THE EFFECT TOPOGRAPHY IN PREDICTION OF WHEAT YIELD

Erdenetuya Boldbaatar[1], Tuvshinbayar D.[1], Munkhjargal O.[1], Buyanjargal M[1]

Mongolian University of Life Sciences, School of Agroecology

ch_erdenetuya@muls.edu.mn, tuvshinbayar@muls.edu.mn

Abstract

Topography is the main factory which affects significantly on soil quality and the production of agricultural products. This paper shows the result of research work in central region cropland of Mongolia, which is some topographic factors such as slope, aspect and elevation derived from SRTM dem (30 m resolution) and the indexes NDVI, SAVI, and GNDVI were calculated by satellite data Landsat 8, dated in August of 2020. This paper shows the result of research work in the central cropland region of Mongolia, which is some topographic factors, such as slope, aspect and elevation derived from SRTM dem (30 m resolution) and the indexes NDVI, SAVI, and GNDVI were calculated by satellite data to Landsat 8, dated in August of 2020. In this survey was conducted over 8000 crop land with 693.0 thousand hectares. We correlated the wheat yield statistic for this year and the topographical factors, also validated in 324 sample plot areas of Selenge and Tov provinces. The indexes which were calculated from remotely sensed data, showed the following results. The NDVI is -0.4 to +0.88 by Landsat 8 satellite data on July 8, 2020. The predicted crop yield by satellite data was 6.2 to 13.9 centners per hectare. 324 random points were selected as a control sample and the correlation with the slope of the land surface and those relationships was 0.79. For the 324 sample plots, the slope deviated by 0-6 meters and the yield difference was 3-5 centners per hectare. This study showed differences in land surface factors affecting crop yield so indicated a need for improved crop management.

Keywords: *slope, aspect, elevation, crop yield, vegetation indexes*

Introduction

Agricultural land in Mongolia was reported at 72.84 % in 2021, according to the World Bank. Agricultural land in Mongolia refers to the share of land area that is arable, under permanent crops, and under permanent pastures. Arable land includes land defined by the FAO as land under temporary crops; temporary meadows for mowing or for pasture; land under market or kitchen gardens, and land temporarily fallow. Land abandoned as a result of shifting cultivation is excluded. Land under permanent crops is land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest. By the end of 2021, Mongolian arable land was 911691.43 hectares, which is 0.8 percent of the Mongolian total land resources.

As for Mongolia, generally farming is carried out at an altitude of 615-1,703 m above sea level, with a slope of 0-39.9 degrees. The general crop land of Mongolia, located in 900-1100 m above sea level, with slope of 0-15.9 degree. Considering the soil of the main agricultural areas of Mongolia, alluvial meadow soil-2.9%, mountain dark brown soil-4.5%, meadow brown soil-4.5%, dark brown soil-25.7%, mountain brown soil- 27.4%, brown soil-30.9%. The mechanical composition of crop land in the main cultivation areas of Mongolia is heavy loam-0.8%, light loam-61.9%, medium loam-24%, and sandy loam-24.0%.

In consideration of public policy intensive agricultural production in Mongolian crop land reached to more than 1.2 million hectares in the last 60 years and in 1986-1990 an average of 784.8 thousand tons of grain per year (including wheat, 638.0 tons of potatoes, 46.2 thousand tons of vegetables) seized a comparably heavy 270-290 kg of grain, about 150-160 kg of wheat and 20 kg of vegetables a share of the country's population, and this time was possible to fully meet the domestic needs.

According to the unified land fund report of Mongolia, crop land in 2016 is 1,067,7 thousand hectares which are included abandoned area with 260,6 thousand hectares [5]. However, in recent years, increased crop land has been playing an important role in supplementing domestic demand for food, but climate change and seasonal harvest play an unpredictable factor.

Monitoring crop growth using optical remote sensing technology and satellite data offers an opportunity to explore vast areas in a short period of time. Nowadays, remote sensing air and satellite imagery based on the survey data and the available crop land monitoring or processing of data collected in the field is a study based on the monitoring point of a selected area.

The northern part of Mongolia, where over 90% of the country's crop land is, is geographically and climatically suited for agriculture. Global warming is causing a decrease in precipitation and an increase in the number of warm days, but it does not change crop yields on the irrigated land. As far as Mongolia is concerned, many studies have shown that it is desirable to consider changes in vegetative chlorophyll as a monitoring of satellite imagery to monitor the situation of crop land and crop stress.

Topography affecting soil quality can significantly affect the production of agricultural products (Ajami et al., 2019).

To evaluate the spatial variation of wheat production and to create regression models between the crop, soil, and topography characteristics. Wheat and soil sampling from different slope positions were collected randomly from 100 points.

Topography by affecting soil quality, can significantly affect the production of agricultural products (Toshan area of Golestan, 2015) in which research work to evaluate the spatial variation of wheat production and to create regression models between the crop, soil, and topography characteristics.

Fertility layers and moisture content of the soil varies per unit area due to surface factors. This can affect crop yields (CHI et al., 2009). The effect of these topographical factors on crop yield is mostly dependent on weather, especially rainfall. Understanding the relationship between topographic factors and yield is important for soil management and agricultural landscapes. However, mechanistic exploration to understand the influence of topographic factors on vegetation remains limited, particularly for mountainous areas having complex terrain (Xiong & Wang, 2022).

