SOIL MOISTURE ANALYSIS USING MULTISPECTRAL DATA IN NORTH CENTRAL PART OF MONGOLIA

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ABSTRACT:

Soil moisture (SM) content is one of the most important environmental variables in relation to land surface climatology, hydrology, and ecology. Long-term SM data-sets on a regional scale provide reasonable information about climate change and global warming specific regions. The aim of this research work is to develop an integrated methodology for SM of kastanozems soils using multispectral satellite data. The study area is Tuv (48°40′30″N and 106°15′55″E) province in the forest steppe zones in Mongolia. In addition to this, land surface temperature (LST) and normalized difference vegetation index (NDVI) from Landsat satellite images were integrated for the assessment. Furthermore, we used a digital elevation model (DEM) from ASTER satellite image with 30-m resolution. Aspect and slope maps were derived from this DEM. The soil moisture index (SMI) was obtained using spectral information from Landsat satellite data. We used regression analysis to develop the model. The model shows how SMI from satellite depends on LST, NDVI, DEM, Slope, and Aspect in the agricultural area. The results of the model were correlated with the ground SM data in Tuv province. The results indicate that there is a good agreement between output SM and SM of ground truth for agricultural area. Further research is focused on moisture mapping for different natural zones in Mongolia. The innovative part of this research is to estimate SM using drivers which are vegetation, land surface temperature, elevation, aspect, and slope in the forested steppe area. This integrative methodology can be applied for different regions with forest and desert steppe zones.

1. INTRODUCTION

Soil moisture (SM) presents an important environmental indicator controlling and regulating the interaction between the atmosphere and the land surface. Furthermore, SM regulates the ratio of runoff and infiltration and controls major energy fluxes. Moreover, SM is also an important factor in plant productivity and it has direct influence on crop productivity. Therefore, the distribution of SM in the landscape, both spatial and temporal, is a key variable of climate system modelling. SM is one of the most important environmental variables in the relation to land surface climatology, hydrology and ecology. In face of the importance of SM, its spatial and temporal assessment is difficult. The standard procedure for SM assessment against all other SM-methods are calibrated the gravimetric method from soil probes in the field. This standard procedure is typically a point measurement. Because of local scale variations in soil properties, terrain (slope, exposition), and vegetation cover the derivation of representative SM-distributions in the field sites is very difficult. Furthermore, field methods are labor intensive, expensive, and sometimes difficult to undertake in the Mongolian landscape. The most accurate method to estimate SM is gravimetric sampling as mentioned above. The soil sample from the field has to be immediately measured by putting the sample for 24 to 48 h in a drying oven at 105 °C, to measure the mass of the dry soil. Further soil bulk densities are required to convert gravimetric (water mass per soil mass) to volumetric values (water volume per soil volume). A comprehensive review about various SMC-methods is presented (Verstraeten, Veroustraete, and Feyen, 2008). In contrast with the previous, remote sensing (RS) techniques which are combined with additional GIS-data are effective because of their spatially aggregated data assessment. By nature, SM is a very heterogeneous variable and varies on small scales with soil properties and drainage patterns. Therefore, information about soil types, soil properties and terrain are important. Satellite measurements integrate over relative large-scale areas, with the presence of vegetation adding complexity to the interpretation. The annual evaporation is 150~250 mm in the steppe zone and over 150 mm in desert steppe and deserted zones. There is SM decrease from north to south (Tsoozol et al., 2008).

The Mongolian horizontal zone is clearly represented in the central comparatively plain part of Mongolia, where the zone of kastanozems soils are divided into three subzones (dark kastanozem, kastanozem, and light kastanozem) (Dorjgotov, 2003). Remote sensing and GIS provide excellent tools for monitoring suitability for development of agriculture land in Mongolia (Ghar et al., 2005). Understanding the spatial and temporal variability of moisture patterns is critically important for food security in Mongolia, and other regions of central Asia. For this reason, it is essential to make research on SM and other suitable drivers for development of agricultural land in Mongolia. This research focused on developing a model for

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estimation of SM using satellite and ground truth for kastanozems soils. The kastanozems soil is the common type in Mongolia.

Many soil studies used only index, wetness index and point measurement from station. For example, Mohamed used the normalized day-night surface temperature difference index (NTDI) with moisture availability (m_a) over Mongolian Steppe during the growing season, and showed a significant inverse exponential correlation with m_a. This result indicates that the NTDI is useful as a surrogate of moisture availability in the steppe terrain of central Asia (Mohamed and Kimura, 2014). Cornicka et al., (2003) developed the approach and compared results with other methods of selecting moisture reference years for hydrothermal simulations. They used climate stations' data for their model (Cornicka, Djebbar, and Dalgliesh 2003; Attorre et al. 2007) determined the moisture index using precipitation and potential evapotranspiration. The moisture index, related to the potential amount of available precipitation, was the most important factor explaining the distribution of Dracaena Cinnabari. Information of climate change and SM from special sensor microwave/imager (SSM/I) was used for African continent (Lu et al., 2013). They concluded that such information is useful in climate change study, but it is only at point scale and is only available at limited locations.

