Drought Vulnerability Assessment in the High *Barind* Tract of Bangladesh Using MODIS NDVI and Land Surface Temperature (LST) Imageries

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Abstract: *The North-Western part of Bangladesh has been experiencing extreme weather and frequent drought conditions compare to the other parts of the country. In this paper, we used MYD13Q1 and MOD11 of Moderate Resolution Imaging Spectroradiometer (MODIS)/Terra in order to extract Vegetation Condition Index (VCI) and Temperature Condition Index (TCI). Finally, these both information helped to derive Vegetation Health Index (VHI) during high summer periods in 2000, 2008 and 2014 to assess drought vulnerability in terms of agriculture. Mainly NDVI (Normalized Difference Vegetation Index) and LST (Land Surface temperature) were the main geospatial data to map Vegetation Health Index (VHI). From the VHI analysis, we found that about 147956 (29% of the total), 173194 (34% of the total) and 191352 (37% of the total) hectare lands as extreme, high and moderate drought areas respectively in the study area. In addition to this analysis, Naogoan and ChapaiNabanganj districts were found as the extreme to high drought vulnerable areas in terms of agriculture.*

Keywords: Barind Tract, Drought, Remote sensing, MODIS, NDVI, LST, Bangladesh.

1. Introduction

The North-Western part of Bangladesh has been experiencing extreme hot weather and frequent drought conditions compare to the other parts of the country. Erratic rainfall pattern creates devastating and repeated droughts in this region and affects agriculture by substantial damage and crop losses [1]. Especially, the high *Barind* Tract suffers from frequent drought situation due to irregular rainfall [2]. The entire *Barind* region and its surrounding areas have very severe water scarcity during *Kharif* and *Rabi* season. The ground water scarcity reveals that water level is declining gradually year-by-year, which creates the draught intensity higher [3]. As the low availability and dispersion of surface water sources for irrigation, withdrawal of ground water turn into the alternative source. Installing deep and shallow tube-wells became traditional and mostly practiced irrigation process in this region since last two decades. Over exploitation of groundwater for irrigation purpose during summer season, accelerates ground water level fall rapidly in such a way that in some points are not achievable for full replenishing during rainy season [4]. As a consequences, soil erosion and land degradation process is taking place over the area and affects the local agriculture potential. Declining rate of rainfall also promotes deteriorating forests and vegetation cover. The altered and extreme weather condition leads reduction of crop production yield and effects on the local socio-economic stability. The drought vulnerability depicts diverse condition but consistent year-by-year [2].

The drought phenomenon is recurrent in the study area that becomes the most vulnerable drought prone area of Bangladesh. Unfortunately, drought condition has received less attention and has less scientific research work compare to other calamities like flood or cyclone. The impact of

drought can be much higher and can occur greater loss than flood, cyclone and storm surge [2], [5],[6]. Drought created huge production loss of crop in the country during the year of 1978-79, 1982 and 1997 [5], [7]. Therefore, it is urgent to conduct proper scientific research work on this issue using appropriate and up-to-date technology.