In our country, it is possible to carry out this type of research in detail and control and increase the crop yield, but these aren't experiences using topographical factory. For that reason, the purpose of this study is the possibility of calculating the influence of surface factors on wheat yield in Bulgan, Selenge, Central, Darkhan-Uul, and Orkhon provinces, which are belongs to the central agricultural regions of Mongolia. The following objectives, are proposed.

1. To determine the surface factor of the study area
2. To calculate the Normalized Difference Vegetation Index (NDVI) in the study area
3. To determine the yield of the wheat field and evaluate the topographic factors

Material and methodology

Study area

More than 9,000 agricultural plots in 62 sum of 6 provinces such as Darkhan-Uul, Orkhon, Bulgan, Selenge, Tuv, and Ulaanbaatar was studied in the agricultural area, in total area 693.0 thousand hectares are cultivated, and currently (Figure 1). 65 percent of Mongolia's total cultivated area is in the central region. As for Mongolia, general farming is carried out at an altitude of 608-1,783 m above sea level, with a slope of 0-39.9 degrees. The general crop land of located in 608-1732 m above sea level, with slope of 0-15.9 degree.

Considering the soil of the main agricultural areas of Mongolia, Alluvial meadow soil-2.9%, Mountain dark brown soil-4.5%, Meadow brown soil-4.5%, Dark brown soil-25.7%, Mountain brown soil-27.4%, Brown soil-30.9%. The mechanical composition of crop land in the main cultivation areas of Mongolia is heavy loam-0.8%, light loam-61.9%, medium loam-24%, and sandy loam-24.0%.

The soil humidity is 4.2-2.8%, in some areas of the forest steppe and steppe zone of the arid area. The climate is steep with humid climate with an average annual precipitation of 230 mm.

Figure 1. Central agricultural zone of Mongolia

Data and Methodology

We used open sourced 16 scene image of Landsat 8 with 12 bands, which sensor is OLI, and a with 30-meter resolution. All satellite image dated on July-August 2020, with atmospheric and geometric correction. However, in addition we used 37 scene images of SRTM DEM with 30-meter resolution covering Tuv, Selenge, Bulgan, Darkhan-Uul, Orkhon and Ulaanbaatar, was downloaded from USGS as https://earthexplorer.usgs.gov/. For correlation slope which is main topographical factory between yields of wheat we used Statistical data of Tov and Selenge Province in 2020 from the Mongolian statistical information service. An estimate was also made on Sentinel 2 satellite data (18-20 of August 2020) to detail the relationship between yield, and NDVI. When choosing the timing of the Sentinel 2 satellite, a time series analysis was done on the Google earth engine.

For spatial analyses and image processing we used the software ArcGIS 10.8, ENVI 4.7. According to the following flowchart, first was derived surface factors by the digital elevation model (DEM), then was calculated the Normalized Difference Vegetation Index (NDVI, and finally, correlation was developed by their value (Figure 2). Each crop plot has set spatial statistics such as elevation, slope, aspect, NDVI, aspect and predicted yield developed by zonal statistics of spatial analyses tools in ArcGIS 10.8.

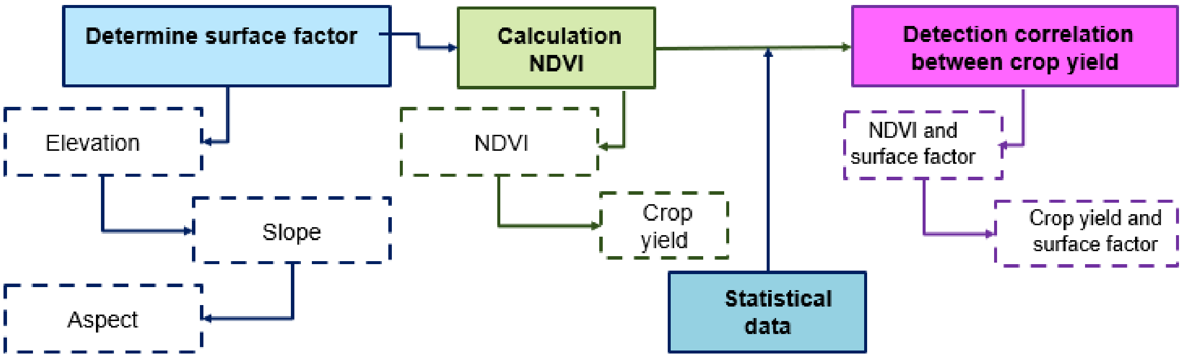


Figure 2. Flowchart of research methodology.

Methodology

For calculation surface factor was used SRTM digital elevation model (DEM) with 30 m resolution to derive the slope and aspect. In doing so, after projecting the downloaded DEM image, Slope and Aspect were calculated using the Surface analyst of the spatial analyst tools of ArcGIS 10.8.

The slope percentage dataset was divided into 5 categories according to a requirement of agricultural suitability method 2015 from Administration of Land Affairs, Geodesy and Cartography for representing levels of slope suitability for crops. The land suitability for the agricultural land-use areas is classified into five classes: namely, high suitable (0-2 degree), suitable (2-4 degree), moderately suitable (4-6 degree), unsuitable (6-12 degree), and highly unsuitable (above-12 degree).

