

MONITORING DROUGHT STRESS INDEX IN WHEAT FIELD OF MONGOLIA USING REMOTE SENSING

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ABSTRACT

Water stress during crop growth, even during short periods of a couple of weeks, is a major cause of yield reduction. The complexity in defining the magnitude of such water stress is due to diversity of crops grown in a given location, variability in soil type and conditions, spatial variability of rainfall, delay in timely of agriculture, and diversity in crop management practices. The problem associated with drought is a recurrent feature in Mongolia. In fact drought is a significant environmental problem too as it is caused by less than average rainfall over a long period of time. In Mongolia about 95 percent of total wheat sown area of the country is rain fed. Mongolian grain productivity needs to occur in an environmentally sustainable manner.

Remote sensing technology is an economical and promising tool for obtaining land surface parameters. A drought index based on land surface temperature should be more efficient than those based on NDVI.

This study was investigates the use of remote sensing data for essential factors for crop growth in cropland area of Mongolia. In this case were used on cloud-free Landsat-7 ETM+ image of Tsagaannuur district of Selenge province, Mongolia for land surface temperature retrieval.

In conclusion, remotely-sensed water stress index provided a useful tool for the evaluation of crop water status especially that of wheat in Tsgaannuur, Mongolia and could be useful for rain fed cropland area and irrigation scheduling.

Keywords: NDVI, Land surface temperature, remote sensing, Mongolia

INTRODUCTION

Mongolia is located in an arid region and climate change reduces crop production due to increased demand for water. Wheat is produced in the high potential areas of Mongolia, which cover only 0.07 % of the total land area.

In Mongolia about 95 percent of total wheat sown area of the country is rain fed. Mongolian grain productivity needs to occur in an environmentally sustainable manner.

Wheat was introduced in Mongolia towards of 1950 of the between the 20th century and has since been grown on an increasing scale in the northwest areas. The wheat growing areas between the 800 and 1200 m, and receive more than 350 mm of rainfall per annum. Due to increasing population and changing lifestyles the demand for wheat has steadily been increasing.

Agricultural production and climate are closely linked, which means any change in climate will affect agricultural production. Climate change will affect the production directly and indirectly, for example, increasing temperature in a specific region will increase evapotranspiration, and therefore, the water requirements of crops especially summer crops. The length of the growing seasons and tolerance to pests and diseases will also be affected.

Water stress during crop growth, even during short periods of a couple of weeks, is a major cause of yield reduction. The complexity in defining the magnitude of such water stress is due to diversity of crops grown in a given location, variability in soil type and conditions, spatial variability of rainfall, delay in timely of agriculture, and diversity in crop management practices. The problem associated with drought is a recurrent feature in Mongolia. In fact drought is a significant environmental problem too as it is caused by less than average rainfall over a long period of time.

Remote sensing technology is an economical and promising tool for obtaining land surface parameters. A drought index based on land surface temperature should be more efficient than those based on NDVI. The drought index that based on normalized difference vegetation index (NDVI) falls short in monitoring drought because NDVI is a rather conservative indicator of water stress, which means that vegetation remains green after initial water stress (Sandholt, 2002). In contrast, land surface temperature (T_s) is more sensitive to water stress (Goetz, 1997). In fact canopy and surface radiation temperature have been suggested as water stress indicators since the early 1960s (Tanner, 1963) and have been popularized since the early 1980s (Jackson, 1981).

The objective of this study is to demonstrate the use of Water Deficit Index (WDI) derived from LANDSAT satellite data for analyzing wheat area.

STUDY AREA

The selected study area Tsagaannuur district is located in the Selenge province, in northeastern Mongolia.

This study area is one of the biggest wheat regions of Mongolia and it is an ideal area for any research related to the environmental problems.

Climate constraints, with unpredictable year-to-year irregularity in rainfall result in reduction of crop productivity. This makes agricultural crop planning difficult, especially in rural areas.