The innovation part of our research is to consider elevation slope and aspects with other environmental drivers in forested mountain and agricultural areas for soil estimation. The elevation, slope and aspect were applied for this methodology which have not been considered in previous studies.

Mongolia also needs satellite image processing for the SM analysis. It will be useful for agriculture and pastureland. This paper proposes that it is important to consider elevation, slope, and aspect for SM in mountainous areas.

2. STUDY AREA AND USED MATERIALS

2.1 Study area

The study area is Bornuur soum from the central agricultural area in Tuv province (48°40'30"N, 106°15'55"E) and located in the forest steppe zone (Figure 1). Four different soil types: kastanozems, greysols, leptosols, cambilsols dominate in Bornuur (Dorjgotov, 2003). Precipitation is 200~300 mm/year and elevation of the study area is 872~1821 m. Bornuur is one of the crop areas in Mongolia. The dominate plants are allium Mongolicum, Iris potaninii, Patriniasibirica and Scutellariabaicalensis (Bayartogtokh et al., 2015).

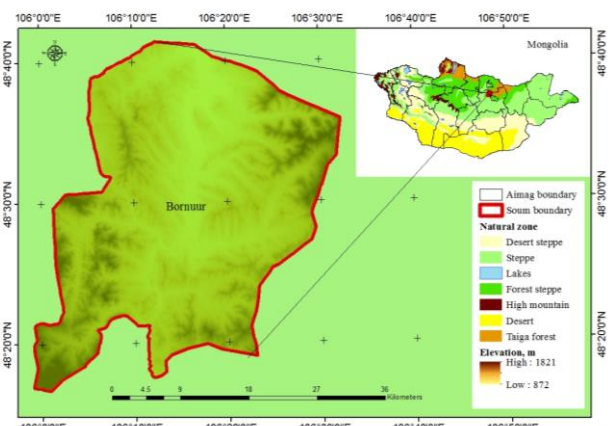

Figure 1. Study area (Bornuur soum in Tuv province in Mongolia)

The thematic soil map with four types of soils and color combination bands 5, 4 and 3 from ETM (Figure 2) was used for the comparison in the research. The kastanozems soils from the study area were investigated for the SM analysis.

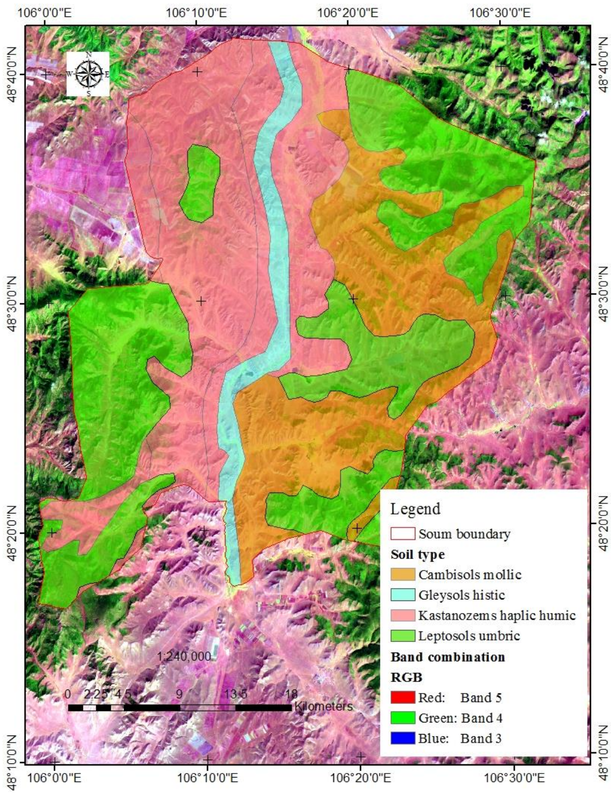

Figure 2. Color composite image from Landsat +ETM bands which are 5, 4 and 3 and thematic soil map (source: Institute of Geography, Mongolian Academy of Science).

2.2 Datasets

2.2.1 Landsat ETM+ & OLI8 satellite data: Landsat 7 enhanced thematic mapper (ETM) image (19 September 2011, path 132, row 26) was downloaded from the USGS earth resource observation and science center (EROS) website, and applied for this research. Landsat ETM+ has a strip. We used Landsat gapfill method to remove the strips (http://glovis.usgs.gov/).