Several studies have conducted with similar environmental topics using satellite data and showed successful and satisfactory results. Yang (2008) used 20 MODIS images to estimate soil moisture condition in the Northern China. He used both NDVI and EVI (Enhanced Vegetation Index) to construct temperature-vegetation feature space and from there, using MODIS, he got result of regional soil moisture condition [8]. A study was carried out in Nakuru region, Kenya to assess agricultural drought severity using Land Surface Temperature (LST) and NDVI images. The researchers found significant information through their research to monitor drought there and early warning [9]. Rajeshwari and Mani (2014) carried out a research on Land Surface Temperature using Landsat 8 data in Dindigul District, Tamil Nadu, India. They found that barren regions show high LST whereas hilly regions with vegetative cover have low LST value [10]. Using MODIS data, Senay (2005) estimated irrigated crop production and monitored crop performance in Afghanistan. They implemented a thermal-based ET (Evapotranspiration) fraction approach and used 1km LST and 250m NDVI data from MODIS [11]. Therefore, the use of the MODIS, NDVI and LST imageries is certainly an advent technology and one of the best options for the present study. The main objective of this study is to assess drought vulnerability in the high-*Barind* tract of Bangladesh using multi-temporal MODIS NDVI and LST imageries. The long-term climate change scenario and distribution can be also reveal through the same assessment.
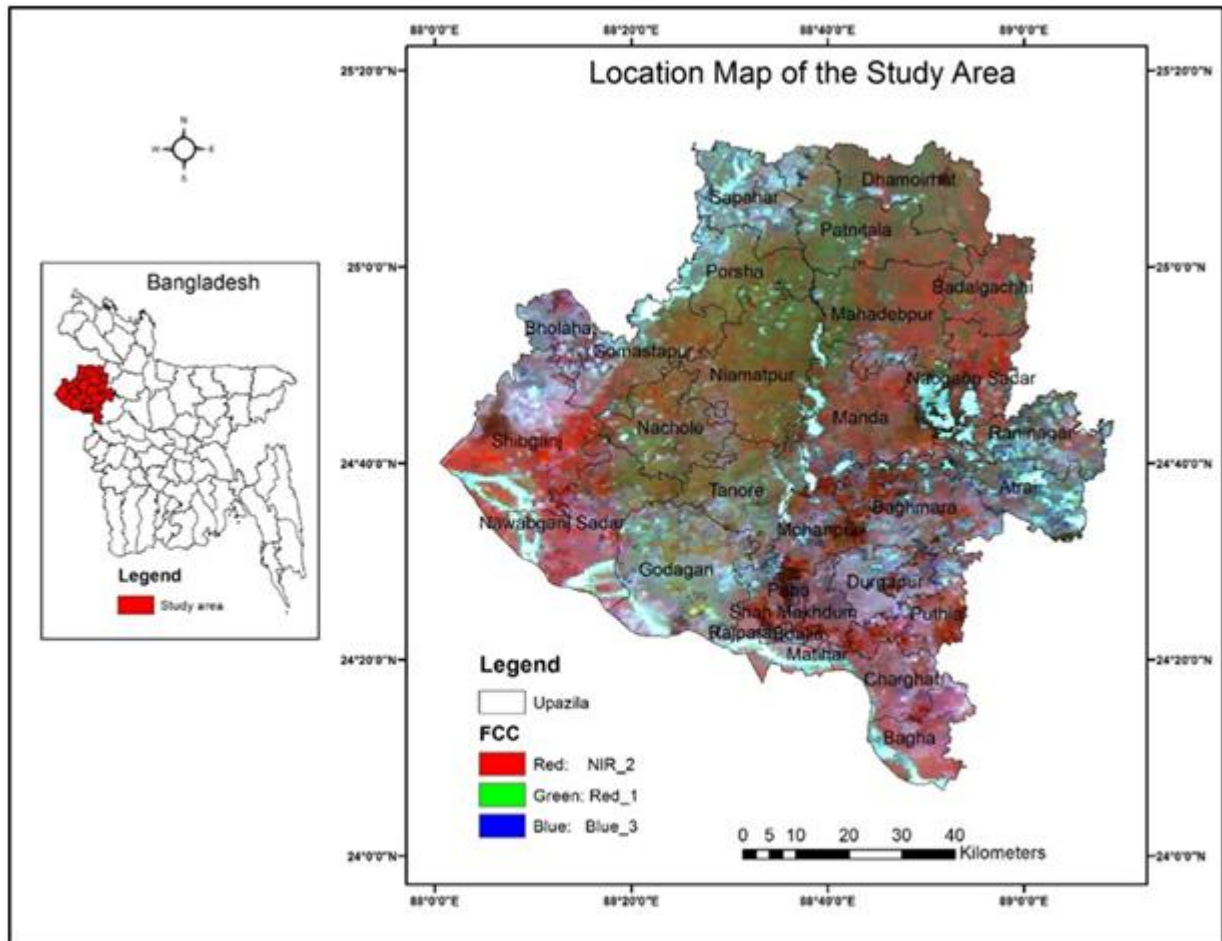
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55

Figure 1: False color composite (FCC) of the study area.

2. Study Area

The study area is located in ChapaiNawabganj, Rajshahi and Naogoan districts of North-west region of Bangladesh. The spatial boundary of the area is between latitude N 24° 00' to N 25° 20' and longitude E 88° 00' to E 89° 00' (Figure 1). The total area covers 7545.2 square kilometer while total population is 6842875 in the three districts [12]. A big portion of the study area comprises *Barind* Tract includes Tanore and Godagari*Upazila* of Rajshahi district, Manda and Niamatpur*Upazila* of Naogaon district and Nachole and Gomastapur*Upazila* of ChapaiNawabganj district.