We calculated the Normalized Difference Vegetation Index (NDVI) in a simple graphical indicator that can be used to analyse remote sensing measurements and observe contains live green vegetation or not (C.F.Chen, 2011). Pigments and chlorophylls on plant leaves strongly absorb visible light with a length of 0.4-0.7 microns, contributing to the process of photosynthesis (D.J.Watson, 1947). Based on this formula, the arrangement of all satellite channels only Visible Red and Near infrared (NIR) bands. The Normalized Vegetation Difference Index has a value between -1 and +1, and the closer it is to +1, the better the vegetation cover or forest area (Shin et al., 2008).

$$NDVI=(NIR-RED)/(NIR+RED) \quad [1]$$

Empirically NDVI products are unstable and vary with soil colour, soil moisture, and saturation effects from high-density vegetation. The calculated NDVI used to validate result of prediction weat yield. The formula calculate crop yield defined by Tom Mueller and Demetrio Zourarakis in 2015, was used to calculate yields (Mueller & Sassenrath, n.d.).

$$\text{Wheat yield} = B_0-B_1*\text{slope gradient} \quad [2]$$

Where B_0-13,9 and B_1-0,486 (0.486 mg per unit slope value)

Result

The main crop land of central agricultural zone of Mongolia located in 608-1132 m above sea level (Figure 3). In Mongolia, a sustainable agricultural region has an elevation between 600-1700 m. The above 1000 m altitudes in Central agriculture region cover 40 percent of the total crop area (Figure 2). According to a requirement of agricultural suitability methodology (2015) in Mongolia most of crop plots in almost suitability elevation for crops.

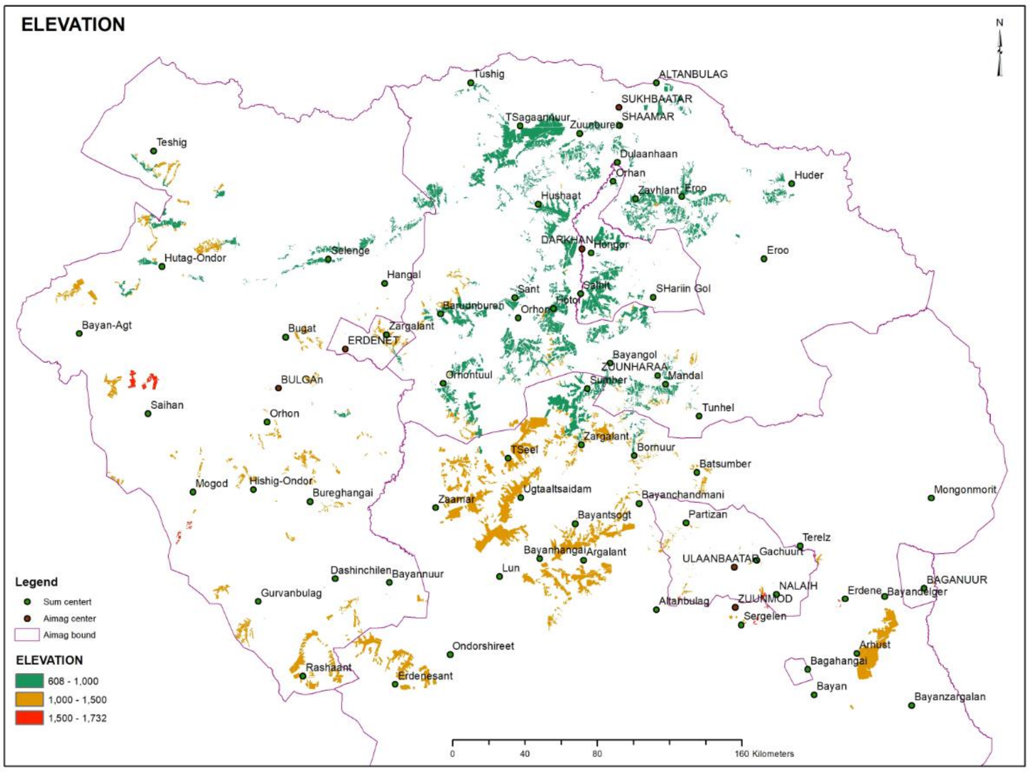


Figure 3. Elevation in the central crop lands

A more than 9000 crop plots in 693.0-thousand-hectare agricultural area were subjected to zonal statistical analysis the elevation aspect and slope gradient of the land surface which calculated from DEM dataset at dimensions of 30x30m. The general crop land of Mongolia located in slope of 0-15.9 degree, the average value was 2.61 (Figure 4).

