Drought Identification in the North-East of Thailand using Multi-Temporal NDVI Satellite Imagery

Thavorntam, W.[1], Wattanagij, N. [1] and Mongkolsawat, C. [1]
Center of Geoinformatics for the Development of Northeast Thailand, Khon Kaen University.
Computer Center Building, Khon Kaen, Thailand, 40002. [1]
Tel :+66 43 348601 Fax : +66 43 348600
Email: watsao@kku.ac.th, nagon.w@gmail.com,charat@kku.ac.th

Abstract : The Northeastern part of Thailand has been frequently subjected to drought and the severity and duration of these events tend to increase every year. The serious negative results of these droughts impact human life, property and agricultural production in Thailand. The Normalized Difference Vegetation Index (NDVI) is a powerful indicator to monitor the vegetation cover over wide areas so the frequent occurrence and persistence of droughts can be detected. Dense vegetation is regard as healthy vegetation while sparse vegetation is assumed to be stressed plants due to water deficiency. The objective of this study was to create an index using Landsat imagery to identify drought conditions in the Northeast of Thailand. NDVI data from Landsat thematic mapper (TM) imagery during dry seasons from 2001 to 2005 was collected and performed using Histogram Matching to develop a mosaic to cover the whole study area. The vegetation covered by the NDVI data was classified into 3 types of land cover ranging from low to high vegetation cover. Monthly rainfall data from 101 stations distributed in the region from 1976 to 2004 were collected and digitally encoded into GIS database. The interpolation of mean annual rainfall for the Northeast region was performed using the Kriging Method. The correlations of changes in vegetation greenness and rainfall in each year were examined through regression analysis. This method was checked against ground truth surveying from the National village status database for accuracy. The results show a high correlation between NDVI and rainfall which could be used as an index to identify drought events in the region.

KEY WORDS: NDVI, Multi-Temporal NDVI Satellite Imagery

1.INTRODUCTION

The Northeastern part of Thailand has been frequently subjected to drought and the severity and duration of these events tend to increase every year. The most serious negative result from drought is water deficiency for agriculture, the major economic sector in the region, which impacts human life, property and agricultural production in the region and the country as a whole. The frequent occurrences of drought are mainly from untimely rainfall and dry spells in the rainy season from June to July and also in last two weeks of September. Many concerned sectors were assigned by the government to monitor and mitigate these disasters but the efficiency of these studies are not very high because their studies just reflected their particular expertise. For example, the meteorological department uses the amount of rainfall to indicate the severity of drought while the agricultural sector measures severity of drought from the amount of agricultural production. This data has not been integrated for analysis and overall relationship.

Remotely sensed data provides spatially continuous data which can be effectively used for drought monitoring, mitigations and warning prediction. The Normalized Difference Vegetation Index (NDVI) has been widely used for monitoring vegetation conditions. NDVI is the spectral contrast between the reflected Near Infrared and Visible band where the contrast value of vegetation is higher than bare soil (Kassa, 1999). Dense vegetation is regard as healthy vegetation while sparse vegetation is assumed to be stressed plants due to water deficiency and when vegetation changes due to the environmental stress, NDVI changes too (Unganai, et al, 1998). There have been several applications of using NDVI and other vegetation indices for drought monitoring such as in the central part of United States, Sudan, India and Mongolia (Albert et al, 2002; Kassa, 1999; Bhuiyan, 2000; Bayarjarrgal, et al, 2000). In addition, in the Drought in the Northeast of Thailand (C. Mongkolsawat et al, 2001) was used to study by applied remote sensed data and GIS to establish 3 drought risk layers; Meteorological drought, Hydrological drought and Physical drought and the severity of drought was classified from very mild to severe . However, analysis of drought risk areas by using GIS takes time for input of analytical data such as rainfall because it is dynamic. Hence, the accuracy of the data depends on the date of data input.

2. OBJECTIVE

The objective of this study was to create an index using Landsat imagery to identify drought conditions in the Northeast of Thailand by examine the correlations of changes in vegetation greenness and rainfall.

3. STUDY AREA

The study area, a part of Northeast of Thailand, covers an area of about 60,000 km^2 and lies between 14° 18´ N to 18° 15´ N and 102° 22´ E 104° 50´ E. The most extensive areas are restricted to paddy field and field crop, small extent of forest is found. The topography is characterized by small hills and gently undulating terrain with sparse vegetation cover. The remaining forests are those of the isolated patches of forest remnant scattered over the area.