2.2.2 ASTER satellite data: In order to develop elevation, aspect, slope we used advanced spaceborne thermal emission and reflection radiometer (ASTER) satellite, global digital elevation model (GDEM) data with 30 m resolution. The ASTER GDEM covers land surfaces between 83°N and 83°S, and is composed of 22,600 1°-by-1° tiles. The ASTER GDEM is in GeoTIFF format with geographic lat/long coordinates and a 1 arc-second (30 m) grid of elevation postings. It is referenced to the WGS84/EGM96 geoid. Pre-production estimated accuracies for this global product were 20 m at 95% confidence for vertical data and 30 m at 95% confidence for horizontal data (http://gdem.ersdac.jspacesystems.or.jp/).

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2.2.3 Ground truth data: SM data was collected during the field trips in Bornuur, Tuv province using traditional method. We took soil samples from the depth 0~50 cm in September 2011 (Table 1, all the corresponding soil types are kastanozems). Traditional method was developed in the following way. First, we collected soil sample data in the study area and found its weight. Next is to dry soil. Traditional method allowed us to measure amount of moisture using dried soil samples (Equation 1).

$$W = (a \cdot 100)/b \tag{1}$$

where W is the SM from traditional method;
a is the amount of water in soil;
b is the dried soil.

Latitude	Longitude	Acquired date	SM		
			(%)	(g)	(mm)
48° 37' 43.68"	106° 09' 11.88"	9/20/2011	5.6153	7.6299	9.474
48° 37' 45.12"	106° 09' 14.76"	9/20/2011	5.7114	10.3022	8.609
48° 37' 46.56"	106° 09' 16.92"	9/20/2011	5.9329	7.9736	9.238
48° 36' 52.56"	106° 06' 52.56"	9/20/2011	7.0703	6.4935	8.446
48° 36' 50.04"	106° 06' 50.04"	9/20/2011	7.3942	6.5171	10.313
48° 36' 52.56"	106° 06' 47.16"	9/20/2011	3.4012	5.4895	7.651
48° 40' 49.08"	106° 16' 23.52"	9/19/2011	2.6161	7.8169	7.947
48° 40' 49.08"	106° 16' 28.56"	9/19/2011	2.4655	7.1989	10.103
48° 40' 50.16"	106° 16' 32.88"	9/19/2011	2.1816	9.3878	11.635
48° 40' 44.04"	106° 16' 24.06"	9/19/2011	2.1605	8.8401	12.275
48° 40' 45.48"	106° 16' 28.92"	9/19/2011	2.2932	8.2269	10.841
48° 40' 45.84"	106° 16' 31.08"	9/19/2011	2.2607	8.6510	9.084

Table 1. Ground truth measurement in Bornuur soum, 18~20 Sept. 2011

3. INTEGRATION METHOD FOR SOIL MOISTURE ANALYSIS

The Equation (2) is used as atmospheric correction for the images in this research (Chavez, 1996). The correction map is in Figure 2.

$$REF = \frac{\pi \cdot (Lsat - Lhaze)}{TAUv \cdot (Eo \cdot \mathrm{Cos}(TZ) \cdot TAUz + Edown)} \tag{2}$$

where:

REF is the spectral reflectance of the surface;
Lsat is the satellite spectral radiance for given spectral bands;
Lhaze is the upwelling spectral radiance (path radiance), value derived from image using dark-object criteria; calculated by using the dark object criteria (lowest value at the base of the slope of the histogram from either the blue or green band);
TAUv is the atmospheric transmittance along the path from ground to sensor, assumed to be 1 because of nadir look angle;
Eo is the solar spectral irradiance;
TZ is the solar zenith angle;
TAUz is the atmospheric transmittance along the path from the sun to the ground surface;
Edown is the down welling spectral irradiance at the atmosphere (Chavez, 1996).

The method schema is illustrated in Figure 3.

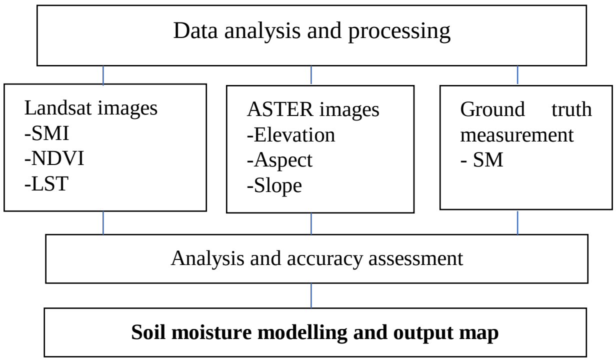


Figure 3. Method schema

SMI was calculated using the Landsat +ETM 7 bands 1 and 4 (Lewis, 1999) Equation (3) for the study area in kastanozems soil (Figure 4).

$$SMI = \frac{NIR}{VisBlue} \tag{3}$$

where *NIR* is the near infrared channels (0.77~0.90 μm); *VisBlue* is the visible blue channels (0.45~0.52 μm).