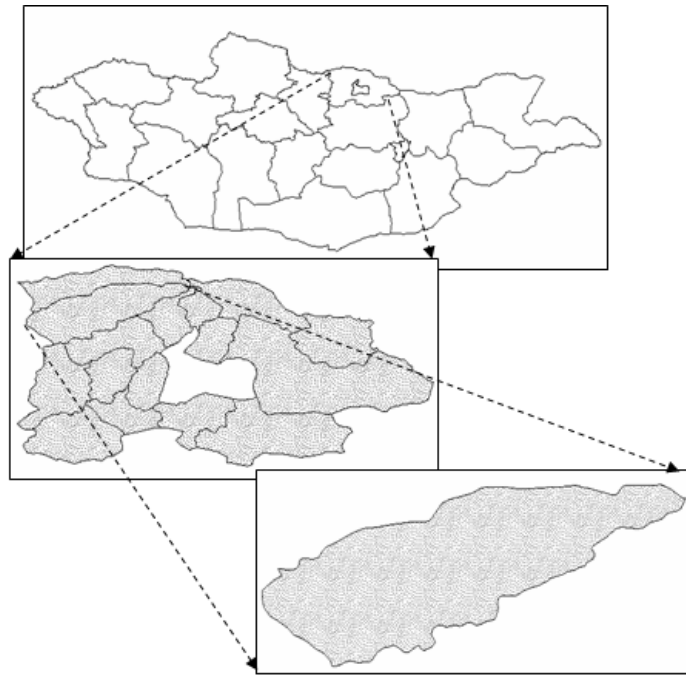


Figure-1. Study area Tsagaannuur district, Selenge province, Mongolia

The climate of the region is semi-arid and the mean annual precipitation is 250-301 mm. The main crops being grown in this region are wheat, fodder crops, potato, and some vegetables. Except for wheat, all other crops are rain fed. The planting dates of wheat and fodder crops are mostly planted in from the mid of May to end of September. Almost all the crops present an important vegetative development in the June–August period. The wheat is harvested between September and early October. Some times rains very late and light in this region, while farmers using artificial cloud insemination methodology.

MATERIALS AND METHODOLOGY

Landsat Enhanced Thematic Mapper (ETM+) image (with path/row 131/26) used and acquired 2000 years and image is cloud free and of good quality.

One image generated by the enhanced thematic mapper (ETM) sensor on board of the LANDSAT 7 satellite were used, covering spectral band 3 (red, with 28.5m pixel resolution), band 4 (near infrared, with 28.5m pixel resolution) and band 6 (thermal infrared, with 60m pixel resolution). In the case of the thermal band (band 6), it was necessary to resample the image to the same resolution of bands 3 and 4. Image processing was carried out with ENVI 4.8 and ERDAS imagine programming tool. The normalized difference vegetation index (NDVI) was computed with the red and near infrared bands. This module uses the following algorithm to determine NDVI:

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

Where:

NIR and R are the reflectances in the near infrared and red bands, respectively. Surface temperature (T_s) was computed with the thermal infrared

band. ERDAS relies on a conversion algorithm based on tables published by Bartoliucci and Chang (1988).

Vegetation lamina tissues strongly absorb incident radiances in blue, purple and red wavelengths and intensively reflect the near infrared (NIR) spectrum. The thicker the vegetation density, the smaller the reflectance in Red and the higher the reflectance in NIR bands become. Because the absorption of the Red range is saturated quickly, only the increase of reflectance in the NIR region could reflect the increase of vegetation. Then, from Red to NIR spectral region, the reflectance of bare soil is high but increases slowly. However, due to the strongest absorption by water, bare soil reflectance decreases distinctly with the increasing of soil moisture especially in the near infrared domain. Therefore, any mathematical operation which could strengthen the difference between NIR and Red could be used to describe the vegetation, surface drought status and discriminate the soil information from the vegetated pixel. All of vegetation indices were based on this theory. Figure-3 is showing methodology.