The area is underlain by a thick sequence of Mesozoic rock, mainly Maha Sarakam Formations which consist of sandstone, siltstone and interbedded rock salts. The soils are inherently low in fertility and have sandy texture. The study is shown in figure 1.

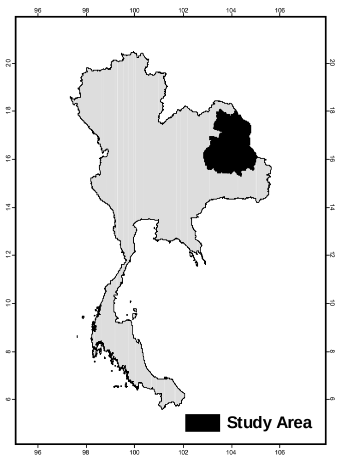


Figure 1. The study area.

4. METHODOLOGY

4.1 DATA COLLECTION AND ANALYSIS

1) Rainfall data

Monthly rainfall data from 101 stations distributed throughout the study area from 1976 to 2004 from the Thai Meteorological Department (TMD) was collected and digitally encoded into GIS database. Yearly Rainfall was classified into 4 periods; dry period (November to April on the next year), rainy period (May to October), Beginning rainy period (May to July) and Ending rainy period (August to October). The interpolation of median rainfall of each period was performed using the Kriging Method to get a spatial pattern of rainfall data in years 2000, 2001, 2002, 2003 and 2004. Average Annual rainfall since 1976 to 2004 was also interpolated to get the spatial pattern of rainfall in the study area for the last 28 years.

This study used the Kriging Method, which is based on statistical theory and computing. This method can provide information of how the size and shapes of zones of spatial dependence can improve the value of local estimates for points or areas. The Ordinary Kriging Method is used to estimate a value at a point of a region for which the variogram is known, without prior knowledge about the mean (Burrough et al, 1998).

Exploratory analysis of rainfall data was used to explore the annual average rainfall and the frequency distribution of rainfall in September and October. The median rainfall data of each period was used as the representative of rainfall data for interpolation. The appropriate variogram model for rainfall data was the Gaussian model because the variation was very smooth and the nugget variance was very small compared to the spatially dependent random variation (Burrough et al, 1998). Cross validation was used to check for measuring the residual between the point and the surface created.

The interpolation was done in Geostatistical Wizards in ArcGIS and the raster grid of each rainfall periods was transfered to PCI Gematica Version 9.0 to examine the correlation with NDVI data.

2) Landsat TM data

The data used was from Landsat TM images acquired on January in 2000, January in 2001, February, March and April in 2002, January and April in 2003, February and March in 2004 and January and February in 2005. Band 3 (Red) and Band4 (NIR) with spectral ranges 0.63-0.69 µm and 0.75-0.90 µm were used to calculate NDVI. The formula for NDVI calculation is;

$$NDVI = (NIR - Red) / (NIR + Red) \qquad (1)$$

From this formula, vegetation can be mapped because the Red band has a higher susceptibility of absorption by chlorophyll than longer wavelengths. Hence, the brightness of vegetation in the Red band is less than NIR because of its lower reflectance (Williams, 1995). The intensity values were calculated pixel by pixel and the result from this formula are ranges from -1 to 1. In order to visualize this calculation result on screen (for 8 bits data), it is necessary to multiply them by 255.

It takes 5 scenes of Landsat TM images to cover the study area so a mosaic of 5 images was used to cover the whole study area. Radio metric and geometric correction was done for each image to improve the accuracy of the mosaic. The histogram of each image was equated by histogram matching techniques which the histogram of an image will be resembled to the histogram of another image.

Unsupervised classification technique was applied to class vegetation cover from NDVI data into 5 types; bodies of water, bare soil, low, moderate and high vegetation cover. This method evaluated each pixel that had a similar value to a single class.