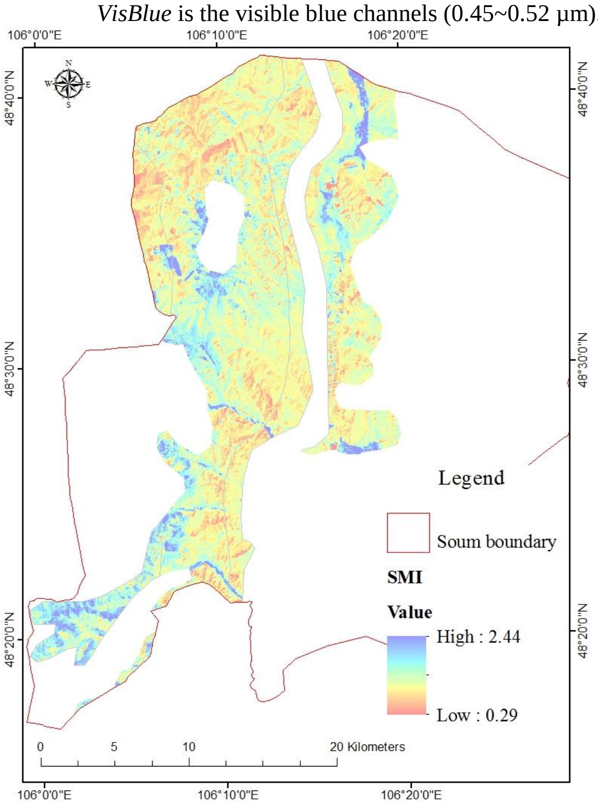


Figure 4. SMI map from Landsat +ETM7

The red (*RED*) and *NIR* channels from ETM were applied in Equation (4) for NDVI calculation (Sellers et al., 1994) (Figure 5):

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{4}$$

The LST was calculated using Equation (5) by (Weng, Lu, and Schubring, 2004) (Figure 6):

$$LST = (\mathrm{BT} + w \cdot \frac{BT}{p}) \cdot \ln(e) \tag{5}$$

where *BT* is the satellite brightness temperature (K);
w is the wavelength of emitted radiance (11.5µm);
p= h*c/s (1.438*10^–2 m K),
h is the Plank's constant (6.626*10^–34 Js);
s is the Boltzman constant (1.38*10^–23 J/K),
c is the velocity of light (2.998*10^8m/s);
$e = 0.004*P_v + 0.986$,
$P_v = (NDVI–NDVI_{min}/NDVI_{max}–NDVI_{min})^2$ is the proportion of vegetation.

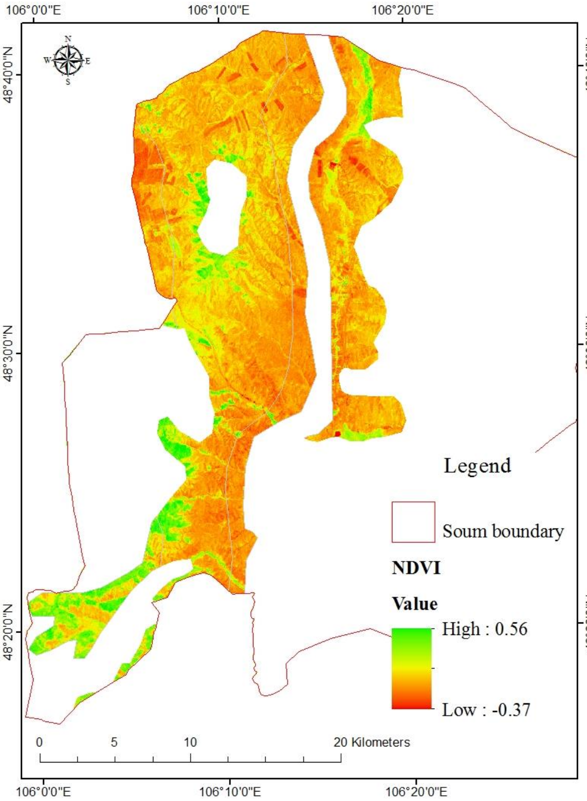


Figure 5. NDVI map from Landsat +ETM7

For elevation, aspect and slope, we used ASTER satellite, GDEM data for 30 m resolution. Figure 7 illustrates the elevation, aspect and slope from 30 m resolution from ASTER in kastanozems soil, Bornuur soum.

In order to develop the model for estimation SM we used the regression analysis. Outputs from the analysis were compared to ground truth data.

