# DROUGHT ASSESSMENT OF MONGOLIA: USING REMOTE SENSING INDEX AND METEOROLOGICAL INDICES

*Battsetseg.T*[a] *, Erdenetuya.M*[b]

[a] *Remote sensing department of National Remote Sensing Center of Mongolia*

baku_5@yahoo.com

[b] *Remote sensing department of National Remote Sensing Center of Mongolia*

m_erdenetuya@yahoo.com

**KEY WORDS:** VTCI, SPI, AI, LST, NDVI

**ABSTRACT:** Mongolia is very vulnerable and harsh temperate climate. The natural disasters such as drought and heavy snowfall states are often observed there. This paper presents detection of drought by calculating the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) over the Forest steppe High Mountain and Gobi Desert zones of Mongolia during the summer growing season (April to October). Utilized data LST and NDVI was obtained long-term (11 years) datasets acquired with the Terra-Moderate Resolution Imaging Spectoradiometer (MODIS). The approach is called Vegetation Temperature Condition Index, which integrates land surface reflectance and thermal properties. VTCI is lower for drought and higher for wet conditions. Furthermore, the ground-measured precipitation and temperature data a study area covering parts of two zones of Mongolia, which used to calculate the Standardized Precipitation Index and the Aridity Index. Finally, these indices indicated the drought years.

## 1. INTRODUCTION

Drought is a natural disaster that causes a significant amount of damage to the economy and society. Drought usually occurs in dry, semi-dry and less moist areas. Mongolia is one of the most arid countries in the world. The geography of Mongolia is varied, with the Gobi desert to the south and with cold and mountainous regions to the north and west. Much of Mongolia consists of steppes. Over Gobi Desert and Desert Steppe arid and semi arid regions often occur the natural disasters such as drought and heavy snowfall states. Drought occurs on an average of once every two or three years and the heavy snowfalls occurs every 5 to 6 years and once 2 to 3 years covering half and quarter of country’s territory, respectively (Shiirevdamba, 1998). The United Nations Environment Program, (2004), suggests a conceptual definition of drought, “a prolonged and abnormally dry and hot period when there is scarcity of water for the normal needs of the affected community or ecosystem”. This general definition was also modified to further develop definitions or specific types of drought such as meteorological droughts, agricultural droughts, hydrological droughts and socio-economical droughts (UNEP, 2004).

Depending on drought and precipitation levels, the condition of the vegetation cover in the pasturelands will differ from year to year. According to a study, during drought years the vegetation cover will diminish by 12-48% in high mountain areas and by 28-60% in the Gobi and steppe regions. Global climate change affects the climate condition of Mongolia that now has an increased intensity of dryness (L.Natsagdorj, D. Dagvadorj, and P.Gomboluudev).

Many remote sensing and based on meteorological station drought indices have been using over the globe to monitor drought and in case of Mongolia the drought estimation indices have been developed and applied, such as Remote Sensing Drought Index (Bayasgalan, 2005) and Normalized Difference Drought Index (NDDI). Ground station data, such as precipitation and land air temperature possess poor spatial resolution, especially in remote regions with difficult access.

Thus I was tested Vegetation Temperature Condition Index (VTCI) and based on the meteorological indices for drought assessment. The prime objective of this study is to assess the spatial occurrences of droughts over the Desert Gobi and Forest steppe High mountain zones of Mongolia.

Sub-objectives of the research:

- To compute the vegetation temperature condition index (VTCI)
- To compute the standardized precipitation index (SPI)
- To compute the aridity index (AI)
- To analyze the differences between VTCI values retrieved from remotely sensed data and observing soil moisture data
- To assess the drought of Mongolia

## 2. CLIMATE DISCRIPTION OF THE STUDY AREA

Mongolia is situated in the central part of the Asia. The country is bounded on the north by Russia and on the east, south and west by China. Mongolia is a land-locked country which covers an area of 1.5 million square kilometers on the southernmost fringe of the Great Siberian boreal forest and the northernmost Central Asian deserts and vast steppes. Mongolia can be divided into six natural zones (UNDP, 1998). These zones differ from each other on the basis of their soil quality, plant and animal species.

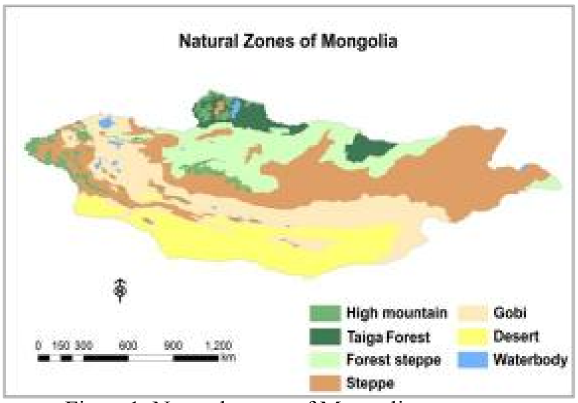



Figure1. Natural zones of Mongolia


Figure2. Integrated two different zones in this study

| | Zone Vegetation type | Area (million km$^2$) | Percent of total area |
|---|---|---|---|
| Desert | Largely unvegetated | 0.297 | 19% |
| Desert Steppe | Short grass prairie with sparse shrubs and scattered small trees | 0.329 | 21% |
| Steppe | Tall grass prairie with a significant for component | 0.407 | 26% |
| Forest steppe | Mixed forests on northerly slopes and grasslands on southerly slopes. | 0.125 | 8% |
| Boreal forest | Coniferous forests with a variable broad leafed component | 0.063 | 4% |
| Mountain | Mixed sub-alpine coniferous forests, alpine meadows and tundra. | 0.344 | 22% |

Table1. Information of zones (UNEP and MNE, 2002)

***Climate:*** Mongolian climate is characterized by long and cold winters, dry and hot summers, low precipitation, high temperature fluctuations, and a relatively high number of sunny days (an average of 260) per year. The average mean air temperature in the warmest month is 15-20C in the north, and 20-25C in the south of Mongolia. In the Gobi Desert and Steppe zones, the summer continues over 3 months. The maximum summer air temperature can reach anywhere 35-39C in the north and 38-41C in the south. In many areas throughout the country, snow cover in winter is very light, so soils are completely frozen in the winter (Chuluun and Ojima, 2002). The total annual precipitation in mountainous regions averages to about 400mm, in the steppe 150-250mm and in the desert-steppe less than 100mm. The number of rainy days decreases from north to south.