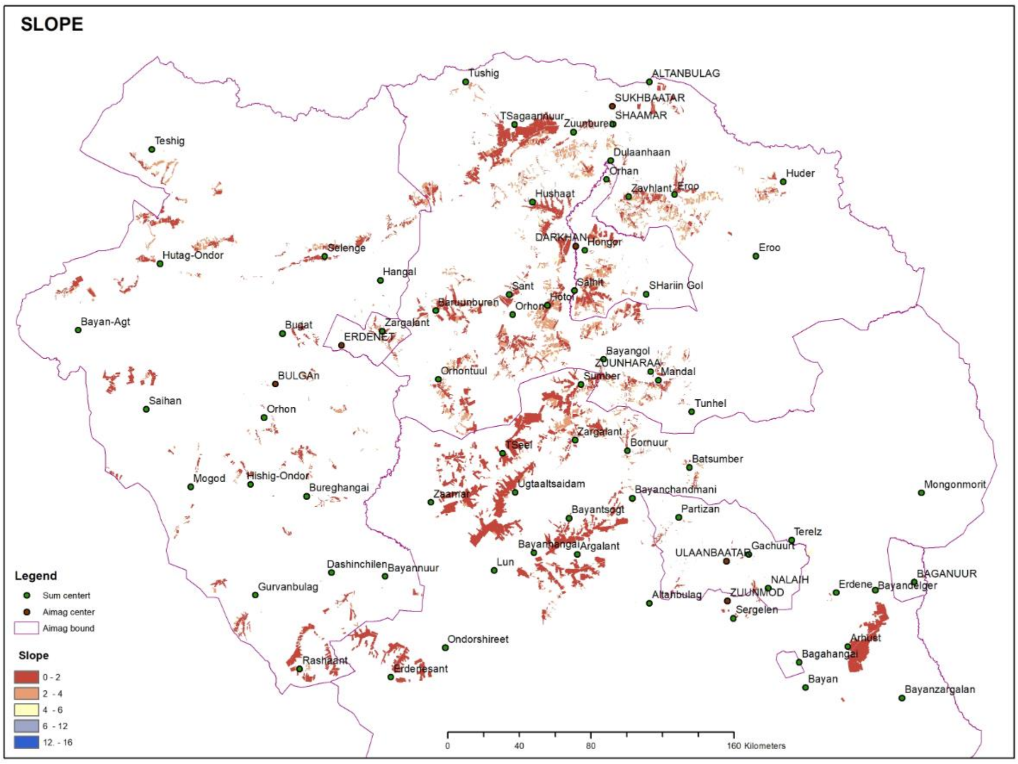


Figure 4. Slope in the central crop lands

According to a requirement of agricultural suitability methodology (2015) in Mongolia most of crop lands in slope and elevation levels of suitability for crops.

The aspect of agricultural plots by zonal statistical analysis showed that the minimum value is -1 degree, the maximum value is 359.73 degrees, the average value is 360.73 degrees, and the standard deviation is 176.67 degrees (Figure 5).

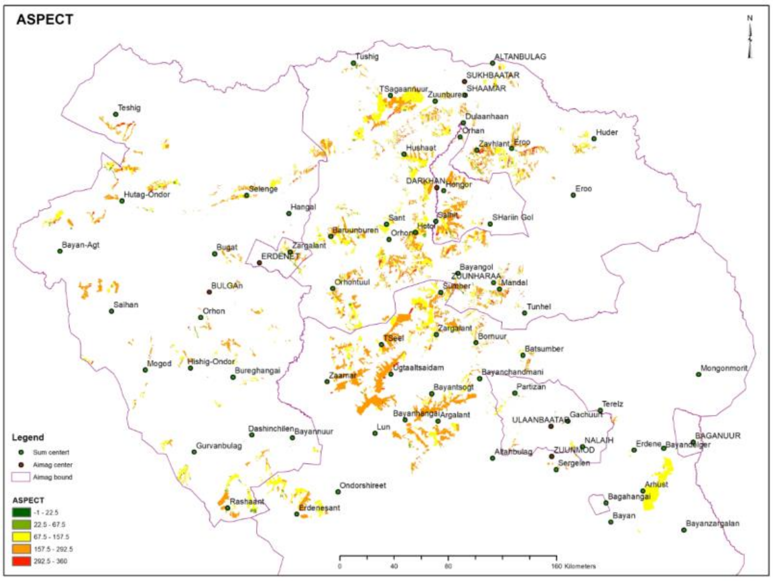
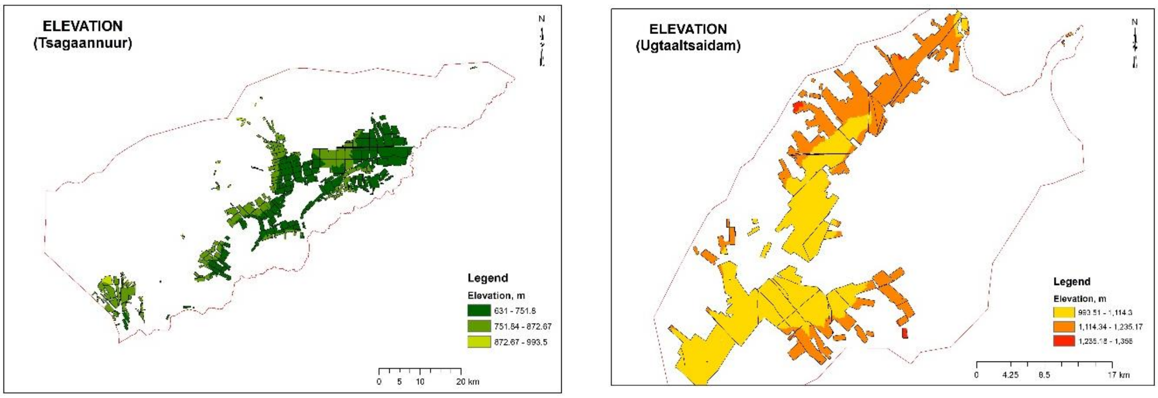


Figure 5. Aspect of cropland zone

For the validation topographical factory, we use 324 plots in the Tsagaannuur sum of Selenge province, and the Ugtaaltsaidam sum of Tov province was considered spatial plots as an example (Figure 6). All plots belong to the suitable category for land surface slope.