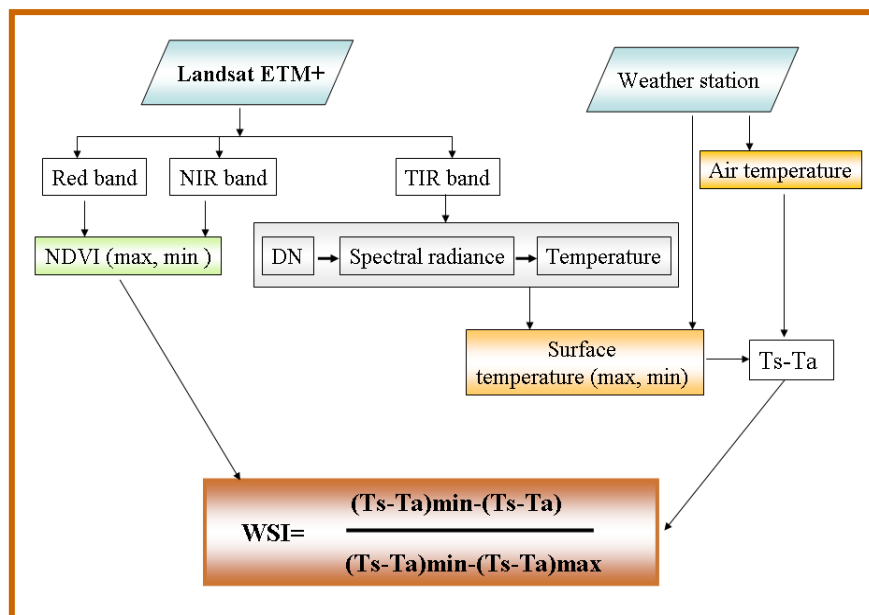


Figure-3 Flow chart of methodology

We determined 2 main values from remote sensing data.

1. Soil line and intercept
2. Surface temperature

Soil line:

Soil line is a linear relationship between the NIR and RED reflectance of bare soil originally discovered Richardson and Wiegand (1977).

$$NIR_{soil} = aR_{soil} + b \quad (2)$$

Where a-soil line slope, b-intercept

The soil line is made up of plots characterizing the spectral behavior of non-vegetated pixels and whose moisture varies obviously. It is not difficult to see from the Figure-4.

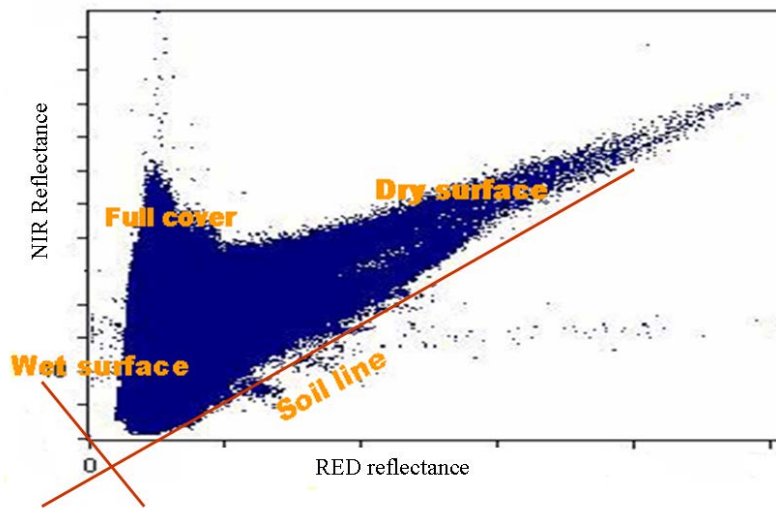


Figure-4 Construction of NIR-Red spectral space using ETM data

The remote sensing method utilized here to determine water crop stress is based on Moran et al, (1994). As explained before, the relationship between $(T_s - T_a)$ and vegetation cover is defined in a trapezoidal (from R and NIR scatter plotter) shape. The vertices of the trapezoid indicate extreme canopy cover and $(T_s - T_a)$ conditions for a specific crop. Vertex 1 represents full vegetation cover and well watered conditions. When crops are not experiencing water stress, the canopy resistance is at minimum.

Hence, when plants are fully transpiring, there is no opposition to water flow and the value is zero. Aerodynamic resistance is also an opposition to flow, and is defined as the resistance from the vegetation toward the atmosphere and involves friction from air flowing over vegetative surfaces (Allen et al., 1998). All these processes produce a larger negative difference between $T_s - T_a$. Vertex 2 captures full vegetation cover under drought. Vertex 3 is saturated bare soil and vertex 4 is dry bare soil. Vertices 2 and 4 implies that crop experiences nearly completely stomatal closure, and, since canopy resistance is directly proportional to stomatal resistance, therefore, $r_c = 1$ and would produce a more positive $T_s - T_a$ value. For this theoretical shape, the term vegetation index/temperature trapezoid is utilized. The lines that connect the four vertices have a particular meaning. The line connecting vertices 1 and 2 is the range of all possible values from well watered, transpiring full cover canopy (vertex 1), to a highly stressed, non-transpiring full cover canopy (vertex 2). The line connecting vertices 1 and 4 describes potential evapotranspiration. Finally, the line connecting vertices 2 and 3 defines the zero ET condition because the surface is completely dry.