***Soils:*** Mongolian soil is divided two soil-bio-climate regions: northern and southern, belonging to special regions of Central Asia. The northern mountainous region is generally characterized by dark brown and brown soils. Because the quality of the soil is good, this region harbours twice or three times the number of species as comparatively found in the Gobi desert region. The southern, southwestern and western parts of the country contain light chestnut, light grey and grey steppe soils (UNDP, 1998).

***Water:*** Mongolia has comparatively high levels of surface and ground water recourses. The southern, central and southwestern parts of the country have few rivers and other water recourses and they are usually situated in depressions without any outflows. Mongolia has 3 811 rivers and streams with a total length of 67 000km, over 3 000 big and small lakes with a total volume of 500 cubic kilometers, about 6 900 springs with steady flows, over 190 glaciers with a total size of about 540 square kilometers and over 250 mineral water springs which form specific water ecosystems.

## 3. MATERIALS AND METHODOLOGY

### *3.1. Data Collection and data processing*

| Remote sensing data | Year | Information |
|---|---|---|
| Land Surface Temperature(LST-8day) | 2000-2010 | MODIS/TERRA |
| Normalized Difference Vegetation Index (NDVI-16day) | 2000-2010 | MODIS/TERRA |
| Vectors | | 1:500.000 |
| **Ground observed data** | **Year** | **Information** |
| Precipitation(P) | 2000-2010 | 111 meteorological stations |
| Temperature (T) | 2000-2010 | 111 meteorological stations |
| Soil Moisture (SM) | 2004-2009 | 5 measured points |

Table2.Used data

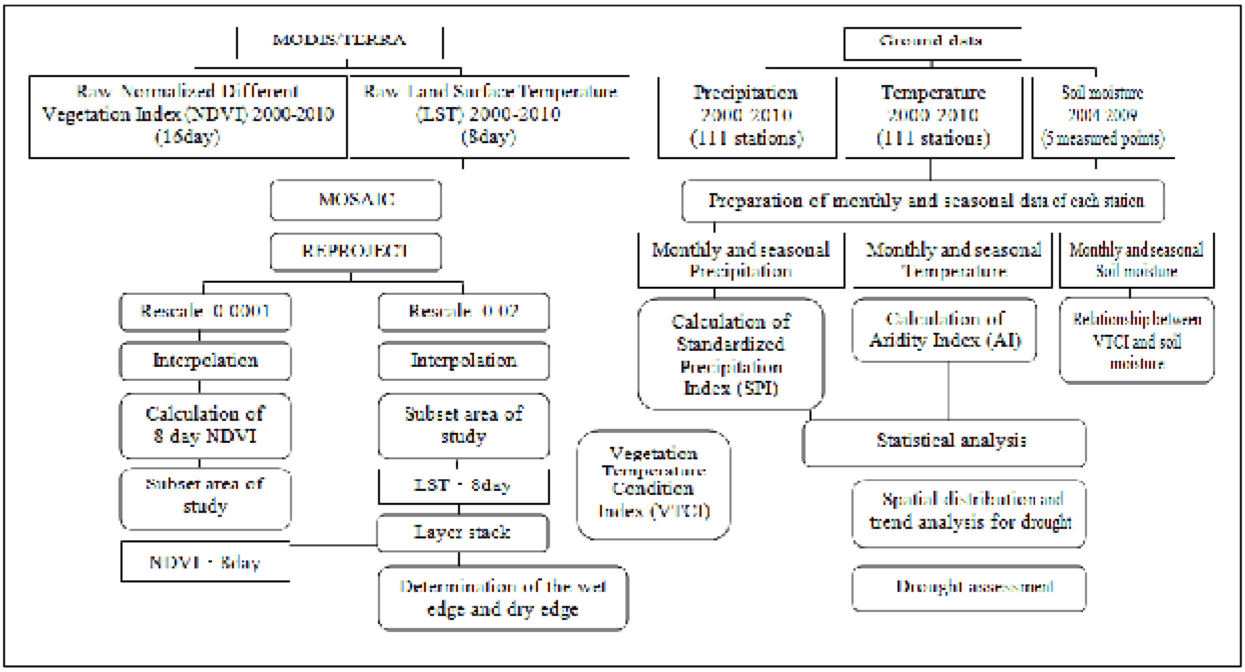



Figure3. Data processing of drought assessment

Used software and data sources:

- ENVI/IDL, ArcGiS
- Origin Pro, Microsoft Office
- http://ladsweb.nascom.nasa.gov/data/
- Meteorological Institute of Mongolia

### 3.2. *Vegetation temperature condition index (VTCI) definition*

Vegetation temperature condition index is defined as:

$$VTCI = \frac{LSTndvi_{i.max} - LSTndvi_i}{LSTndvi_{i.max} - LSTndvi_{i.min}} \quad (1)$$

where:

$$LSTndvi_{i.max} = a + bNDVIi$$

$$LSTndvi_{i.min} = a' + b' NDVIi \quad (2)$$

Where $LSTndvi_{i.max}$ and $LSTndvi_{i.min}$ are maximum and minimum temperature for a given NDVI. $LSTndvi_i$ is the remotely sensed data derived surface temperature at a given pixel for a given NDVI. The coefficients a, b, a' and b' are estimated from the scatter plot of LST and NDVI in the area. The shape of the scatter plot is normally triangular at a regional scale (Gillies *et al*. 1997, Wang *et al*.2001) if the study area is large enough to provide a wide range of NDVI and surface moisture conditions. It can be physically explained as the ratio of temperature differences among the pixels (figure1). The numerator of equation (1) is the difference between maximum and minimum LSTs of the pixels. In figure4, LSTmax can be regarded as the dry edge where there is less soil moisture availability and plants are under dry conditions; LSTmin can be regarded as the wet edge where there is no water restriction for plant growth (Gillies *et al*. 1997, Wang *et al*.2001). The value of VTCI ranges from 0 to 1; the lower the value of VTCI is the higher occurrence of drought.