As for the aspect, crop plots of Ugtaaltsaidam were in the southeast, south, and southwest directions, while crop plots of Tsagaanuur were located in the east, southeast, and south directions.



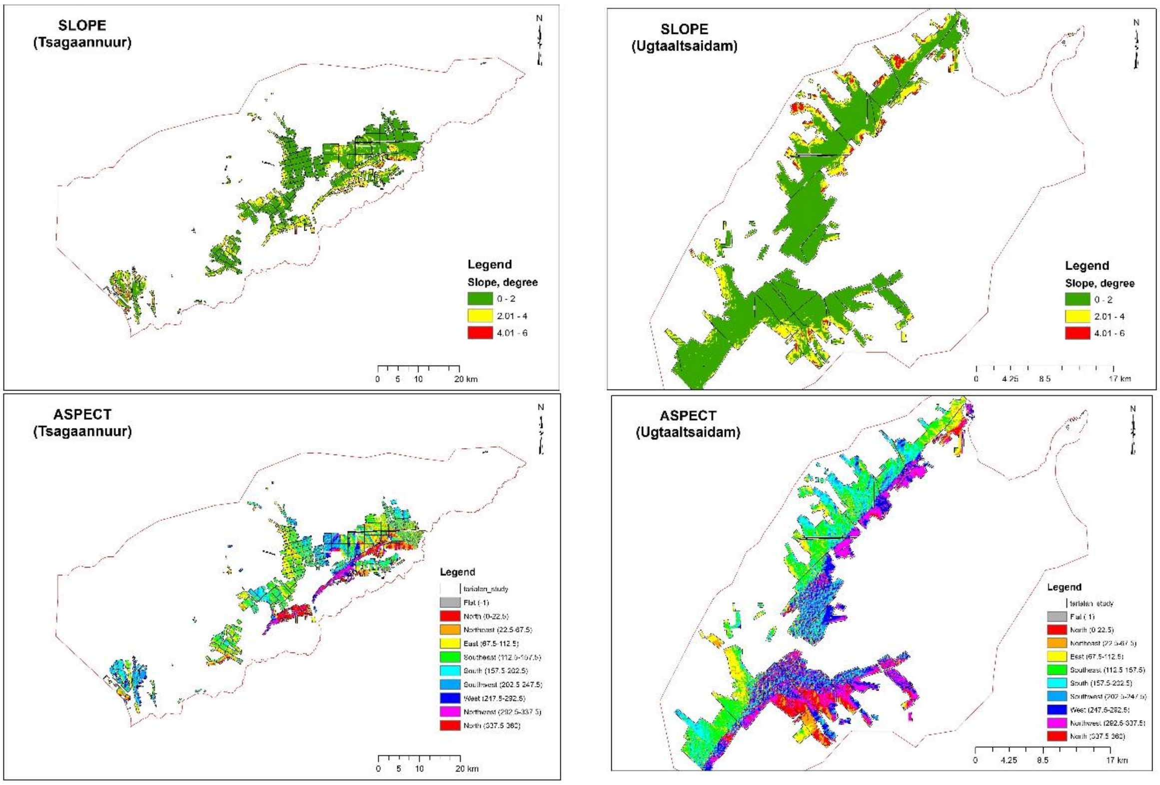


Figure 6. Spatial of crop plots.

In the vegetation study used so many vegetation indices were calculated using satellite data. We calculated main index as the normalized difference vegetation index (NDVI) by Landsat8 dated in august 2020. All cultivated land in central cropping zone has the minimum value is 0.26, the maximum value is +1, the average value is +0.59, and the standard deviation is +0.15 (Figure 7).