The *Barind* region is characterized by very high temperate and low rainfall area. The annual temperature and rainfall is between 8°C to 44°C and 1500mm to 2000mm respectively. The imbalance of the seasonal rainfall affects badly to the groundwater level and the local agricultural pattern. The Monsoon season (June to October) covers 80% of total rainfall of the area whereas other seasons cover only the rest of 20% rainfall [13]. Therefore, there is an extreme water scarcity in most of the *Barind* tract. The *Barind* tract lies between the catchment of the River Ganges (The Padma, Bangladeshi part) and its tributaries drainage system of the Mahananda, Atrai and Purnabhaba Rivers.

The whole *Barind* tract has higher elevation than the area surrounding. From mean sea level, the average elevation of the *Barind*tract varies from 22 m (western part) to 40 m

(north-eastern part) high [13]. It is believed that the *Barind* tract was originated due to tectonic uplift in the Pleistocene Period [14]. The area is underlain by basement and sub-surface faults [13]. It is situated in the western stable shelf region of the Bengal Basin [13], [15]. The surface sediments of the *Barind* tract area are mostly covered by yellowish grey to red clay (*Barind* Clay). The weathering feature changes the iron dominant sediments towards red color. The red clay thickness of the surface layer varies place to place averaging 6 m in the south western part up to 30 m in the north-western part [13]. Monsur and Paepe (1994) divided the*Barind* tract area into two formations based on local stratigraphy [16]. The first formation consists of*Barind* clay and sand. This formation is highly oxidized and weathered, reddish brown clay to silty clay whereas the second formation is named *Rohonpur*Silty Clay and represents clay to silty clay and yellowish grey in color [14].

3. Supporting Data and Materials

To carry out this study, The Moderate Resolution Imaging Spectroradiometer (MODIS) imageries from July 2000, July 2008 and July 2014 were used. These imageries were 16-Day L3 Global 250 m and collected from the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC). Mainly six channels; NDVI, EVI, Blue, RED, NIR and MIR were used for computing different algorithm for image calculation. On the other hand, MOD11 of MODIS landsurface temperature and emissivity were used to extract

Paper ID: SUB151014

56

land surface temperature over the study area. The other information of the imageries used in the study is presented in Table1.

MOD11	July, 2000	1 KM	Band 31/32	8 Day
MOD11	July, 2008	1 KM	Band 31/32	8 Day
MOD11	July, 2014	1 KM	Band 31/32	8 Day

Table 1:MODIS NDVI and LST data characteristics.

MODIS/ Terra	Date of Acquisition	Resolution (Meter)	MODIS Product	Composition
MYD13Q1	July, 2000	250	Vegetation Indices (NDVI/EVI)	16 Day
MYD13Q1	July, 2008	250	Vegetation Indices (NDVI/EVI)	16 Day
MYD13Q1	July, 2014	250	Vegetation Indices (NDVI/EVI)	16 Day