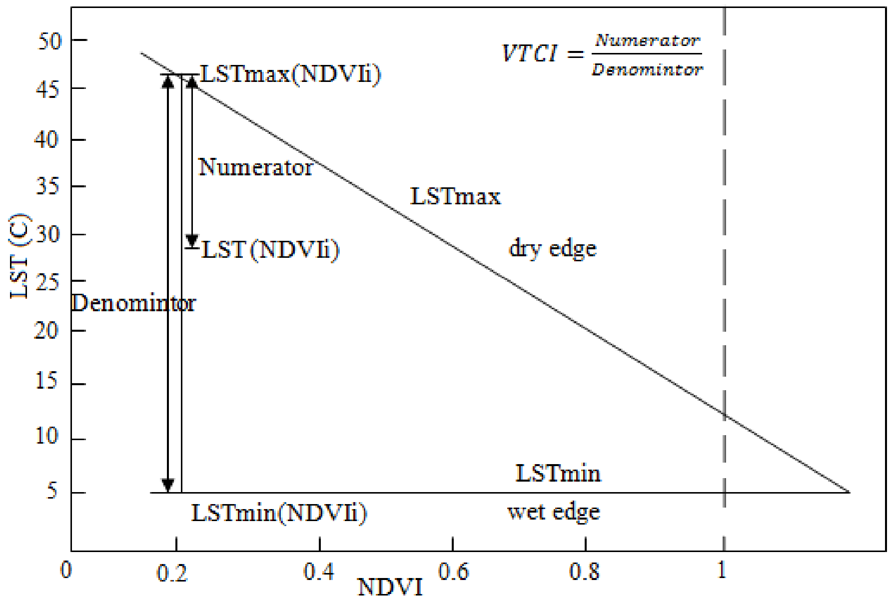



Figure4. The physical interpretation of VTCI

### *3.3. Standardized Precipitation Index (SPI) definition*

The Standardized Precipitation Index (SPI) was designed by McKee et al. (1993) to quantify precipitation deficit for multiple time scales which 1, 3, 6 and 12 months. These time scales reflect different water recourses. The SPI is defined for each of the above time scales as the difference between monthly precipitation on 1, 3, 6 and 12 months time scale ($x_i$) and the mean value ($\dot{x}$), divided by the standard deviation (s),

$$SPI = \frac{x_i - \dot{x}}{s} \quad (4)$$

Where $x_i$ is the monthly rainfall amount and $\dot{x}$, $s$ are the mean and standard deviation of rainfall calculated from the whole time series of monthly values. According to Edwards and McKee (1997) values less than -2.0 (extreme drought) are expected to appear 2 to 3 times in 100 years. In the present study the classification of McKee et al. (1995) and Komuscu (1999) was used to estimate condition.

| SPI | Probability of occurrence | Komuscu (1999) and McKee et al. (1995)drought classes | Agnew (2000) drought classes |
|---|---|---|---|
| Less than -2.00 | 0.023 | Extreme drought | |
| Less than -1.65 | 0.050 | | Extreme drought |
| Less than -1.50 | 0.067 | Severe drought | |
| Less than -1.28 | 0.100 | | Severe drought |
| Less than -1.00 | | Moderate drought | |
| Less than -0.84 | 0.201 | | Moderate drought |
| Less than -0.50 | 0.309 | | No drought |
| Less than -0.00 | 0.5 | Mild drought | No drought |

Table3. Classification scale for the SPI values

### *3.4. Aridity Index (AI) definition*

Many indices have been proposed to quantify of dryness of a climate at a given location. Aridity index indicates meteorological drought. Meteorological drought is the cause of other drought types such as hydrological drought, agricultural drought and socio-economic drought (Shi *et al*. 2007).It refers to an unusual water deficit resulting from inter-annual or seasonal variation in various weather factors (e.g. precipitation and air temperature). Aridity index is an indicator to describe the aridity or humidity. It has been frequently used in studies of global change, especially aridity and desertification (Meng *et al*. 2004). A lot of aridity indices have been developed since 1900. In this study selected Martonne aridity index ($I_{dm}$) which could represent monthly aridity. This index was designed by De Martonne in 1926 (Livada and Assimakopoulos 2007) and is described by the following equation:

$$I_{dm} = \frac{P}{T+10} \quad (5)$$

Where, P (cm) is the annual precipitation and T (° C) is the annual mean temperature. The equation is appropriate for temperatures greater than -9.9° C. The De Martonne aridity index decreases with increasing aridity.

| Classification | Aridity Index |
|---|---|
| Hyper arid | AI<0.03 |
| Arid | 0.03<AI<0.20 |
| Semi-arid | 0.20<AI<0.50 |
| Dry sub humid | 0.50<AI<0.65 |