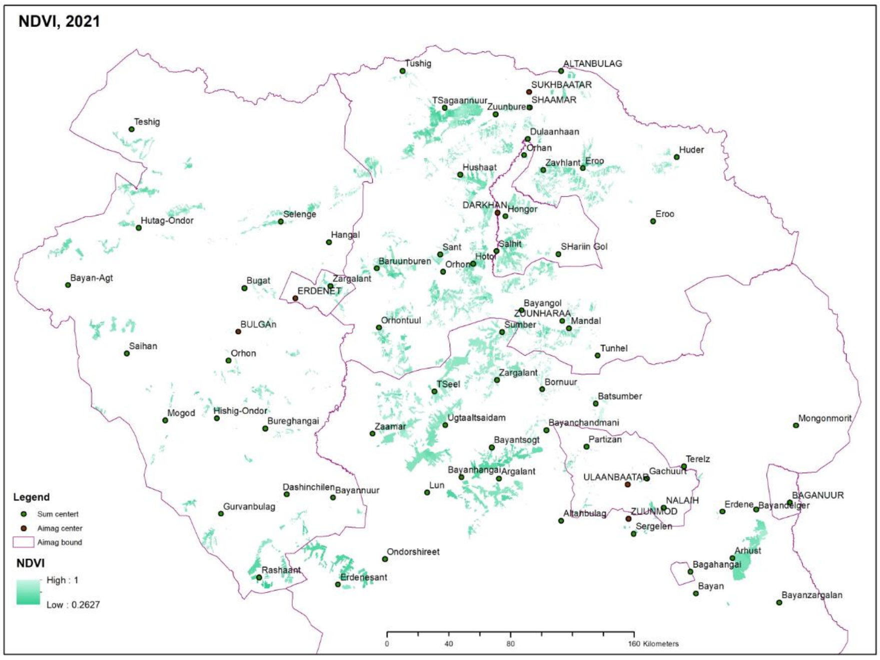


Figure 7. Vegetation indices.

After that, a time series analysis on GEE was performed on Sentinel 2 satellite data in Tsagaanuur Sum of Selenge Province and Ugtaaltsaidam Sum of Central Province in detail (Figure 8). The 2 datas with the highest NDVI values were selected (18-20 of August 2020). Sentinel 2 satellite data of that time was downloaded and corrected in SNAP program, all channels were converted to 10 m resolution and NDVI calculation was made. Considering the NDVI values, the values ranged from -0.25 to +0.92.

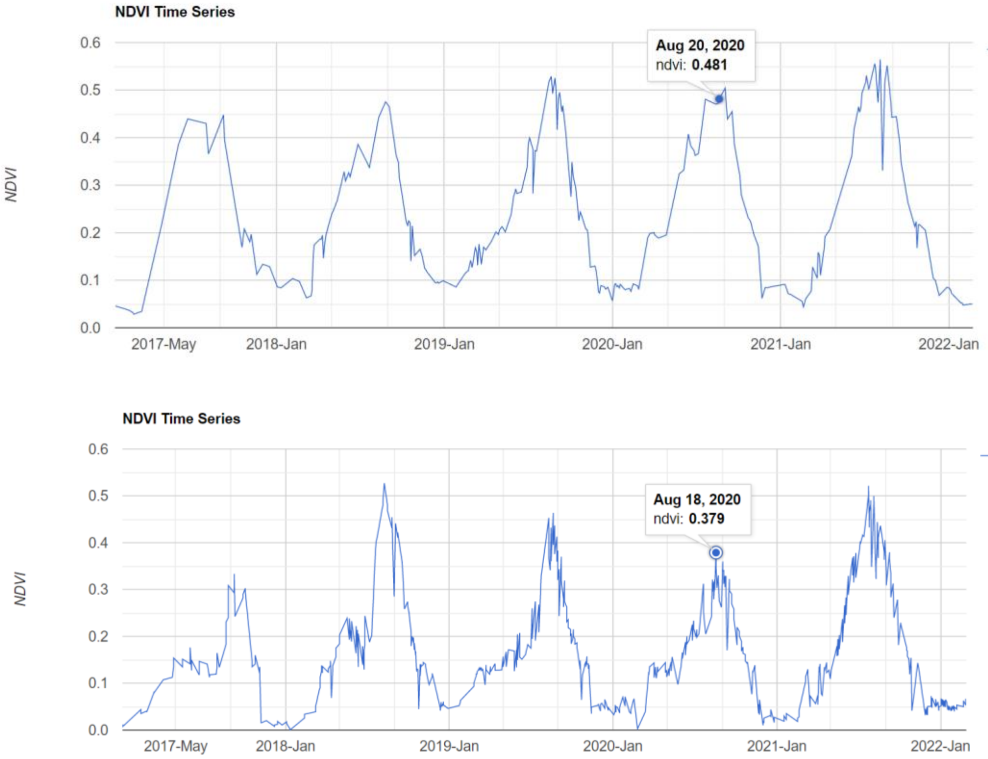


Figure 8. Time series analysis for Sentinel 2 of Ugtaaltsaidam, and Tsagaannuur sum.

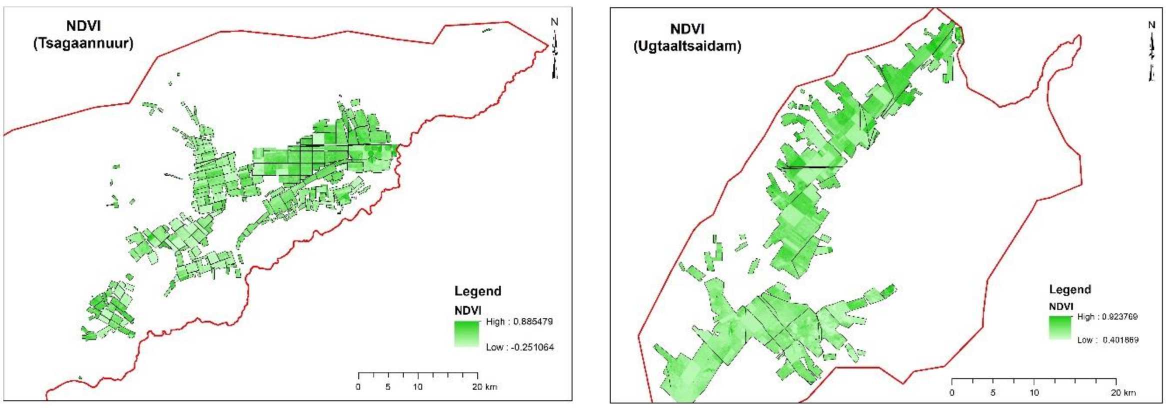


Figure 9. NDVI of Ugtaaltsaidam, and Tsagaannuur sum.