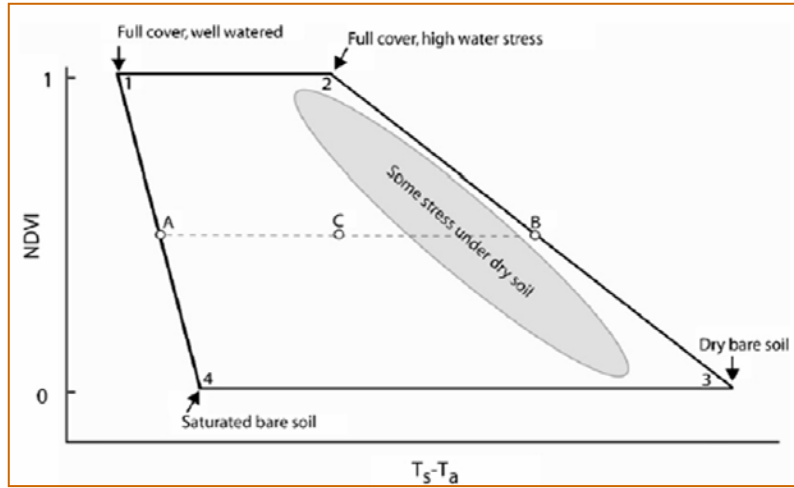


Figure-5 Moran's trapezoid derived from Figure-4 (Moran et al., 1994)

However, there is one important assumption to consider for the construction of the trapezoid. This assumption relies in considering that $(T_s - T_a)$ is a linear function of vegetation cover, whereby, the lines connecting the vertices 1-4 and 2-3 are straight (Moran et al., 1994). This statement is supported by Kustas and Daughtry (1990) who found that T_s could be calculated from air, soil and canopy temperature and vegetation cover measurements taken in Arizona. For a particular set of $(T_s - T_a)$ and vegetation index (for example, point "C" in Fig 5), the ratio of the AC/AB distances is defined as the water deficit index. As a result, WDI = 0 refers to conditions under irrigation and WDI = 1 to conditions of maximal stress. In addition, the ratio of the distances CB/AB is defined as the relationship between the actual and potential evapotranspiration (Moran et al., 1994).

To determine the corners of the empirical trapezoid, measured extreme values of wheat NDVI (full cover under wet and dry soil) and the difference between surface and air temperature (full, partial foliage and bare soil) were used.

In the case of drought conditions, the average value of $(T_s - T_a)$ was 0 (with the maximum 1°C), with an NDVI value of 0.9 for full cover. Once the vertices were defined and the empirical trapezoid was built, the equations of the straight lines formed by the vertices 2-3 and 1-4 were obtained. The equation of the straight line formed by vertices 1-4 provides the point of the minimal value of $(T_s - T_a)$ for a given value of NDVI (point "A" in Fig. 5) as

$$(T_s - T_a)_{\min} = a_1 - b_1 NDVI \quad (3)$$

Where: a_1 and b_1 are the intercept and slope of the straight line with vertices 1-4. On the other hand, the equation of the straight line formed by vertices 2-3 supplies point "B" or the maximum value that $(T_s - T_a)$ can have for a given NDVI value as:

$$(T_s - T_a)_{\max} = a_2 - b_2 NDVI \quad (4)$$

From formula (2) and (3) given us for our general methodology how to define water stress index (see Figure-3 shown general methodology).

Final formula is:

$$WSI = \frac{(a_1 - b_1 NDVI) - (T_s - T_a)}{(a_1 - b_1 NDVI) - (a_2 - b_2 NDVI)} \quad (5)$$

The images are used to estimate the parameters required to compute water stress on wheat. Surface temperature (T_s) was computed with the thermal infrared band. The soil line and intercept are made up of plots characterizing the spectral behavior of non-vegetated pixels and whose moisture varies obviously.

Land surface temperature (LST) defines:

In estimation of LST from TIR data, the digital number of the image pixel needs to be converted into spectral radiance using the sensor calibration data (Markham and Barker, 1986) and emissivity correction. The methodology of LST define algorithm is very easy. All algorithms are available in the Landsat data guide.

Converting ETM+ thermal bands to temperature:

The Landsat Enhanced Thematic Mapper Plus (ETM+) sensors acquire temperature data and store this information as a digital number (DN) with a range between 0 and 255. The first step is to convert the DNs to radiance values. The second step converts the radiance data to degrees Kelvin. In this case we calculated LST from Landsat ETM data used by with ENVI 4.8 programming tool. Land surface radiances derived from Landsat ETM+ TIR data were subsequently converted to radiance values, it is simply a matter of applying the inverse of the Planck function to derive temperature values.