Table4. UNESCO (1979) Aridity classification

## 4. RESEARCH RESULTS

### *4.1. Precipitation in past 10 years for 2 zones*

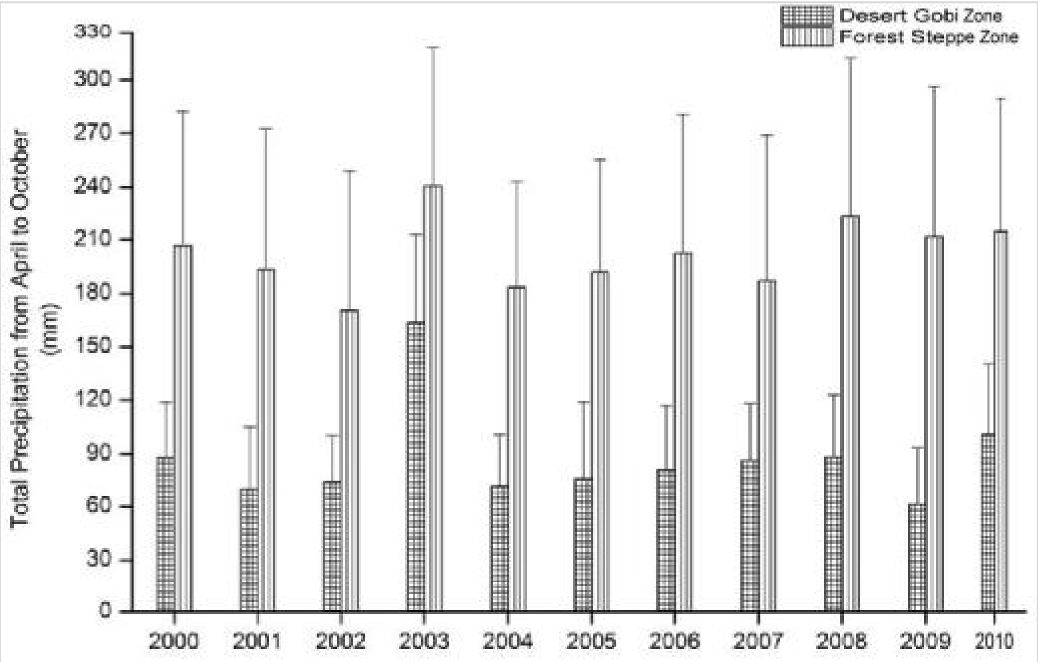



Figure5.

2001, 2002 and 2009 are greatly affected by drought especially in Desert Gobi zone, but from the total precipitation in growing season, we cannot extract drought accordingly, therefore, we separate the precipitation and other analysis into three seasons to extract seasonal drought.

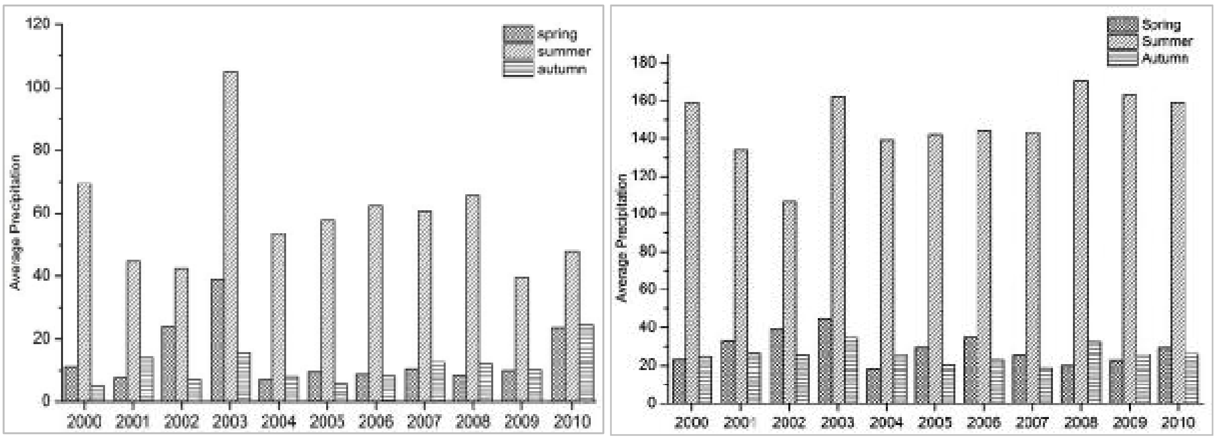



Figure6 (a) Desert Gobi zone (b) Forest steppe and High mountain zones

An average seasonal precipitation of two zones is low. Especially in Desert Gobi zone's 2001, 2002 and 2009 years are very low. 2003 year is higher than other years.

Forest steppe High Mountain zone's also 2002 year is low precipitation. About 85 to 90 percent of the precipitation falls during the three summer months (Shiirevdamba, 1998).

### *4.2. Vegetation temperature condition index (VTCI) in two zones in from 2000 to 2010*

An average of seasonal vegetation temperature condition index (VTCI) of two zones

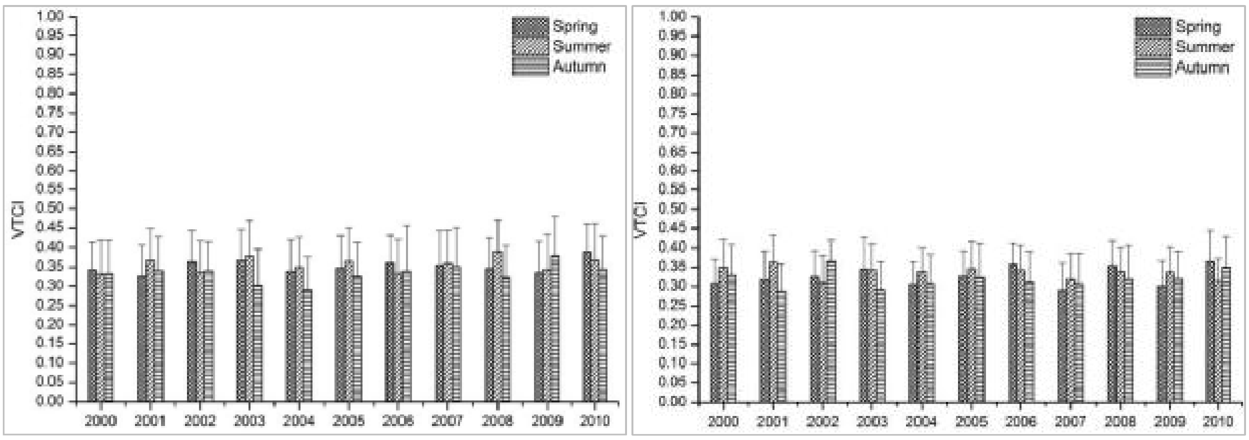



Figure7 (a) Desert Gobi zone (b) Forest steppe and High mountain zones

From this two figures:

- Mongolia was dry in from 2000 to 2010
- The VTCI range is from 0 to 1. In the from 2000 to 2010 years value of VTCI was generally low in two zones . It was indicated occurred drought in Mongolia.