A vector polygon file of 29 *Upazilas*under three districts were used to extract the main study area from the MODIS scenes. Mainly ENVI v.4.5 and ArcGIS v.10 software were used to process all kinds of image processing tasks and final layouts. Moreover, average annual rainfall and temperature were linked with the resultant maps.
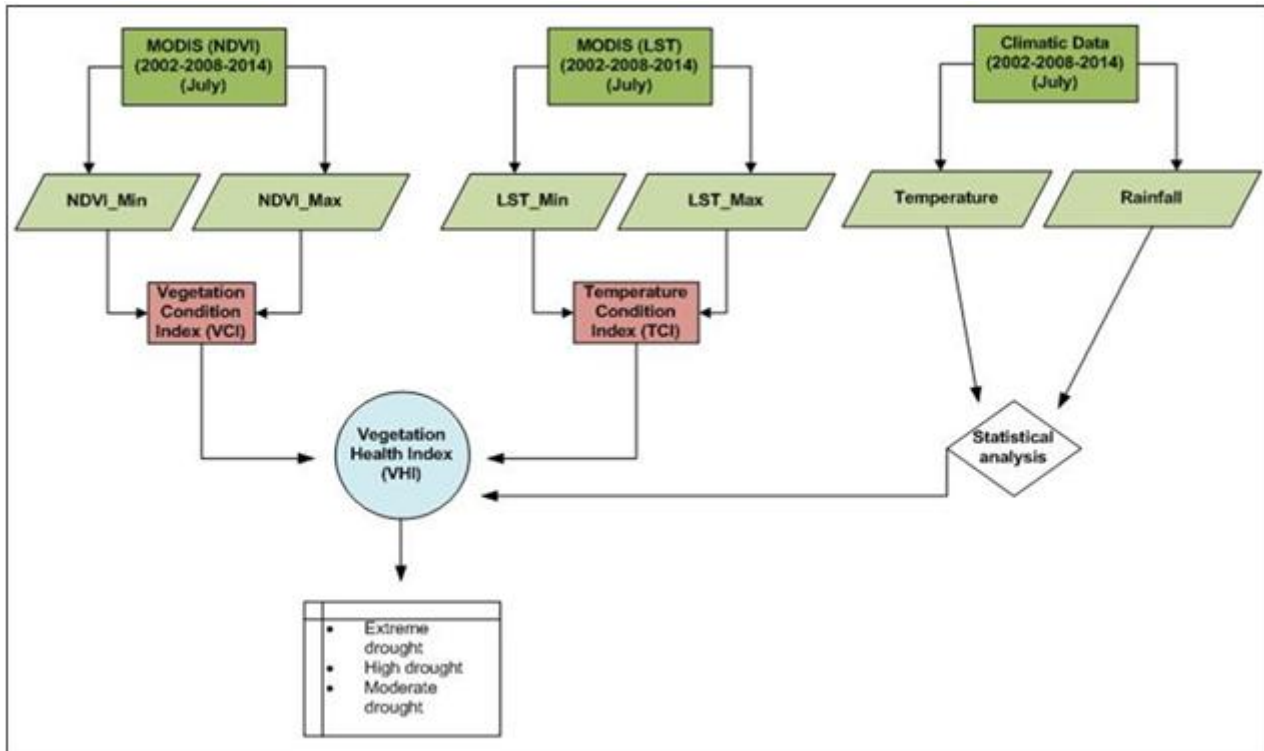

Figure 2: The methodology used in the study.

4. Methodology

The methodology used in the study is presented in Figure 2. NDVI and LST from MODIS imageries were used to estimate drought vulnerability in the study. In addition to this data, average monthly temperature and rainfall information were used.

4.1 NDVI for Vegetation

NDVI is a widely used slope based vegetation index using red and near infrared band. It is one of the most widely used vegetation indexes [17], [18]. Furthermore, the measurement scale has the desirable property of ranging from -1 to 1, with 0 representing the approximate value of no vegetation, and negative values non-vegetated surfaces [19]. We used NDVI for mapping vulnerability of drought. NDVI has been used to detect drought in various parts of the world in the recent decades [20]. The following equation (1) was used to calculate open water and winter crops in the study:
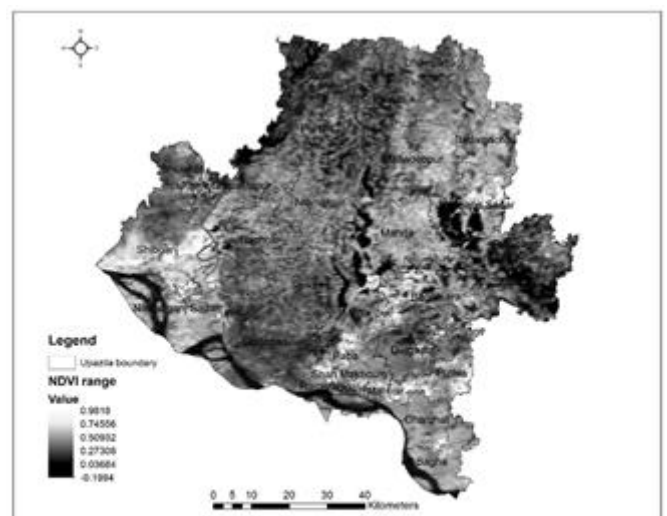
$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \quad (1)$$

Figure 3: Average NDVI ranges of the July month of the year 2002, 2008 and 2014 in the study area.