The NDVI showed the greenness of wheat in August and recommended monitoring its phenology during the vegetation period and predicting its yield. In predicting wheat yield, the land slope was selected as the most important topographic factor (Figure 10).

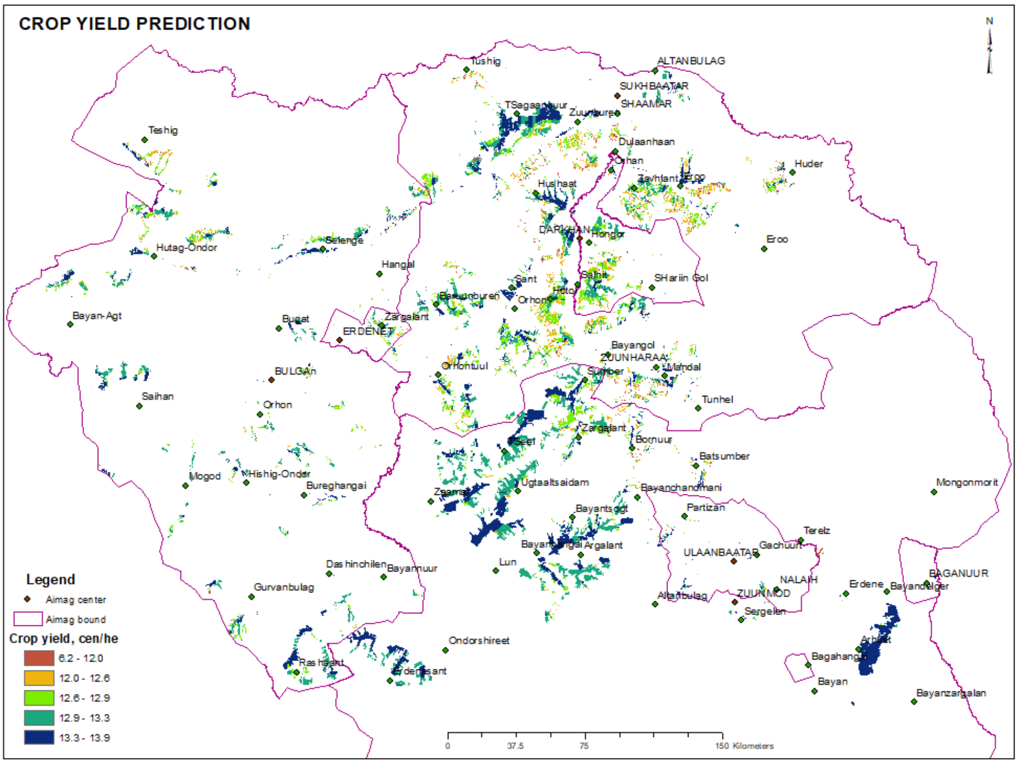


Figure 10. Predicted wheat yield

The 324 selected plots had a yield of 11.8 centner/ha to 13.77 centner/ha. There was a low yield in the highlands and a high yield in the lowlands (Figure 11).

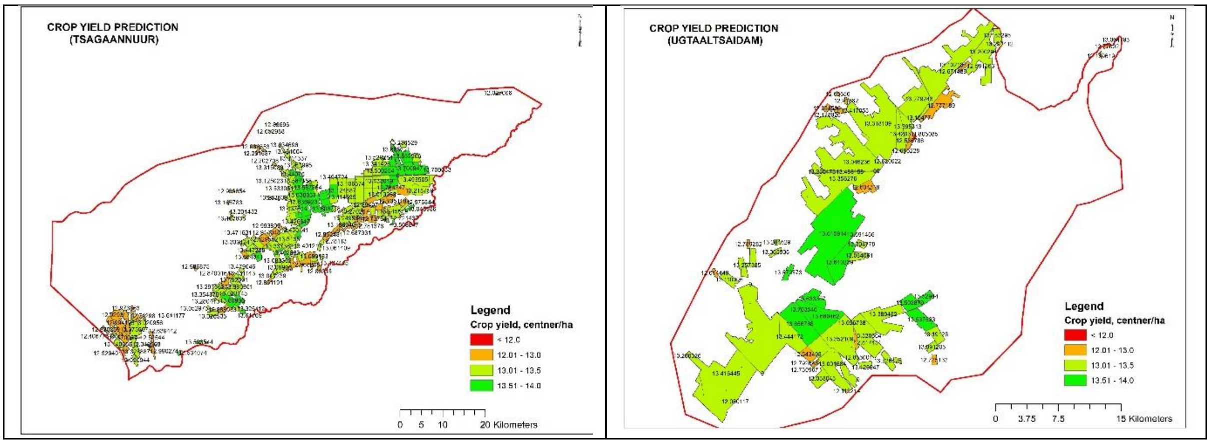


Figure 11. Wheat yield from satellite data.