Vegetation Temperature Condition Index (VTCI) 2003 and 2009 year

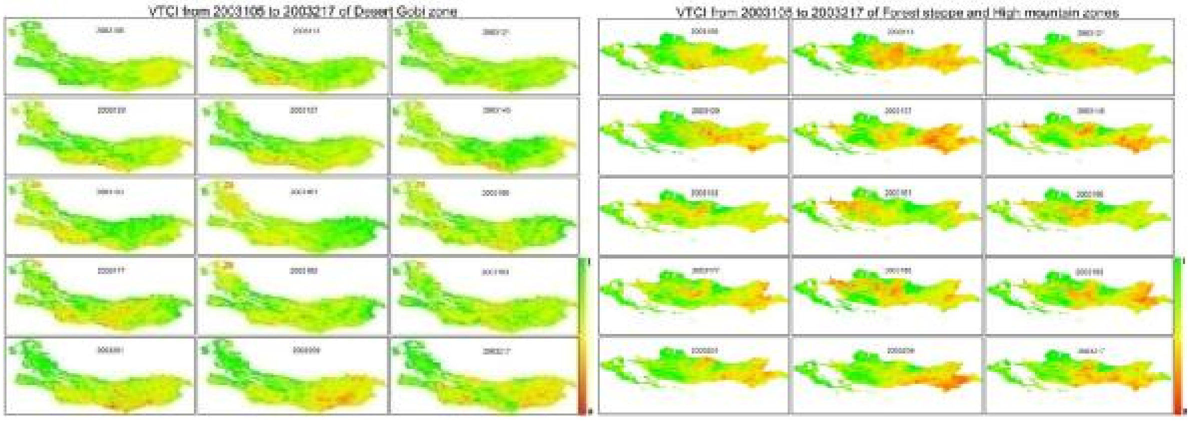



Figure8 (a) Desert Gobi zone (b) Forest steppe and High mountain zones

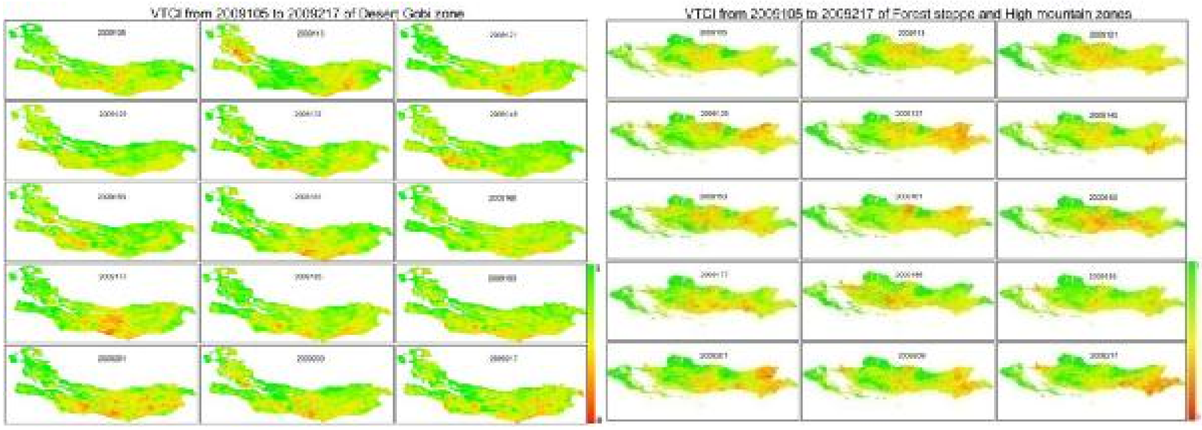



Figure9 (a) Desert Gobi zone (b) Forest steppe and High mountain zones

### *4.3. Descriptive statistics on precipitation and standardized precipitation index (SPI)*

Average seasonal SPI of two zones

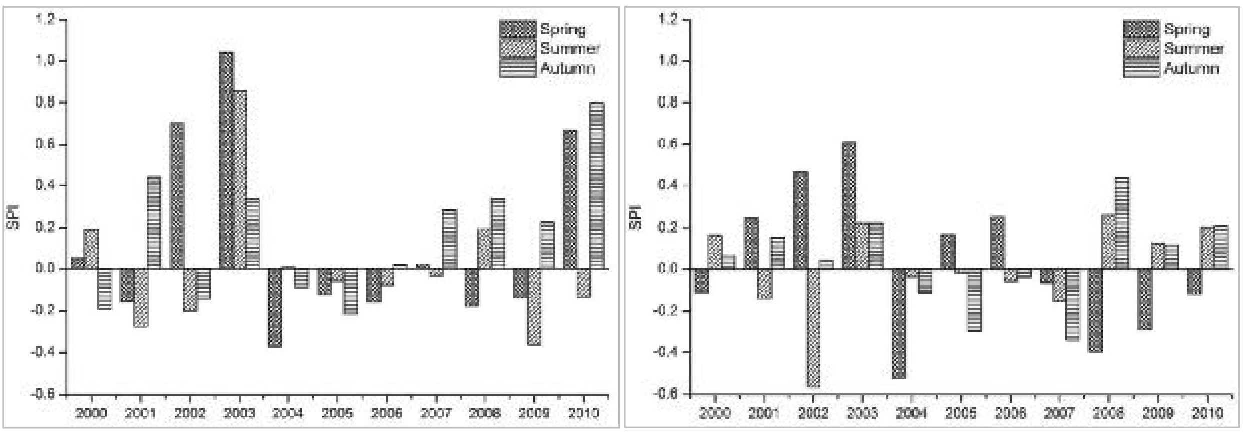



Figure10 (a) Desert Gobi zone (b) Forest steppe High mountain zones

From 10(a) figure:

- 2009 is affected by drought, the summer is drier than other years (spring 10.0mm, summer 39.7mm, autumn 10.2mm, total is 59.9mm)
- 2001 and 2002 are very dry years, especially in the summer time
- 2003 is very wet year

From 10(b) figure:

- Every years generally very dry
- 2002 is very dry year, mainly because of low precipitation in summer (106.5mm, total is 170.9);
- 2003 is a wet year (spring 44.8, summer 162.4, autumn 34.7. total 242.0mm)

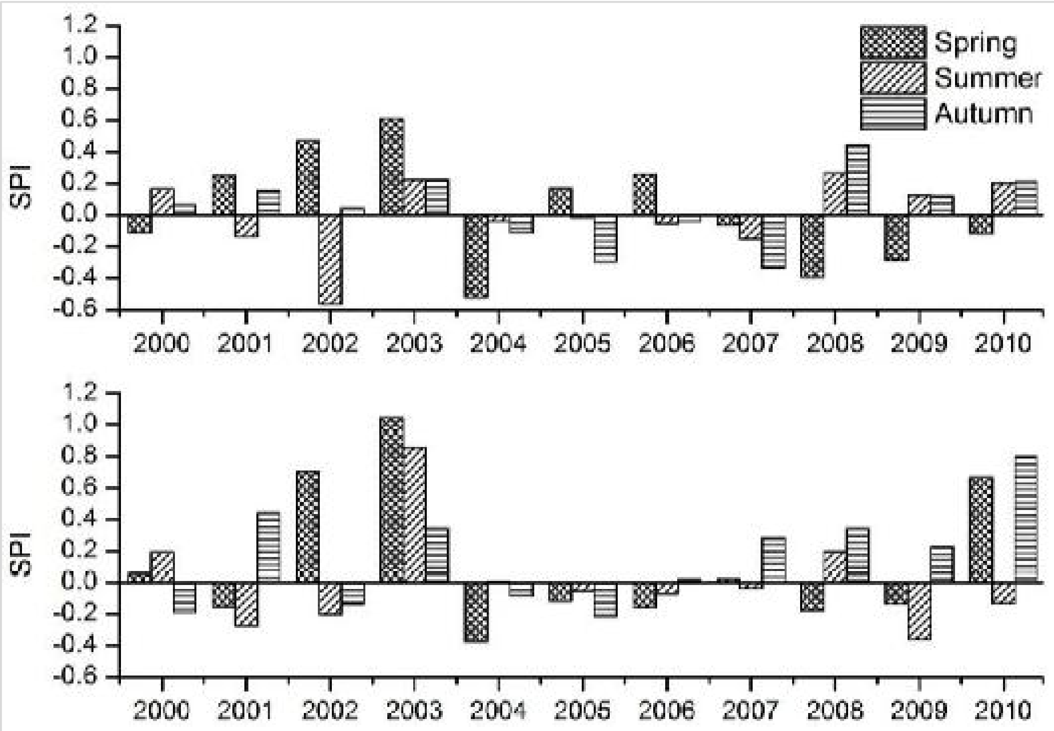



Figure11.

After comparing SPI, there is coincidence and difference of SPI in two zones:

- 2003 is wet year in two zones
- 2002 is dry year in two zones
- Special difference: 2009 in not dry in Forest steppe High Mountain zones, but 2009 in very dry in Desert Gobi zone; 2010 also quite different

### 4.4. *Results of Aridity Index (AI) in two different zones*

Average Aridity Index (AI) of two zones

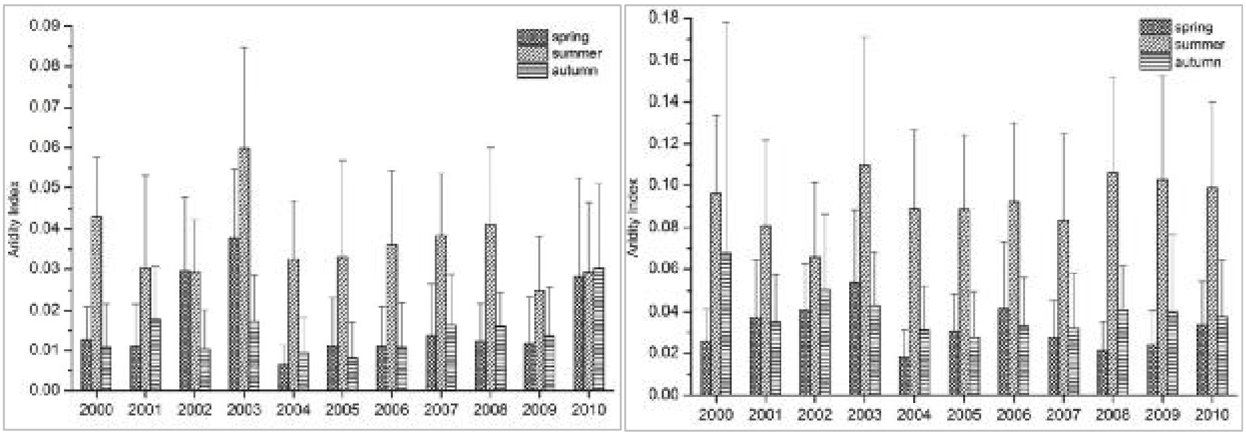



Figure12 (a) Desert Gobi zone (b) Forest steppe High mountain zones

From 12(a) figure:

- From 2000 to 2010 years are generally dry in the Desert Gobi zone
- Especially 2001, 2002 and 2009 years are very dry, 2003 year is wet year in the Desert Gobi zone

From 12(b) figure, we can know:

- 2002 year is dry year in the Forest Steppe High Mountain zones
- In this zone generally wet.