Finally, all NDVI maps of 2002, 2008 and 2014 were super-imposed into an average NDVI map (Figure 3).

4.2 Land Surface Temperature (LST)

The combination of NDVI and LST has provided better understanding of drought events with their close inter-relations with surface drought status [20]. We used 1 km resolution of 8 day MODIS11A2 data in order to calculate land surface temperature during July 4 to July 27 in 2002, 2008 and 2014. Finally, these three LST maps were converted to an average LST map.

4.3 Drought Vulnerability Analysis

We used there equations to generate a final map of drought vulnerability in the study area. These calculations are below:

4.3.1 Vegetation Condition Index (VCI)
VCI is a widely used algorithm for estimating vegetation condition based on NDVI min and max value. The VCI is expressed in percentage (%) and gives an idea where the observed value is situated between the extreme values (minimum and maximum) in the previous years [21]. The below equation (2) was used to calculate VCI:

$$VCIj = \frac{(NDVIj - NDVImin)}{(NDVImax - NDVImin)} * 100 \quad (2)$$

Where, $NDVI_j$, $NDVI_{Min}$, $NDVI_{Max}$ are the average maps of July 2002, 2008 and 2014.

4.3.2 Temperature Condition Index (TCI)
This index has been used as an effective agricultural drought index to monitor the spatial pattern of vegetation over a region (equation 3) [22].

$$TCIj = \frac{(LSTmax - LSTj)}{(LST max - LSTmin)} * 100 \quad (3)$$

Where, LST_j, LST_{Min}, LST_{Max} are the average maps of July 2002, 2008 and 2014.

4.3.3 Vegetation Health Index (VHI)
VHI represents overall vegetation health [23]. It also indicates agriculture drought. We used the below equation (4) for generating vegetation health index.

$$VHI = 0.5 * VCI + 0.5 * TCI \quad (4)$$

To derive vegetation health index in terms of drought, we leveled 0-10%, 10-20% and 20-30% VHI values as extreme, high and moderate drought vulnerability respectively in this study.

5. Results and Discussion

In this paper, we used vegetation health index (VHI) as the main method to extract agriculture drought in the study area using vegetation condition index (VCI) and temperature condition index (TCI) from July imageries of 2000, 2008 and 2014. From the VHI analysis, we found that about 147956 (29% of the total), 173194 (34% of the total) and 191352 (37% of the total) hectares land as extreme, high and moderate drought areas respectively in the study (Figure 4).

Figure 5 indicates that, extreme agriculture drought (0-10% VHI) in Naogoan district, particularly north and middle part. Rajshahi district is in high drought (10-20% VHI) and

ChapaiNawabganj district has moderate drought indication (20-30% VHI) (Figure5). High depletion rate of groundwater, diminishing evidence of open surface waterbodies, low vegetation coverage, erosion of top soil are being exposed as the main driving forces to bring vulnerability of drought in the study area.
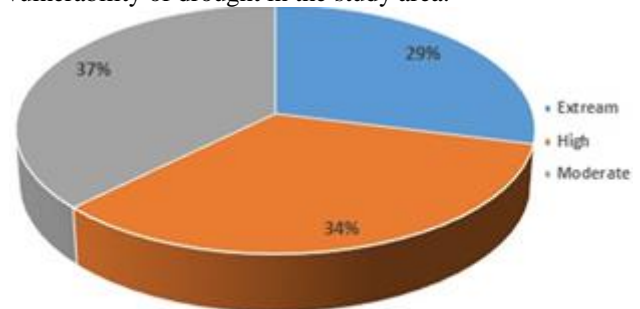

