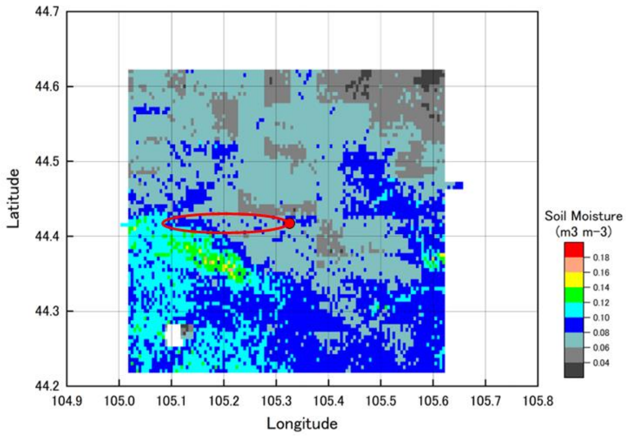

Fig. 2. Spatial distribution of thermal inertia-derived soil moisture around the Tsogtovoo observatory on 26 January 2019 with the observatory location (red symbol) and the source area of westerly wind (red eclipse).

data (1 km). In this study, soil moisture in individual surrounding areas of eight SYNOP observatories is estimated. The areas of the estimation are approximately 50 km squares centered by the SYNOP stations as depicted in (see Fig. 2). The period of the above data used for the analysis is between January and May of the years 2018 and 2020. The grid resolution of the estimation is 500 m which is twice the satellite data resolution (250 m).

Source area analysis

To estimate soil moisture of effective areas corresponding to dust observations at the individual SYNOP stations, the source area analysis proposed by [23] is employed. A representative value of soil moisture in the source area depending on the wind direction can be corresponded to the wind speed at each dust observation. The comprehensive procedure of this method is referred to [17] for details. The shape of the source area used in this study is an eclipse-like shape with approximately 20 km in wind direction and approximately 2 km in the cross direction in maximum as used in [17]. The source area analysis combined with the spatial estimation of soil moisture is applied to the eight SYNOP observatories in the valley and the surroundings, *i.e.* Altai (Al, 46.40°N, 96.25°E), Bayankhongor (BK, 46.13°N, 100.68°E), Bayanundur (BU, 44.62°N, 98.70°E), Bogd (Bo, 44.65°N, 102.17°E), Saikhanovoo (SO, 45.45°N, 103.90°E), Dalanzadgad (DZ, 43.58°N, 104.42°E), Tsogtovoo (TsO, 44.42°N, 105.32°E), and Mandalgobi (MG, 45.77°N, 106.28°E). Initials are used for references in (see Fig. 3).

3 Result

Spatial distribution of thermal inertia-derived soil moisture

Fig. 2 shows an example of the spatial distribution of thermal inertia-derived soil moisture around the Tsogtovoo observatory with the source area on 26 January 2019 when dust storms were observed due to the strong westerly wind

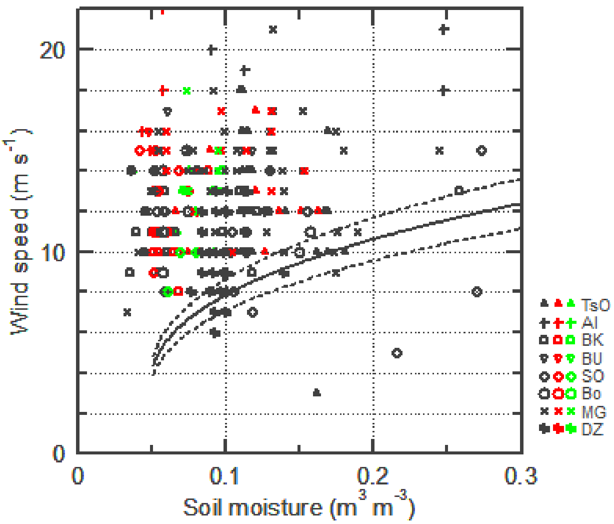

Fig. 3. Scatter plots of surface wind speed to the thermal inertia-derived soil moisture. The solid curve denotes the threshold wind speed Matsushima et al. (2020) determined.