3) Correlation between NDVI data and Rainfall data

The correlation coefficient between NDVI data and rainfall gird data was calculated to evaluate the correspondence between NDVI spatial patterns and rainfall patterns. From 2000 to 2004, the correlation coefficient of 4 periods of rainfall and one NDVI each year were calculated. There is one NDVI Image of each year so the dry period in 2004 was compared with NDVI image in January, 2004 and rainy periods in 2004 were compared with NDVI image in January 2005, because rainfall of the three or four preceding months was considered to be effective for vegetation in that month. This resulted in 20 correlation coefficient values (5 years x 4 periods).

3) Field Survey data

The ground truth surveying data from the National village status database (NRD2C) was used to check for accuracy. NRD2C data in 2001 and 2003 from the Department of Community Development were used because it has indicator indexes to identify the development level of the villages including water shortage level. The majority of water shortage problem villages in the study area were in the Off-Season Agriculture Activity's indicator variable of 2001 and Water for Agriculture's indicator variable in 2003. The NRD2C data was linked to village locations in GIS by using village codes and can present the location of the villages that have water shortage problem for agriculture. The classifications of NDVI data were checked against the location of these villages to evaluate the relationship between the location of water shortage problem and vegetation health.

5. RESULT & DISCUSSTION

5.1 Rainfall

The frequency distribution of annual rainfall of 101 stations from 1976 to 2004 is shown in figure 2. The minimum was 701.90 mm while the maximum was 3278 mm. The mean and standard deviation were 1371.07 mm and 363.44 mm respectively. The example of annual rainfall of 2 stations in the West (Kalasin Station) and Northeast (Nakhon Phanom Station) of the study area is shown figure 2 where rainfall is fluctuated overtime. Rainfall in September and October in the Northeast comes from northeast monsoon where the amount of rainfall is higher than in the West of the study area. To examine the relationship of rainfall to vegetation cover, rainfall in September and October in 2000 to 20004 was examined because it had an influence on the health of vegetation four or five months later. There is a significant variation of rainfall in these two months with a significant decrease in October 2003 and 2004. This decrease in rainfall effected the amount of vegetation cover with moderate and high vegetation cover declining in January 2004 and February 2005.The figure of frequency distribution of rainfall in these two months was shown in the figure 3.where x-axis represents number of rainfall stations and y-axis represents the monthly rainfall. The value -1 means monthly rainfall data in that month has not been recorded. It can be seen in 2003 and 2004, rainfall in October are rarely measured which could be effected to the result of rainfall analysis and the correlation of rainfall to NDVI.

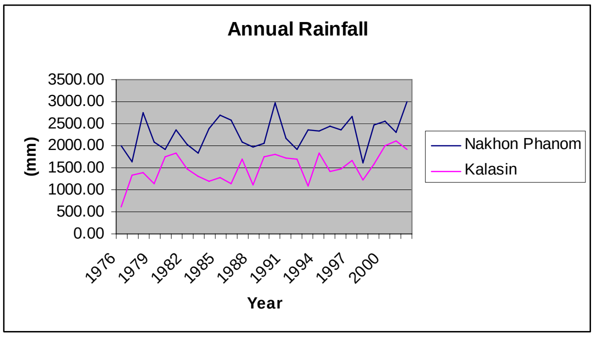
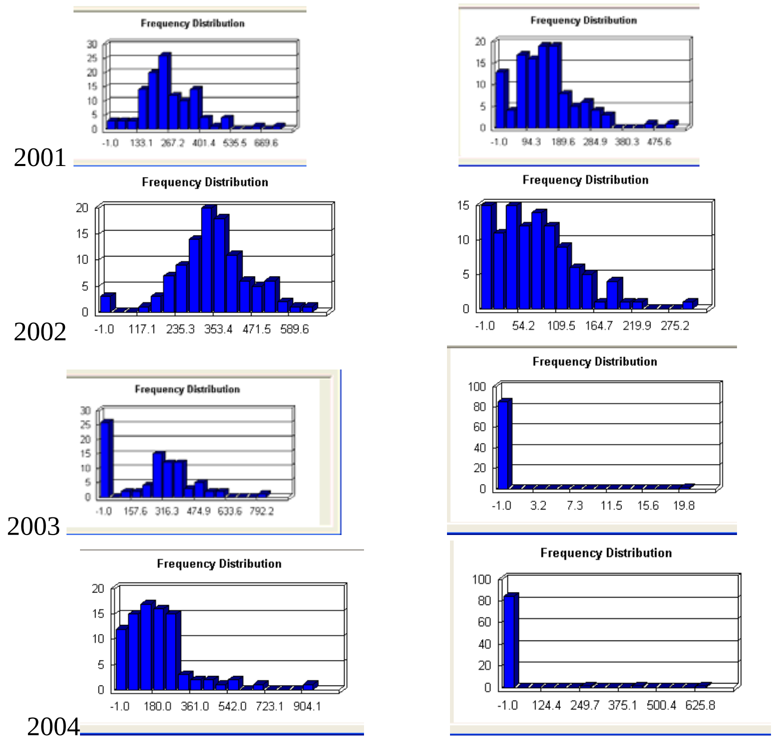