For atmospherically corrected data the formula to convert radiance to temperature is:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{CV_{R2}} + 1\right)}$$

Where: T is degrees Kelvin

CV_{R2} is the atmospherically corrected cell value as radiance (from step 2)

$K_1=666.09$

$K_2=1282.71$

LCT Validation

One of the major problems in the validation of remote sensing data with ground truth observation is the dissimilarity between the spatial scales of field thermometers or local observation office data and that of satellite sensors. The comparison of local observation centers data with that of satellite (area averaged) data is meaningful only when the test site is homogeneous in temperature and emissivity at various spatial scales involved.

RESULTS AND CONCLUSION

In this case were used on cloud-free Landsat-7 ETM+ image of Tsagaannuur district of Selenge province, Mongolia for LST retrieval.

Figure-6 shows final calibrated image of the study area and Figure-7 shows the empirical trapezoid compared with field and remote sensing data.

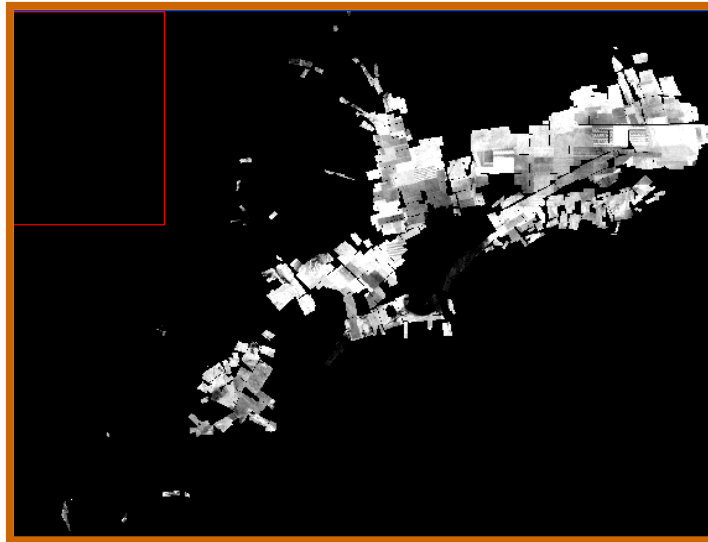


Figure-6 Calibrated image 2002-07-24 ETM+,
Study area Tsagaannuur, Selenge

The blue points represent randomly chosen remotely sensed measurements from the area planted with wheat. Both sampling methods were done to verify that all the samples fall within the limits of the empirical trapezoid.

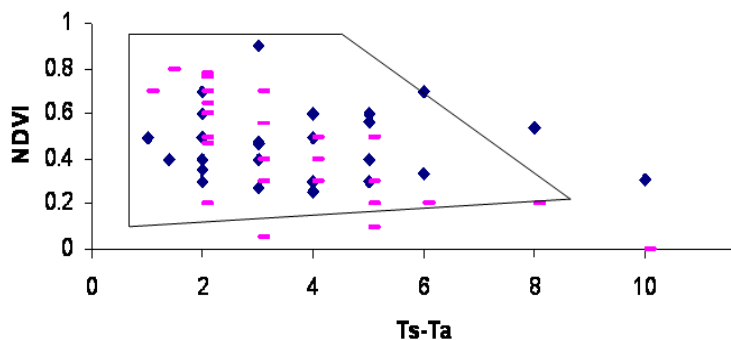


Figure-7 WSI in wheat field

This study shows a good agreement of LST derived from Landsat-7 ETM+ TIR data with ground temperatures over thermally homogeneous wheat area and present study has found a significant result for crop drought monitoring by integration of satellite data and meteorological data.

The trapezoidal shape obtained in this work was very similar to that from Moran et al. (1994) and Yang et al. (1996); however, it differs in the range of NDVI and (Ts-Ta) values. The trapezoid method should be applied for each specific crop in order to optimize water stress determination and irrigation management.

LANDSAT data allows estimation of the amount of water stress on small lots and parcels and in large crop fields, in part due to its broad swath width and high spatial resolution. As a result, remote sensing allows estimation of crop water dynamics at both regional and local scales. Furthermore, rapid developments in remote sensing, with the incorporation of improved satellites or sensors, may lead improved accuracy and new applications in the near future.

LST retrieval is quite useful for frequent monitoring of any study area with greater reliability with selective ground temperature measurements. The accuracy of LST retrieved for satellite data can be further improved with accurate measurements of surface emissivity and estimates of atmospheric parameters at each pixel.

In conclusion, remotely-sensed water stress index provided a useful tool for the evaluation of crop water status especially that of wheat in Tsgaannuur, Mongolia and could be useful for rain fed cropland area and irrigation scheduling.

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