We assume SM derived from satellite and it depends on variables such as LST, NDVI, elevation, aspect and slope. F is function of dependent variables, shown as Equation (6).

$$PSMI=F(NDVI, LST, Elevation, Aspect, Slope) \quad (6)$$

Therefore, for this assumption, the multivariate regression analysis was selected. The multi-dimensional linear regression model can be described as:

$$y_i=\beta_0+\beta_1x_{i1}+\beta_2x_{i2}+\beta_3x_{i3}+\beta_4x_{i4}+\beta_5x_{i5} \quad (7)$$

where y_i is the observation variable;
β_0 is the intercept,
β_1~β_5 is the coefficients;
x_i is the variables.

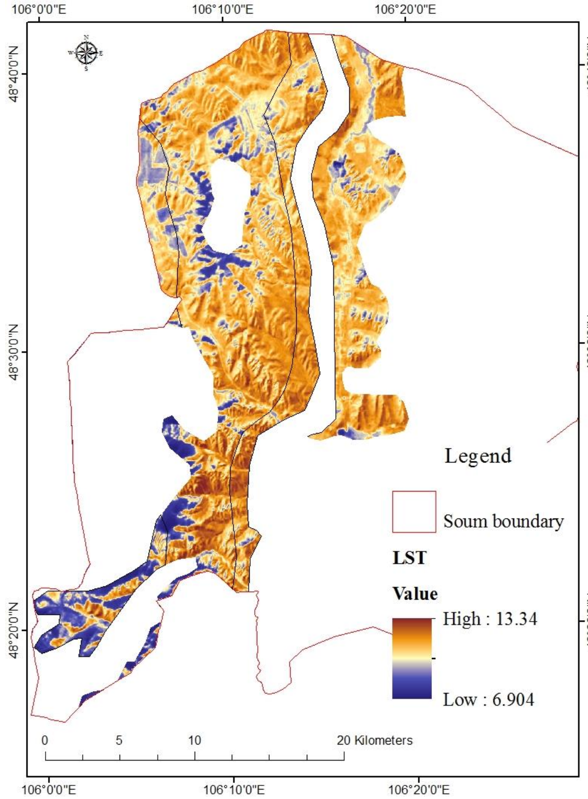
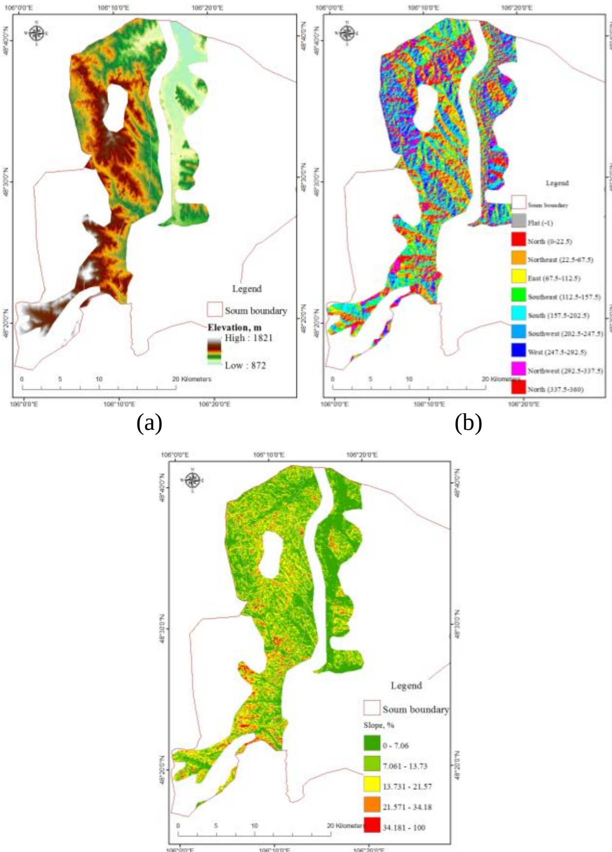


Figure 6. LST map from Landsat +ETM7



(a) (b)
(c)
Figure 7. (a) Elevation map, (b) Aspect, (c) Slope in Bornuur soum; source: ASTER-SRTM 30 m resolution data

Collinearity test for all variables (NDVI, LST, elevation, aspect, and slope) were estimated in table 2. B is regression coefficient of unstandardized coefficients, Std.Error is Standard error of unstandardized coefficients, Beta is beta coefficient of standardized coefficients, t is t-statistics for the coefficients, Sig. is significance of collinearity.
In order to develop the SM model, we used multiple regression analysis (Equation (7)). The variance inflation factor (VIF) values are between 1~10, which shows that there is no multicollinearity for the regression model (Table 2). Also, correlation analysis showed that there are no strong correlations between independent variables. The independent variables are NDVI, LST, elevation, aspect and slope.

