Proceedings of Civil and Water Resources Engineering Conference
3-4 November 2017, BIAM Foundation, 63 Eskaton, Dhaka, Bangladesh
ISBN: 978-1-925488-52-4

Vegetation Response to Drought Using Remotely Sensed Drought Indices in Southern Part of Barind Tracts

Abir Biswas and Rahatul Islam

TCI illustrated greater vegetation stress at thecenterof the region, whereas VCI and VHI inclinedtowards the west and north-west side. The worst drought depicted by TCI occurred in 2010-2011 followed by 2007-2008. However, VCI and VHI revealed the period 2009-2010 to display thepoorest vegetation health. The indices can accurately depict the impact of drought on vegetation, but may also be improved by revising the classifying mechanism or coefficient in VHI estimation.

Keywords: drought, vegetation response, TCI, VCI, VHI, Barind, remote sensing

1. Introduction

Drought is identified as an environmental disaster, primarily caused due to the lack of rainfall overan extended period of time (Marsh & Singh, 2010). The low rainfall is responsible for the decrement in expected surface and groundwater causing reduced water supply, deteriorated water quality, crop failure, and reduced productivity, diminished power generation, disturbed riparian habitats, and suspended recreation activities, as well as affect a host of economic and social activities (Riebsame et al., 1991).

Bangladesh has already shown an increased frequency of droughts in recent years, damaging the agricultural economy, especially in the northwest region. According to Brammer (1987) and Murad& Islam (2011), northwest Bangladesh is the most vulnerable region in terms of drought. Barind Region is a major part of the north-west region suffering from drought. The drought in this region has been monitored by Jahangir Alamet. al. (2013) and Rahman et.al. (2017). The hazard footprint of drought are generally greater and longer than other hazards, which makes it simpler to monitor the severity and location, which may vary depending on the region or season.

There is an abundance of measures and indices used to monitor drought. Some of the most popular indices include Standardized Precipitation Index (SPI; McKee et al., 1993, 1995) and Palmer Drought Severity Index (PDSI; Palmer, 1965). However, the method to compute such measures are either quite difficult or they require the collection of extensive data, which may not beeasily accessible. Since many satellite images are freely available in addition to GIS and remote sensing, providing an affordable, reliable

---

Abir Biswas, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, abiswas3128@gmail.com
Rahatul Islam, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, rahat.6205@gmail.com

ISBN: 978-1-925488-52-4

and efficient interface for image processing and analysis, it can make the process of monitoring drought conditions much easier.

Among the many remotely sensed drought indices, Normalized Difference Vegetation Index (NDVI), Temperature Condition Index (TCI), Vegetation Condition Index (VCI) and Vegetation Health Index (VHI) are mostly used to monitor the impact of drought on vegetation (Kogan, 1990, 1995), which are further used in other studies to calculate the crop yield and delineate areas with poor vegetation growth. The latter three indices will be used in this study to analyze the vegetation response to drought.

2. Literature Review

The three indices TCI, VCI and VHI are generated for the purpose of measuring vegetative stress in the study area.

The Temperature Condition Index(TCI) was developed using the Land Surface Temperature (LST) derived from Advanced Very High Resolution Radiometer (AVHRR) based observations in thermal bands. The purpose behind it was to understand the extent of temperature based vegetative relative stress and also stress caused due to surplus wetness due to adverse climatic and hydrologic factors (Kogan, 1995). The Land Surface Temperature composites for any desired time scale (eg. weekly, monthly) is calculated and measured for a certain time period separated by a fixed time interval. Thelong-termmaximum and minimumLST of the multiple images are extracted. The TCI is then calculated by (Kogan, 1995):

$$TCI(\%) = (LST - LST_{min}) / (LST_{max} - LST_{min}) * 100 \quad \text{(Eq.1)}$$

Where LST, LST_{min}, and LST_{max} are the seasonal average of monthly land surface temperature, its multi-year absolute minimum, and maximum, respectively (Bhuiyan et. al., 2006). It is able to distinguish the relative changes in thermal condition.

The National Oceanic and Atmospheric Administration (NOAA) developed an AVHRR-based Vegetation Condition Index (VCI) that is useful for drought detection and tracking. They are not only suitable for detecting drought but determine the time of onset, intensity, duration and impact on vegetation. It is a very beneficial tool for both long-term, intensive, distinct, widespread as well as short-term, localized and non-distinct droughts. However, prior to the calculation of VCI, the Normalized Difference Vegetation Index (NDVI) needs to be generated. NDVI reflects the vegetation condition through the ratio of responses in near-infrared (NIR) and visible red (R) bands (Tarpley et. al., 1984).

$$NDVI = (\rho_{NIR} - \rho_{RED}) / (\rho_{NIR} + \rho_{RED}) \quad \text{(Eq.2)}$$

ISBN: 978-1-925488-52-4

Where ρ_{NIR} represents the surface reflectance of the NIR band and ρ_{RED} represents the surface reflectance of the red band. However, in the case of the study, the NDVI is not calculated. Instead, the MODIS NDVI product is used, where the NDVI is already generated and the values are simply used in this study for estimation purposes.The NDVI composites for any desired timescale is calculated and measured for a certain time period separated by a fixed time interval. The long-term maximum and minimum NDVI of the multiple imagesare extracted. The VCI is then calculated by (Kogan, 1990, 1995):

$$VCI(\%) = (NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) * 100 \quad \text{(Eq.3)}$$

Where NDVI, $NDVI_{min}$, and $NDVI_{max}$ are the seasonal average of smoothed monthly NDVI, absolute multi-year minimum and maximum, respectively (Bhuiyan et. al., 2006). Weather impact is a major component of vegetative drought. NDVI's strong ecological component subdues the weather component. However, VCI is able to separate fluctuations due to weather from the long-lasting changes in theecosystem (Kogan, 1990, 1995). This means that unlike NDVI, which displays seasonal vegetation dynamics, VCI ranging from 0% to 100% is able to reflect the changes in a relative manner from extremely bad to optimal condition (Kogan, 1995; Kogan et. al., 2003).