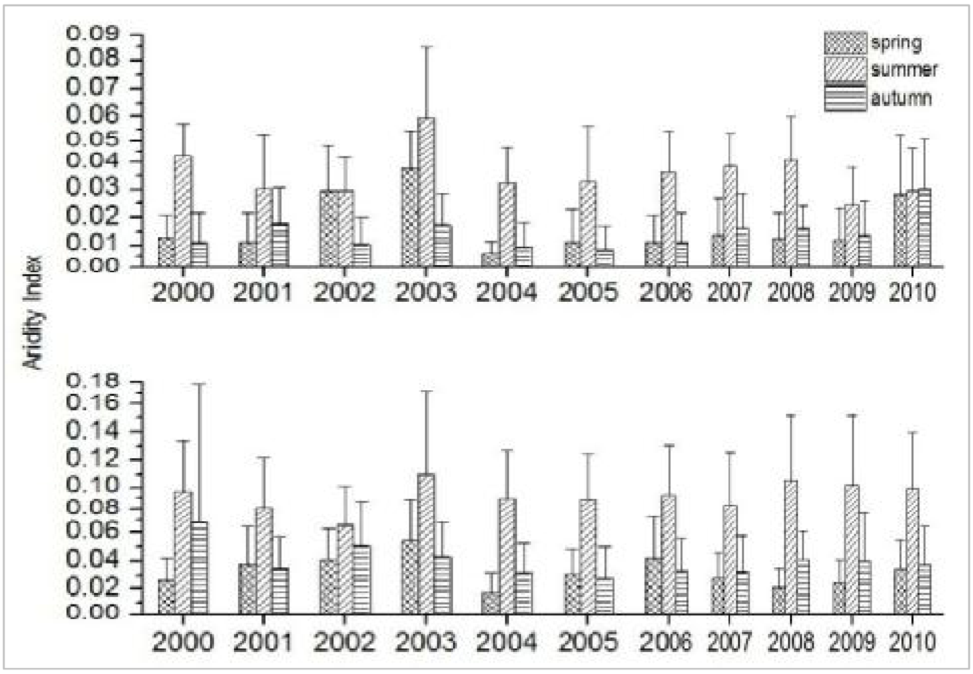
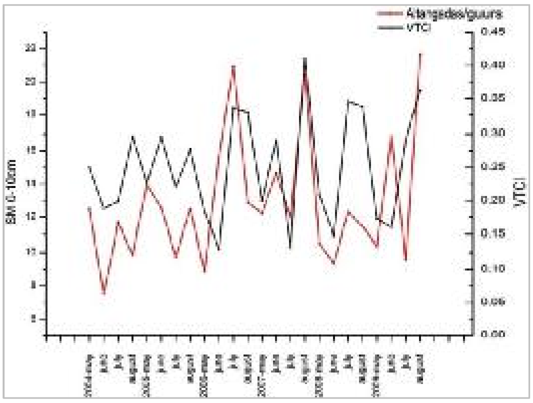



Figure13.

According to the Aridity classification of UNESCO (1979) (table3) the value which is lower than 0.03 is classified as hyper dry and value from 0.03 to 0.2 dry. In Desert Gobi zone every year is dry especially 2001, 2002 and 2009 years are hyper dry in summer time. The value of Aridity Index (AI) of Forest steppe High Mountain zones is higher than Desert Gobi zone. However, this zone is also dry. The year 2003 is wetter than others in two zones.

### 4.5. *Relationship between VTCI and ground observed soil moisture*



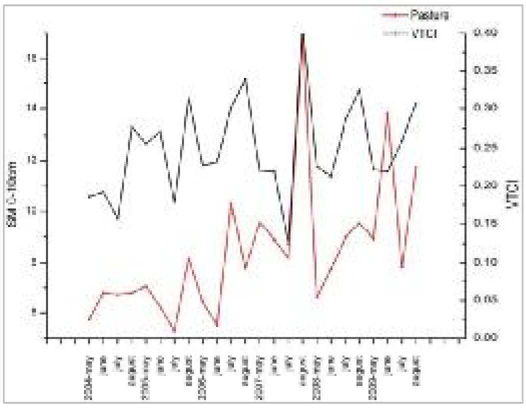
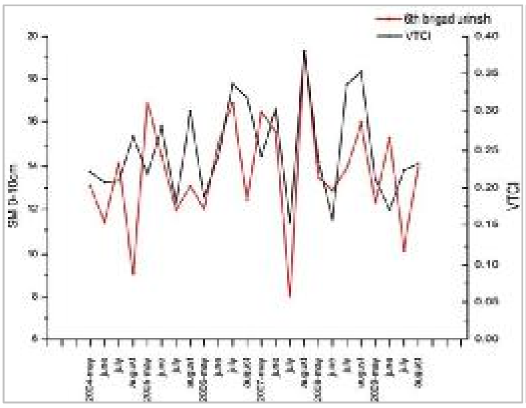
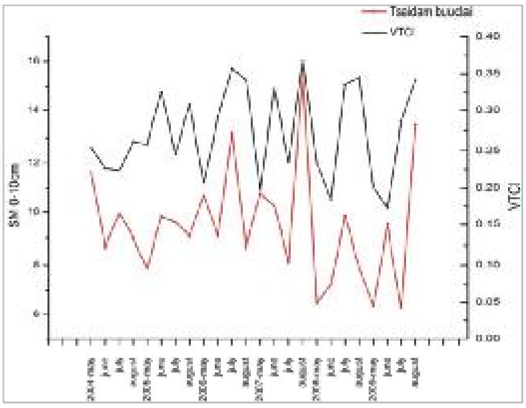
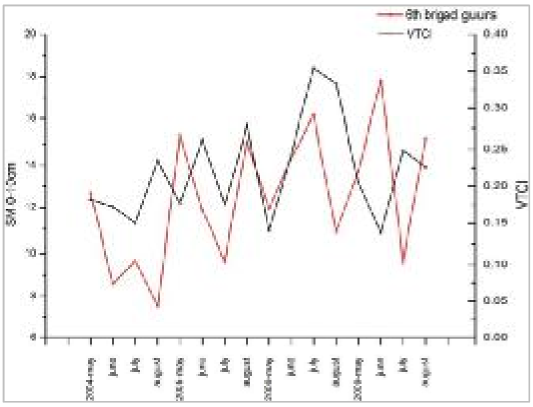