Coefficients*							
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF (1-10)
(Constant)	0.542	0.225		2.407	0.053		
NDVI	1.183	0.226	0.348	5.238	0.002	0.682	1.466
LST (^{0}C)	0.022	0.004	0.728	5.953	0.001	0.201	4.965
Elevation (m)	0.000	0.000	–0.257	–1.647	0.151	0.124	8.097
Aspect (0-360^0)	–7.167E–006	0.000	–0.005	–0.054	0.959	0.321	3.116
Slope (%)	–0.004	0.005	–0.073	–0.829	0.439	0.390	2.563
*: Dependent variable: SMI							

Table 2. Result of regression analysis

From the assumption (Equation (6)), we developed the model for predicted soil moisture. Equation (8) was used for the development of predicted SMI (PSMI) of the model in this research:

$$PSMI = 0.348 * NDVI + 0.728 * LST - 0.257 * Elevation - 0.005 * Aspect - 0.073 * Slope \quad (8)$$

4. RESULTS

To validate the model, we selected 12 samples from Table 1 (additional 21 points) where ground truth for SM was measured.
There's a significant positive relationship between SMI and PSMI (p<0.001) in the table 3 and figure 8. The scatter plot of the PSMI from the model and SMI from satellite is shown in Figure 8 with (R^2=0.903) for kastanozems soil.

		Prediction SMI	SMI
Prediction SMI	Pearson Correlation	1	0.951**
	Sig. (2-tailed)		.000
	N	33	33
SMI	Pearson Correlation	0.951**	1
	Sig. (2-tailed)	.000	
	N	33	33
**. Correlation is significant at the 0.01 level (2-tailed).			

Table 3. Correlations between the PSMI and SMI

Also, there are significant positive relationship between ground truth measurement and PSMI (p<0.001) in the table 4 and figure 9. The ground measurement data was compared with the PSMI from the model (R^2=0.65) (Figure 9).

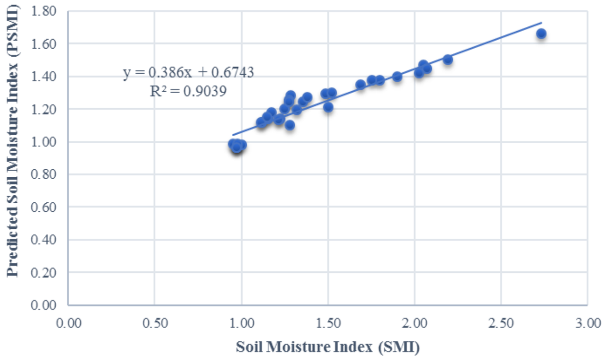


Figure 8. Relationship of SMI from satellite and PSMI

		SM (mm)	Preciction SMI
SM (mm)	Pearson Correlation	1	.806**
	Sig. (2-tailed)		.000
	N	33	33
Prediction SMI	Pearson Correlation	.806**	1
	Sig. (2-tailed)	.000	
	N	33	33
**. Correlation is significant at the 0.01 level (2-tailed).			

Table 4. Correlations between the ground truth measurement and PSMI

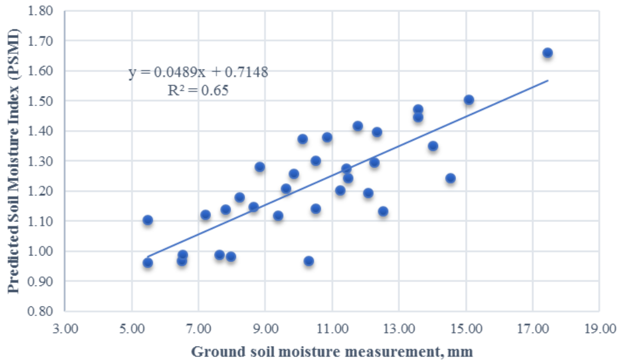


Figure 9. Relationship of ground soil moisture measurement and PSMI

We used the Equation (8) for the estimation of kastanozems soil in the Table 5. This output was compared with ground truth data and shows moisture positive relation. In the table 5, the variables are described in detail. For instance, the soil moisture ground truth measurement, soil moisture index (SMI), normalized difference vegetation index (NDVI), land surface temperature (LST), elevation, aspect, slope and predicted soil moisture index (PSMI).

SM ground truth measurement (mm)	SMI from satellite	NDVI	LST (°C)	Elevation (m)	Aspect (0-360^0)	Slope (%)	PSMI
9.474	0.95	0.03	31.19	1072	285.95	4.77	0.99
8.609	0.97	0.03	29.75	1070	270.00	2.62	0.97
9.238	1.00	0.04	29.75	1071	270.00	1.97	0.98
8.446	0.98	0.00	33.08	1181	288.43	6.22	0.97
10.313	0.98	0.01	33.08	1188	285.95	4.77	0.99
7.651	0.97	0.01	32.38	1173	298.61	8.22	0.96
7.947	1.15	–0.01	38.62	900	185.71	6.59	1.14