Figure 2. Average annual rainfall and its frequency distribution of 101 stations from 1976 to 2004.



a) September b) October

Figure 3. Frequency distribution of rainfall in September and October in 2001 to 2004.

For the interpolation method, the Box-Cox transformation is usually used to adjust the skewness in the data, but it has not been used in this study area because the rainfall stations were spread randomly over the area. The appropriate range and model to fit the semivariogram is important because we can determine the optimal weighting for interpolation (Burrough et al, 1998). The 300 km^2 is the appropriate range for this study because after this range there is no spatial dependence between the data points. The ranges can give an answer of how large a window in weight moving average should be. The Gaussian model is chosen to fit the semivariogram. Although the nugget is larger than the exponential model but it gives smoother surface. The interpolation of Rainfall in each period was done from 2000 to 2004 and it results in 20 maps

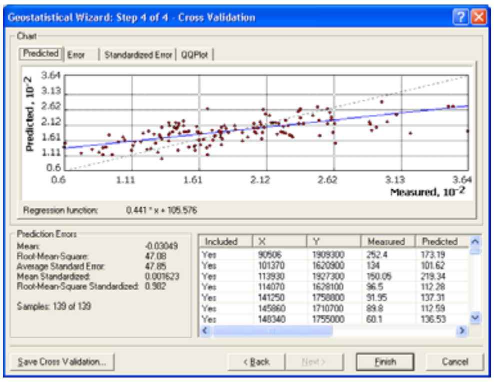


Figure 4. The cross validation and the prediction chart for median rainfall in rainy period (May, 2003 to October, 2003)

The example of the cross validation and the predicted chart of rainy period in 2003 are shown in figure 4. The Cross validation computes the residuals for all data points, and the self-consistency of the variogram is tested by a mean difference of residuals of zero and a variance of 1 (Burrough et al, 1998). The dashed line shows where the data should fall. High rainfall is expected to be less while low rainfall is expected to be more. The mean, Root-Mean-Square and Average Standard Error are -0.03, 47.08 and 47.85 respectively. A mean of -0.03, shows there is little or no skewness. The Root-Mean-Square Standardized is 0.98 means the ability of prediction x can describe the regression function about 98 percent. The figure of the result of the Ordinary Kriging interpolation of rainfall data in 4 periods from 2000 to 2004 is shown in figure 5.

As a result, rainfall patterns in the study area are varied in different periods. From figure 5, the pattern of increasing median rainfall from southwest to northeast is evidence**.** From 2000 to 2004, in dry season, the higher rainfall is mostly found in the northeast and the rainfall has slightly increased from 2000 to 2004. In beginning of rainy period in 2000 to 2001, the amount of rainfall is high in the north but after this year it has continuously decreased. In the ending of rainy period, the region is influenced by the northeast monsoon so rainfall is significant higher than the beginning of rainy season.

5.2 NDVI

The result of NDVI images of study area from 2000 to 2005 are represented in figure 1. High vegetation cover was represented with brighter tones while the darker tones are was bare soil and bodies of water. In January and February, when the satellite images were taken, is the dry season, so vegetation cover tends to be low. Low vegetation was the biggest proportion of vegetation cover and the percentage of low vegetation from 2000 to 2005 are 13.77, 21.90.18.18, 13.06, 14.54 and 25.26 respectively (Figure 6). In high hill area, forest types are evergreen and deciduous, the vegetation cover was considered high vegetation only for evergreen forest areas while it was considered moderate vegetation in deciduous forest. There are some irrigated areas in the lower part of Ubonratana dam in the west of the study area and the vegetation was consider moderate and high because of water from the dam available for agricultural activities.