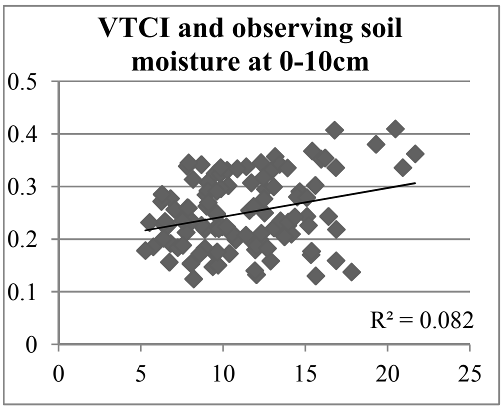

Figure14(a). (b)




(c) (d)




(e) (f)

Figure14. Monthly VTCI on average in from 2004 to 2009 and observing soil moisture at 0-10cm

An average monthly vegetation temperature condition index (VTCI) and observing soil moisture 0-10cm soil depth were not correlated, as shown in figure14.

## 5. CONCLUSION

The present research monitored the drought condition in Mongolia. The data obtained for analysis was divided into two different zones, Desert Gobi and Forest Steppe High Mountain zones. The study utilized different three indices such as VTCI, SPI and AI. The value of these indices was very low which indicates a drought condition in from 2000 to 2010. The year 2001, 2002 and 2009 are affected by drought in two zones, while only year 2003 was a non - drought. The desert Gobi zone is more affected than Forest Steppe and High Mountain zones.

## 6. REFERENCES


- Bayarjargal Y., et al. 2006. A comparative study of NOAA-AVHRR derived drought indices using change vector analysis. Remote Sensing of Environment 105, pp 9-22.
- Donglian Sun., Menas Kafatos. 2007. Note on the NDVI-LST relationship and the use of temperature-related drought indices over North America. Geophysical research letters, vol. 34, L24406, doi: 10.1029/2007GL031485.
- Wan Z., Wang P., Li X. 2004. Using MODIS Land Surface Temperature and Normalized Difference Vegetation Index products for monitoring drought in the southern Great Plains, USA. INT. J. REMOTE SENSING, vol. 25, NO. 1, pp 61-72.
- Yang X., Wu J.J., Shi P.J., Yan F., 2006. Modified triangle method to estimate soil moisture status with moderate resolution imaging spectroradiometer (MODIS) products. Program, China (2006BAD20B02)
- Caccamo G., Chisholm L.A., Bradstock R.A., Puotinen M.L. 2011. Assessing the sensitivity of MODIS to monitor drought in high biomass ecosystems. Remote Sensing of Environment 115, pp 2626-2639.
- ZHANG Jinhua., JIANG Luguang., FENG Zhiming., LI Peng. 2012. Detecting effects of the recent drought on vegetation in Southern China. Journal of Resources and Ecology. 2012 3 (1) 0 pp 043-049, doi:10.5814/j.issn.1674-764x.
- ARNON Karnieli., et al. 2009. Use of NDVI and Land Surface Temperature for Drought assessment: Merits and Limitations. Journal of climate, vol 23, doi: 10.1175/2009JCLI2900.1.
- Goldammer, J.G., Fire situation in Mongolia. International Forest Fire News No. 36, 2007. pp 46-66.
- Bayarjargal Yu., Adyasuren Ts., Munkhtuya Sh. ACRS2000. Drought and Vegetation Monitoring in the Arid and Semi-Arid Regions of the Mongolia using Remote Sensing and Ground data.
- Livada I., and Assimakopoulos V.D. 2007. Spatial and temporal analysis of drought in Greece using the Standarduzed Precipitation Index (SPI). Thear.Apll. Climatol. 89, pp 143.153. Doi10.1007/s00704-005-0227-z. Netherlands.
- Damdin Dagvadorj., Rogelio Z. Aldover., Anna Stabrawa. Mongolia: Assessment Report on Climate Change 2009, Ministry of Environment, Nature and Tourism, Mongolia ISBN: 978-99929-93403-X
- Natsagdorj L., Dagvadorj D. 2010. Adaptation of Climate Change. ISBN: 978-99929-93403-X
- Siirevdamba Ts., 1998. Biological Diversity in Mongolia, First National Repirt, Ministry for Nature and the Environment, Ulaanbaatar, Mongolia, pp 106.
- Maliva R., Missimer T. Arid Lands Water Evaluation and Management, Environmental Science and Engineering, DOI: 10.1007/978-3-642-29104-3_2, Springer-Verlag Berlin Heidelberg 2012.
- Chuluun T., Ojima D. 2002. Land use change and carbon cycle in arid and semi-arid lands of east and central Asia. Science in China, Life Sciences – Series C, No. 45 Supp., pp. 48-56.
- Natsagdorj., Dagvadorj., Gonboluudev P. 1998. Climate change in Mongolia and its future trend. A sciebtific Organization of Meteorological Institute, No. 20, Ulaanbaatar, pp.114-133.