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10.103	1.12	–0.02	37.71	905	185.19	3.62	1.12
11.635	1.12	–0.01	37.71	899	18.43	7.26	1.12
12.275	1.28	0.10	38.39	900	263.66	2.97	1.28
10.841	1.17	0.02	38.62	904	236.31	4.73	1.18
9.084	1.15	0.00	37.94	904	243.43	2.93	1.15
11.48	1.36	0.27	29.92	1072	175.10	6.71	1.24
12.26	1.49	0.31	29.92	1070	175.10	4.20	1.30
14.01	1.69	0.38	29.92	1071	210.06	11.56	1.35
12.11	1.80	0.43	29.98	1194	55.89	13.56	1.37
13.57	2.05	0.49	29.98	1188	13.67	7.49	1.47
11.75	2.03	0.45	29.98	1173	58.40	11.61	1.42
10.50	1.52	0.29	29.75	934	130.03	5.27	1.30
11.23	1.25	0.16	33.08	935	147.70	9.43	1.20
10.50	1.22	0.10	33.08	936	147.30	6.31	1.14
9.87	1.28	0.20	32.38	930	73.30	3.56	1.26
12.34	1.90	0.20	38.62	927	161.60	1.43	1.40
12.09	1.32	0.18	29.92	930	158.90	0.00	1.20
7.49	1.28	0.13	29.98	912	145.50	9.48	1.10
12.54	1.22	0.14	29.98	918	171.50	3.54	1.13
14.54	1.27	0.23	29.98	919	185.90	3.35	1.24
9.63	1.50	0.28	29.75	900	63.43	27.57	1.21
15.09	2.19	0.50	29.75	905	210.97	16.55	1.50
17.44	2.73	0.60	29.75	899	177.88	8.58	1.66
11.44	1.38	0.21	33.08	905	24.77	8.07	1.27
10.85	1.76	0.36	29.92	904	10.01	9.48	1.38
13.57	2.07	0.46	29.98	904	8.13	21.56	1.45

Table 5. Kastanozems soil's measurement in Bornuur soum, 18~20 Sept. 2011

For the test model, Equation (8) was applied to another 25 points in Bornuur (Table 6) and developed soil moisture map (Figure 10). The table 6 shows the additional points with the estimated variables (SMI, LST, Elevation, Aspect, Slope and PSMI).

Latitude	Longitude	SMI	LST (^{0}C)	NDVI	Elevation (m)	Aspect (0-360^0)	Slope (%)	PSMI
106° 9' 12"	48° 37' 43.8"	0.9512	31.187	0.0263	1072.0	285.945	4.774	1.023
106° 9' 14.6"	48° 37' 45.3"	0.9744	29.746	0.0270	1070.0	270.000	2.623	1.002
106° 9' 17"	48° 37' 46.7"	1.0000	29.746	0.0380	1071.0	270.000	1.967	1.017
106° 6' 52.4"	48° 36' 52.6"	0.9756	33.084	0.0000	1181.0	288.435	6.221	1.007
106° 6' 50.4"	48° 36' 50.4"	0.9750	33.084	0.0130	1188.0	285.945	4.774	1.026
106° 6' 47.3"	48° 36' 52.6"	0.9744	32.376	0.0133	1173.0	298.610	8.216	1.000
106° 16' 23.7"	48° 40' 49.1"	1.1522	38.619	–0.0093	900.0	185.711	6.590	1.172
106° 16' 28.4"	48° 40' 49.9"	1.1176	37.712	–0.0172	905.0	185.194	3.621	1.154
106° 16' 32.9"	48° 40' 50.5"	1.1154	37.712	–0.0085	899.0	18.435	7.258	1.151
106° 16' 24.7"	48° 40' 44.6"	1.2826	38.393	0.1028	900.0	263.660	2.969	1.314
106° 16' 28.8"	48° 40' 45.4"	1.1739	38.619	0.0189	904.0	236.310	4.729	1.212
106° 16' 31.2"	48° 40' 45.9"	1.1489	37.940	0.0000	904.0	243.435	2.933	1.182
106° 16' 16.6"	48° 40' 48.5"	1.205	38.17	0.093	909	184.90	11.517	1.261
106° 16' 44.56"	48° 40' 38.34"	1.180	36.80	–0.025	895	40.43	11.629	1.095
106° 16' 40.29"	48° 40' 35.6"	1.340	37.26	0.068	907	0.00	1.311	1.253
106° 16' 36.41"	48° 40' 35.86"	1.306	37.71	0.058	904	315.00	3.709	1.242
106° 16' 42.76"	48° 40' 43.72"	1.204	38.85	0.009	886	74.36	8.512	1.193
106° 16' 40.62"	48° 40' 48.88"	1.189	37.71	–0.023	906	41.99	8.822	1.126
106° 17' 9.25"	48° 40' 29.71"	1.111	43.29	0.042	893	193.39	7.078	1.334
106° 17' 12.25"	48° 40' 33.32"	1.152	44.16	0.060	903	284.74	6.442	1.376
106° 16' 30.5"	48° 40' 19.43"	1.184	43.29	0.045	934	340.46	10.785	1.315
106° 16' 50.31"	48° 40' 22.85"	1.128	41.31	0.050	895	68.20	7.062	1.300
106° 16' 40.81"	48° 40' 30.67"	1.170	43.51	0.019	900	27.87	3.738	1.324
106° 9' 35.81"	48° 37' 57.5"	0.905	29.75	0.040	1073	8.62	10.943	0.983
106° 9' 52.73"	48° 38' 2.47"	0.927	30.47	0.000	1052	62.82	13.637	0.945