The change in vegetation overtime from 2000 to 2005 is remarkable. The area of moderate and high vegetation has declined from 2000 to 2002 and it has increased in 2003, after this it has decreased again because of a change in rainfall pattern in the preceding year. In October, 2002 there were floods in several areas downstream so while the images were taken a few months later in January, 2003, the soil is moist which reflected to good healthy vegetation. However, since 2003, the severity of drought has increased because the amounts of rainfall were less in September and October in 2003 and 2004 which reflected less vegetation occurrence.

The vegetation cover from NDVI was randomly checked with the location of water shortage's villages in 2001 and 2003. The result shown that most of these villages were located in low vegetation.

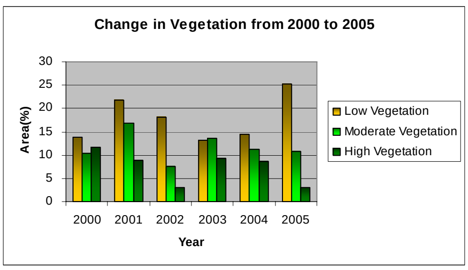


Figure 6. Change in Vegetation from 2000 to 2005

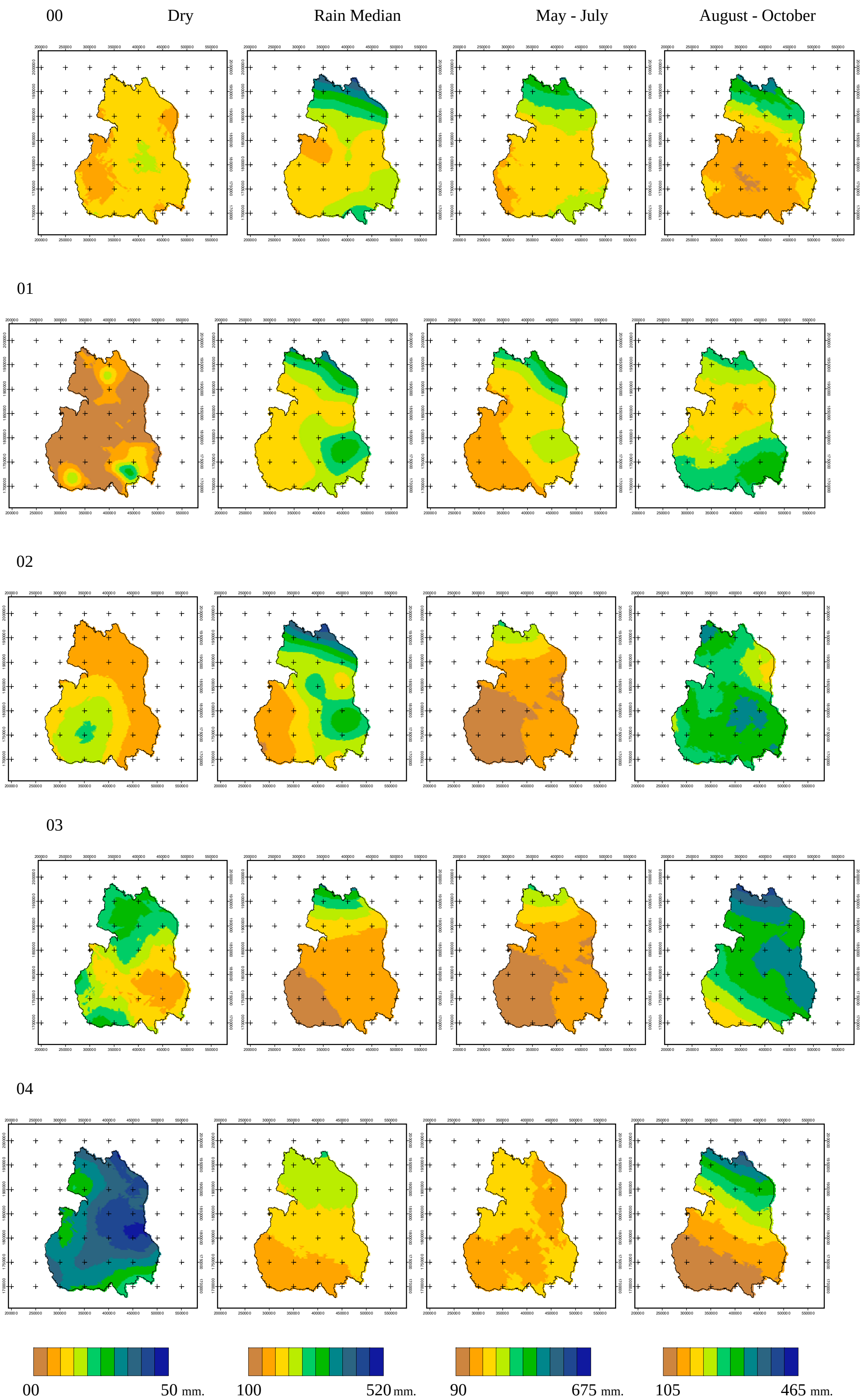


Figure 5. The result of the Ordinary Kriging interpolation of rainfall data in 4 periods from 2000 to 2004.

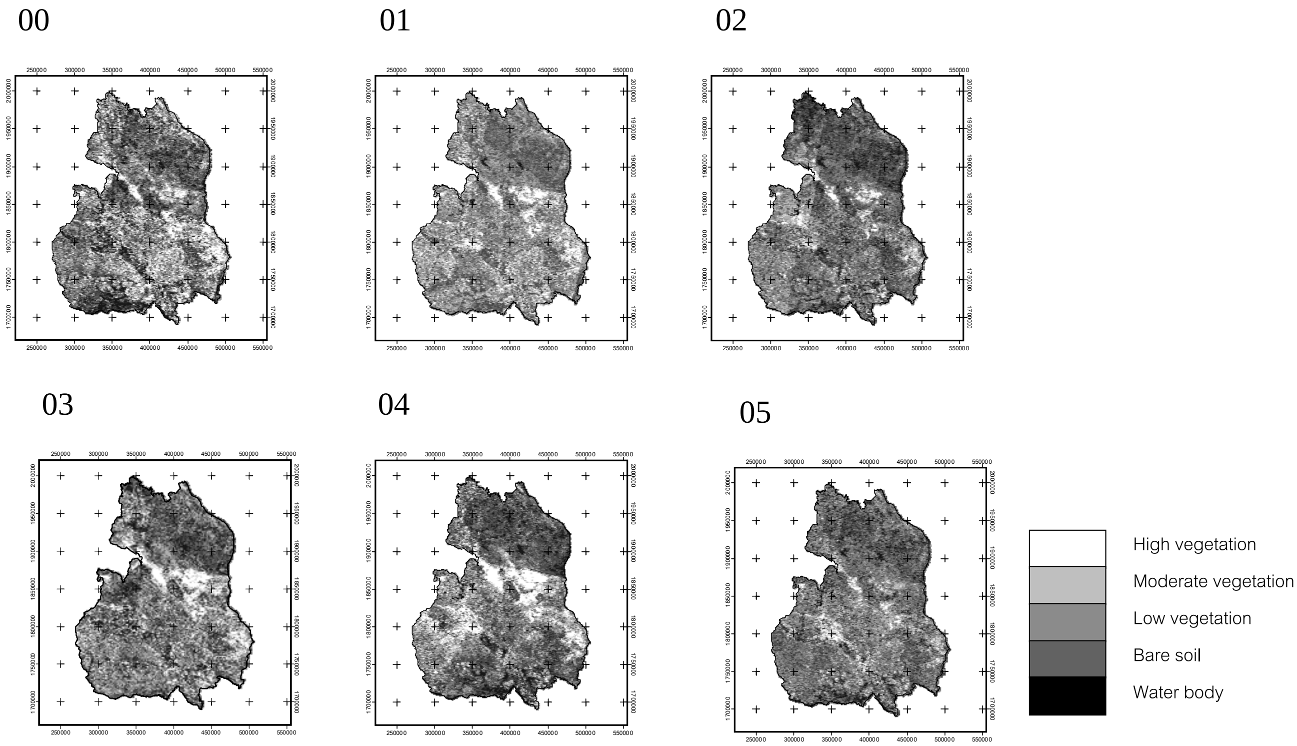


Figure 7. NDVI images of study area from 2000 to 2005.