(10-11 m s^{-1}). It was quite dry in most areas except the southwest side of the map, in which a small basin was included and it was relatively moist. The source area mostly covered dry areas, which showed dust particles came from the dry areas to the observatory location.

Threshold wind speed as a function of soil moisture

The threshold wind speed is analyzed using estimates of thermal inertia-derived soil moisture in the source area at respective dust observation timings and the corresponding wind speed at the same timings. The group of scatter plots of the effective samples (n = 300) looks like having an envelope curve that almost coincides with the curve of the Tsogtovoo data determined by [17] (see Fig. 3). The solid curve is the [16] formulation of the threshold wind speeds, in which the parameters are adapted to the Tsogtovoo data. The dashed curves in (see Fig. 3) are 10% higher or lower than the wind speeds of the solid curve, respectively, which represents the ambiguity derived from the soil moisture having estimation error and the observed values of wind speed being discrete (on a 1 m s^{-1} basis). Values of the threshold wind speed are approximately 8 m s^{-1} for the soil moisture being less than 0.1 m^3 m^{-3} and approximately 10 m s^{-1} for the soil moisture being more than 0.1 m^3 m^{-3}. The 5-percentile wind speeds (weak side) of all dust storm observations classified according to the soil moisture into a 0.01 m^3 m^{-3} basis almost correspond to the above threshold wind speeds. Most of the plots lie above the -10% curve, which illustrates no significant difference from the results of the previous study. Some plots of Dalanzadgad lying around 0.1 $m^3 m^{-3}$ of soil moisture may show the threshold wind speed is lower than that of the other observatories. The outliers being far below the curves (6 of 300 effective samples) are attributed to errors in estimating thermal inertia, which is found compared to the values of the thermal inertia of near dates, or due to too weak wind speed (less than 5 $m s^{-1}$) when the SYNOP code was 09 (dust storm occurred in an adjacent area or preceding hours).

Wind characteristics of dust storm occurrences
It is found that strong winds accompanying dust storms often occur when the cold horizontal advection prevails [24]. This result is derived by comparing surface wind speed at Altai, Bayanundur, and Tsogtovoo to the horizontal temperature gradient at the 700 hPa and the 850 hPa levels calculated from the Global spectral model data of the Japan Meteorological Agency. The other result shows the channeling effect of the valley topography because the actual wind directions when the wind speeds were more than 10 $m s^{-1}$ were mostly west at Tsogtovoo and Altai regardless of the geostrophic wind directions.

4 Discussion and Conclusions

The result illustrated in (see Fig. 3) implies the threshold wind speed is almost the same in the valley and the surroundings. [15] reported the threshold wind speed was 7.2 $m s^{-1}$ for Dalanzadgad and 6.6 $m s^{-1}$ for Sainshand, which corresponded to the value for soil moisture being less than 0.1 $m^3 m^{-3}$, but lower than that for soil moisture being larger. [25] investigated the threshold wind speed using the SYNOP data and reported the threshold wind speed in the Gobi Desert (8.9±2.2 $m s^{-1}$) which is comparable with the present results. The threshold wind speed for Dalanzadgad (7.0 $m s^{-1}$) is also comparable to the present results. The meteorological analysis shows that horizontal cold advection prevails in dust storm occurrences, which is consistent with frequent occurrences of dust storms at the timings of the cold front passing [1].
This paper shows some preliminary results of the erodibility and the erosivity in the Gobi Lakes Valley and the surroundings. The threshold wind speeds are mostly comparable with the previous studies. However, this study has just started and is presently being conducted. We should use the field observation data compared with the model results and other data to clarify the comprehensive erodibility including vegetation indices in the valley combined with the geomorphological conditions and the soil properties in areas such as the adjacent surface of the lake water bodies, as well as the erosivity with the topographic effects of the valley, and to find the trend or fluctuations of the erodibility and erosivity after analyzing data of the last two decades.

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