Table 6. SM related drivers in Bornuur soum (additional points)

The results of the PSMI model was compared with the ground SM measurement (traditional) data in Tuv province (r^2=0.65). The output map from the modelling for kastanozems soil is shown in the Figure 10. The maximum value of PSMI data is 1.56, the minimum is 0.0.

We divided PSMI into 3 classes which are low (0.0~1.0), moderate (1.1~1.5) and high (1.6~high). Also, we classified ground truth measurements into 3 similar classes (low, moderate and high). We overlaid randomly our ground truth points on the map and made validation.

In Table 6, we present the matrix evaluation for the validation. The result of PSMI was compared with ground truth measurement (table 7). PSMI result was compared with SM distribution model Erdenetsetseg (1996). The correlation coefficients were respectively 69% and 66% respectively.

		Classes derived from satellites				Commiss ion	Producer's accuracy (%)
		0-1.0	1.0-1.5	1.5<	Sum		
Ground truth measurements	low	5	2	0	7	0.29	71.43
	moderate	4	16	3	23	0.30	69.57
	high	0	1	2	3	0.33	66.67
	Sum	9	19	5	**33**		
Omission		0.44	0.16	0.60			
User's accuracy (%)		55.56	84.21	40.00			
Overall accuracy: 69.70 %; Kappa coefficient: 0.43							

Table 7. Comparison of developed model and ground measurements

The positive results (Figure 8 and Figure 9) should be investigated further, and it needs a more detailed analysis of high-resolution satellite data.

5. CONCLUSSION

The long-term moisture will be useful for climate change, drought monitoring and other environment studies. The moisture index was estimated for central part of Mongolia based on MODIS-PET and precipitation station data during the growing season from May – August of 2000-2013. SM is vital for Mongolian agriculture development. SM analysis is needed to assist dry land grain growers to make improved and informed decisions.

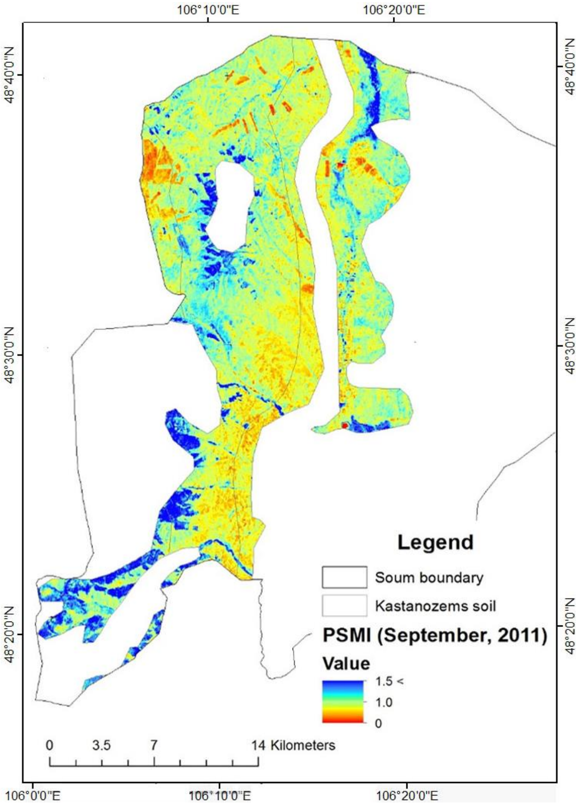

Figure 10. Soil moisture map from the model on kastanozems soil

Since less research has been carried out in dry land, policy makers at regional level were not available to make decisions for crop growers in central agricultural areas. This research will aid the crop sector to develop agriculture land, and improve crop quality to expand the Mongolian food demand. SM monitoring also will provide useful insights for pasture land management in other regions of Mongolia. The model developed for this research could be applied for other ecological zones. Only forest steppe region was taken for the analysis. This model (PSMI) can be applied for the same regions using remote sensing methodologies.

In the future, we will apply the integrative model all over the Mongolian landscapes. Since Mongolia has six different landscapes. SM monitoring is important for Mongolian agricultural development. There is a regional plan to develop agricultural land in Mongolian mountain forested areas.

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