Figure 4: Estimated total agriculture drought areas in the study area.
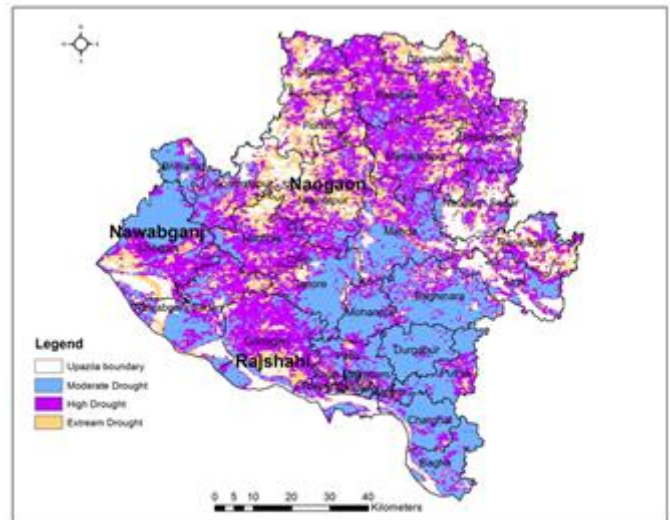

Figure 5: Extreme, high and moderate drought vulnerability in the study area.

We used July month data due to its hot climatic condition in terms of annual temperature and rainfall characteristics. Figure 6 shows that temperature has an increase trend while rainfall has decreased tendency. Apart from the devastated floods in 2003, 2005 and 2011, all the years experienced low precipitations that lead to drought vulnerability over the study area (Figure 6).

A regression analysis was performed between NDVI and land surface temperature. This result found very less relationship between vegetation and land surface temperature during July in the study area (Figure 7). It explains that vegetation is not predominant feature during July due to very hot climatic condition and less surface water bodies as well as high delegation rate of ground water table.
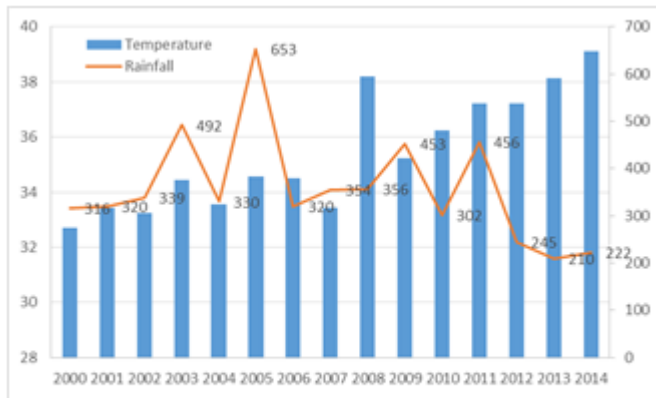
Figure 6: Annual temperature and rainfall from 2000 to 2014.

6. Conclusion

A significant amount of areas were found as extreme, high and moderate vulnerability to agriculture drought prone in the study area, which can be put at risk in terms of agriculture productions, socio-economic condition, livelihoods, biodiversity as well as overall sustainable development. The government and related development agencies can consider it as serious environmental issue for future regional development. In this study paper, only MODIS NDVI and LST maps were used to identify drought vulnerability mapping. Therefore, the further study should be based on different multi-resolution and multi-sources information. The model we used, vegetation health index, was viable to extract the outputs in the study.

References

[1] FAO (Food and Agriculture Organization), "Livelihood Adaptation to Climate Variability and Change in Drought-prone Areas of Bangladesh. Institutions for Rural Development", Project Report, FAO, Rome, Italy pp.97, 2006.

[2] A.T. Alam, M.S. Rahman, A.H. Saadat, M. Huq, "Gamma Distribution and its Application of Spatially Monitoring Meteorological Drought in Barind, Bangladesh," Journal of Environmental Science and Natural Resources 5 (2), pp. 287-293, 2012.

[3] S. Shahid, M.K. Hazarika, "Groundwater Drought in the Northwestern Districts of Bangladesh," Water Resour Manage, Vol. 24, pp. 1989–2006, 2010.doi: 10.1007/s11269-009-9534-y

[4] S. Shahid, "Spatial Assessment of Groundwater Demand in Northwest Bangladesh," International journal of Water 5(3), pp. 267-283, 2010.doi: 10.1504/IJW.2010.030590

[5] B.K. Paul, "Coping mechanisms practiced by drought victims (1994/5) in North Bengal, Bangladesh," Applied Geography, Vol. 18, pp. 355–373, 1998.