5.3 Correlation between NDVI and Rainfall

The correlation coefficient between NDVI data and rainfall gird was calculated to evaluate the correspondence between NDVI spatial patterns and rainfall patterns. Table 1 lists the correlation coefficients between NDVI and rainfall.

Table 1. Correlation coefficients between NDVI and rainfall from 2000 to 2005

Rainfall Periods	**NDVI (Year)**					
	2000	2001	2002	2003	2004	2005
Dry (November - April)	0,94	0,55	0,82	0,81	0,93	-
Rainy (May - October)	-	0,9	0,88	0,92	0,84	0,93
Rainy period 1(May -July)	-	0,92	0,84	0,95	0,83	0,96
Rainy period 2 (August - October)	-	0,88	0,91	0,79	0,92	0,81

The values of the correlation coefficients are relatively high and quite different according to the season because rainfall has a high influence to NDVI. Rainfall in dry period in 2000 compared with NDVI in 2000 while rainfall in rainy period in 2000 was compared with NDVI in 2001. The most effective correlation coefficient value is in the correlation between rainy period and NDVI in a year later. From table 1, correlation coefficient value in rainy period remained high except in 2002 and 2004 because of a dry year in 2001 and 2003 which the correlation coefficient dropped remarkably.

6. CONCLUSION AND RECOMMENDATION

The result of this study shows NDVI from Landsat TM which is influenced by the spatial distribution pattern of rainfall. The highest correlation between NDVI and rainfall is found in rainy periods, about three or four months before imaging. The classification of NDVI was checked against the village's locations which have the water shortage problem and it was found that most of these villages were located in low vegetation cover. The health of vegetation cover from NDVI has a feed back effect on rainfall because of its strongly correlated. Hence, NDVI could be used as an index for prediction of vegetation health and to identify drought events of the region rapidly which high NDVI is less droughts effect.

REFERENCES

[1] Albert J. Peters, Elizabeth A. Walter-Shea, Lei Ji, Andres Vina, Michael Hayes and Mark D. Svoboda. 2002. Drought Monitoring with NDVI-Based Standardized Vegetation Index. Photogrammetric Engineering & Remote Sensing, Vol. 68, No. 1, January 2002. pp. 71-75.

[2] Bayaijargal, Y., Adyasuraen, T. and Munkhtuya, S. 2000. Drought and Vegetation Monitoring in Arid and Semi-Arid Regions of the Mongolia using Remote Sensing and Ground data. The 21[1th] Asian Conference on Remote Sensing.

[3] Benjamin Lloyd-Hughes and Mark A. Saunders. 2002. *A Drought Climatology for Europe.* International Journal of Climatology. 22: 1571-1592 (2002)

[4] Burrough, P. A. & McDonnell, R. A., 1998. Principles of Geographic Information Systems. Oxford University Press Inc., New York.

[5] C. Mongkolsawat, P. Thirangoon, R. Suwanwerakamtorn, N. Kaladee, S. Paiboonsak and P. Champathet. 2001. An Evaluation of Drought Risk Area in Northeat Thailand using Remotely Sensed Data and GIS. Asian Journal of Geoinformatics, Vol. 1. No. 4. June 2001.

[6] Kassa Alemayehu. 1999. Drought Risk Monitoring for the Sudan using NDVI 1982- 1993. http://www2.soas.ac.uk/Geography/WaterIssues/OccasionalPapers/AcrobatFiles/OCC25.PDF. [Online Accessed 22/12/03]

[7] Damizadeh, M. Saghafian, B. and Gieske, A. 2001. Atudying Vegetation Responses and Rainfall Relationship Based-on NOAA/AVHRR Images. The 22[nd] Asian Conference on Remote Sensing 2001, Singapore.

[8] Soo-Hyun Shin, Joung-Mi Ryu, Yoon-II Park and Kyu-Sang Lee. 2003. Potential of drought Monitoring with Multi-Temporal Normalized Difference Vegetation Index in North-East Asia. The 24[th] Asian Conference on Remote Sensing.

[9] Unganai, L.S. and F.N. Kogan, 1998. Droght monitoring and corn yield estimation in southern Africa from AVHRR data. Remote sensing of Environment, 63:219-232.

[10]Williams, J. 1995.*Geographic Information from Space*. Praxis Publishing Ltd. England.