Finally, the correlation of wheat yield with indices was calculated (Figure 12). In order to compare the 2020 yield statistics determined using satellite data of the cropland with the slope value of the land surface, 324 randomly selected and calculated the relationship between the slope and the yield value of that point, the correlation coefficient is 0.79.

The fields we selected had slopes of less than 6 degrees, which were found to be negatively and strongly correlated with yield. This indicates that the yield can be increased due to the decrease in the slope.

In our field, however, NDVI had no correlation with slope.

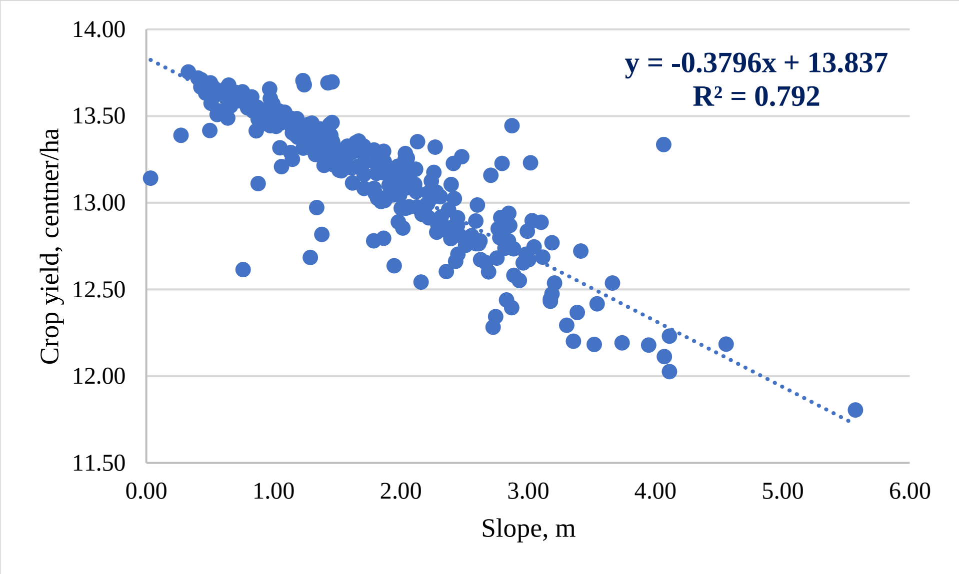


Figure 12. Correlation between wheat yield and slope.

In the result we determine that the land below 6 degrees of the surface does not have any influence on determining the yield, but it is inversely related above 6 degrees.

Table 1. Correlation table of crop yield, NDVI, and slope.

	NDVI	*Slope*	*Crop yield*
NDVI	1		
Slope	0.036559	1	
Crop yield	-0.05246	-0.88995	1

Discussion

According to the results of the research, the correlation between the crop yield determined using satellite data and the surface slope was 0.71. When making the calculation, more than 500 points were selected, and the yield was predicted 6.2-13.9 centners per hectare. Also, the average slope of cultivated fields in the central agricultural region of our country was 2.61 degrees.

We have compared this result with International researchers have been conducting detailed research on this matter.

Bao-Liang et al. (2009) selected two agricultural sites, Alvena and Hepburn, Saskatchewan, Canada, and investigated how topographic parameters were related to wheat yield under two geographic and climatic conditions in the Canadian prairies. In dry years, the correlation of grain yield was 0.73-0.79, but in years with high rainfall, the correlation was slightly lower. As our country has a dry climate, it is consistent with the above results.

Therefore, in the study of researchers Ajami (2019), it was determined that the grain yield is high in areas with a low slope, i.e. areas with a slope of less than 10 degrees, while the yield is low in areas with a high slope. From the above results, it may be related to the accumulation of organic matter, nitrogen, and potassium in the areas with low slope.

Also, research on “Delineation of suitable cropland areas using a gis based multicriteria evaluation approach in the central agricultural region of Mongolia” by researcher Dorjsuren (2020) was carried out in all the agricultural provinces of Mongolia. We took it in detail through the central region, which is mainly agricultural.

The results of our study were consistent with the results of the above researchers, and it may be possible to further study this study by comparing it with parameters such as climatic factors and soil moisture.

Conclusion

To conclude from all of the above;

1. Considering the surface factors of the 693 thousand hectares of cultivated land in the central cropland zone of our country, the elevation was 608-1132 m above sea level, and the slope was 0-15.6 degrees.
2. In August 2020, the normalized difference vegetation index (NDVI) had a value of 0.26 to +1. It is the highest value of wheat and after this period its saturation becomes high.
3. The yield value determined using satellite data was from 11.8 to 13.77 centner/ha, and when 324 points were selected as a control and the crop yield, and the land surface slope was calculated, the correlation coefficient is 0.79.
4. In addition, the cultivated fields selected as examples had a slope of fewer than 6 degrees, and these were negatively and strongly correlated with yield (r=-0.88). This indicates that the yield can be increased due to the decreasing slope.
5. In the future, this research needs to be studied extensively, comparing it with meteorological data and soil parameters.

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