[6] S. Shahid, "Spatial and Temporal Characteristics of Droughts in the Western Part of Bangladesh,"Hydrol. Process, Vol. 22, pp. 2235–2247, 2008.doi: 10.1002/hyp.6820

[7] S. Ramsey, A.R. Subbia, S. Bass, I. Juergens, "Livelihood Adaptation to Climate Variability and Change in Drought-prone Areas of Bangladesh,"

[8] X. Yang, J.J. Wu, P.J. Shi, F. Yan, "Modified Triangle Method to Estimate Soil Moisture Status with Moderate Resolution Imaging Spectroradiometer (MODIS) Products," The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Part B8, Beijing, Vol. XXXVII, pp. 555-559, 2008.

[9] K.I. Kapoi, O. Alabi, "Agricultural Drought Severity Assessment Using land Surface Temperature and NDVI in Nakuru region, Kenya,"In Proceedings of Global Geospatial Conference, Addis Ababa, Ethiopia, 4-8 November 2013.

[10] A. Rajeshwari, N.D. Mani, "Estimation of Land Surface Temperature of Dindigul District using Landsat 8 Data," International Journal of Research in Engineering and Technology, 03(05), pp. 122-126, 2014.

[11] G.B. Senay, M. Budde, J. Rowland, "Evaluating MODIS data to estimate irrigated crop production in Afghanistan using a Thermal based ET fraction approach,"In Proceedings of Pecora 16 'Global Priorities in Land Remote Sensing' Sioux Falls, South Dakota, 23-27 October 2005.

[12] BBS (Bangladesh Bureau of Statistics),"Population Census 2011-Preliminary Report," Statistic Division, Ministry of Planning, Government of Bangladesh, 2011.

[13] A.H. Reza, Q.H. Mazumder, "Evaluation of Hydrogeological Conditions of Sapahar and Porsha Upazillas, Barind Tract, Bangladesh." Journal of Life Earth Science, 1(1), pp. 15-20, 2005.

[14] T. Rashid, M.H. Monsur, S. Suzuki, "A Review on the Quaternary Chracteristics of Pleistocene Tracts of Bangladesh," Okayama University Earth Science Reports 13(1), pp. 1-13, 2006.

[15] D. Guha, "Tectonic Framework and Oil and Gas Prospects of Bangladesh," In Proceedings of the 4th Annual Conference, Bangladesh Geological Society, Dhaka, 1976.

[16] M. Monsur M, R. Paepe, "Quaternary Stratigraphy of the Madhupur area of the Bengal Basin. Bangladesh," Jour Sci Res, 12 (1) pp. 41-47, 1994.

[17] L. Zhu, R. Tateishi, "Application of Linear Mixture Model to Time Series AVHRR NDVI Data,"In Proceeding of 22nd Asian Conference on Remote Sensing, Singapore, 5-9 November, 2001.

[18] S. Hassan, "Assessment of Landuse and Land Degradation in the North-Westren Part of Bangladesh using Landsat Imagery," TRITA Master's Thesis, Division of Geoinformatics, Royal Institute of Technology (KTH), Stockholm, Sweden, GIT EX 09-013:1-73, 2009.

[19] N.G. Silleos, T.K. Alexandridis, I.Z. Gitas, K. Perakis, "Vegetation Indices: Advances Made in Biomass Estimation and Vegetation Monitoring in the Last 30 Years,"Geocarto International, 21(4), pp. 21-28, 2006.

[20] A. Khalil, M. Wahab, M.K. Hassanein, B. Ouldbdey, B. Katlan, Y. Essa, "Drought Monitoring over Egypt by using MODIS land Surface Temperature and Normalized Difference Vegetation," Nature and Science, 11(11), pp. 116-122, 2013.

[21] Copernicus, "Vegetation Condition Index (VCI)," Global Land Service, The European Earth Observation Programme, 2014. [Online].Available: http://land.copernicus.eu/global/products/vci. [Accessed: 2 December, 2014].

[22] N. Patel, B.R.Parida, V. Venus, S.K. Saha, V.K. Dadhwal, "Analysis of Agricultural drought using vegetation temperature condition index (VTCI) from Terra/ MODIS satellite data," Environmental Monitoring Assessment, 2011.doi: 10.1007/s10661-011-2487-7

[23] F. Kogan, "Operational Space Technology for Global Vegetation Assessment," Bulletin of the American Meteorological Society, 82 (9), pp. 1949-1964, 2001.

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