While higher TCI and VCI values are able to portray better thermal and moisture condition of vegetation, the Vegetation Health Index (VHI) was developed by Kogan (2001) to represent the overall vegetation health. This index is distributed among five classes that are used for drought mapping.

$$VHI(\%) = (0.5 * TCI) + (0.5 * VCI) \quad \text{(Eq.4)}$$

Among other studies, Wan et. al., (2004), Singh et. al. (2003), Rojas et.al (2011) all conducted studies using either or all of TCI, VCI and VHI for agricultural drought monitoring. Whereas, Ungani&Kogan (1998), Prasad et. al. (2006), Liu&Kogan (2002) and Rahman et. al. (2009) used the indices for crop yield estimation studies.

3. Methodology

The first step was the selection of the study area, and since drought occurred in the Barind region, the districts covering the southern Barind tracts was selected covering Rajshahi, Naogaon, Joypurhat, Bogra and Natore.

ISBN: 978-1-925488-52-4

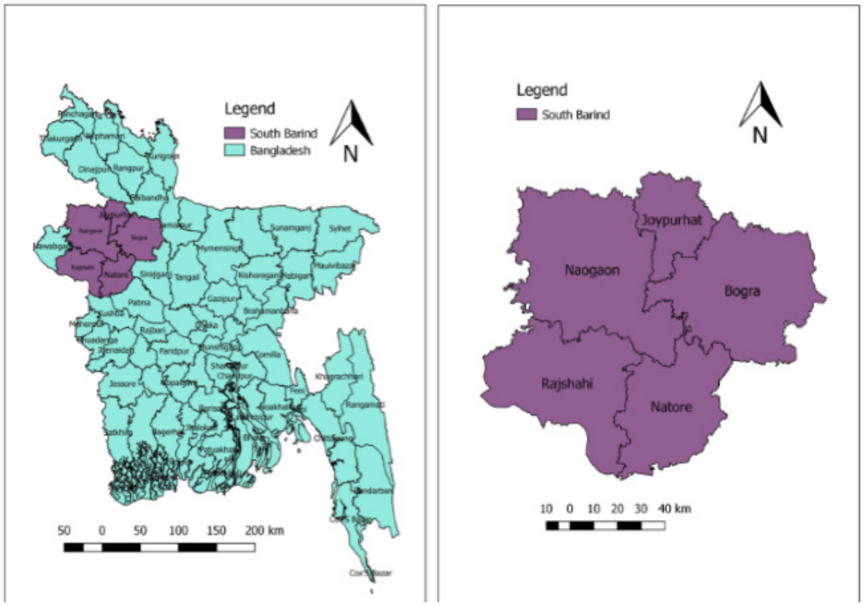

Figure 1: Map of Study Area

Following that, Moderate Resolution Imaging Spectroradiometer (MODIS) images for November from one year to February of the next were dused for the periods of 2005-2006 to 20016-2017, implyinga total of 12 time periods. Only November, December, January and February were selected as these months fall within the dry period and the images are mostly cloud-free, providing with better pixel values in the imagesas water scarcity usually happens during this timeframe. A total of 48 images were accumulated.

Table 1: MODIS images used in the study

Image	Description
MODIS MOD11B3 V6	The MOD11B3 version 6 product provides average, monthly per pixel LST with a pixel size of 5600 meters (m).
MODIS MOD13A3 V6	The MOD13A3 version 6 product contains average, monthly per pixel NDVI with a pixel size of 1000 meters (m).

Source: Wan, 2015; Didan, 2015

The monthly LST images from November of one year to February of the next (four images for each month) were averaged to form a common averaged LST image for that particular time period (i.e. 2005-2006 being the first time period and 2016-2017 being the last). The same was done for all the other time periods, making a total of twelve 4-month LST images, which carried the value of the average LST for the four months. The same process was applied to the MODIS NDVI products, which resulted in 4-month NDCI images, which carried the value of the average LST for the four months for the 12 time periods.

ISBN: 978-1-925488-52-4

The next step includes determining the multi-year absolute minimum and maximum LST and NDVI within the study area (i.e. LST_{min}, LST_{max}, $NDVI_{min}$, $NDVI_{max}$). These LST and NDVI values along with the existing LST and NDVI value of the pixels in the 4-month images were used to calculate the TCI and VCI respectively, using the equations mentioned above (Eq.1 and Eq.2). Therefore, for the TCI, twelve images are generated for the twelve time periods. The same was done for VCI. The VHI was calculated using the TCI and VCI using equation 4 (Eq.4) for each of the time periods.

When a total of 36 images have been generated (twelve for each index), these images are classified into five classes according to the table given below:

Table 2: Classification Schemes for Drought Monitoring using TCI, VCI and VHI

Drought Classes	**TCI / VCI / VHI**
Extreme Drought	<10
Severe Drought	<20
Moderate Drought	<30
Mild Drought	<40
No Drought	>40

Source: Kogan, 2002

The end result is the generation of 12 classified images for each indices, displaying the severity of thedrought, throughout the years within the Southern section Barind region. Finally, the spatiotemporal changes in drought severity are analyzed.

4. Results

The final classified images derived from TCI, VCI and VHI are used to determine the vegetation health from the different dimensions.

ISBN: 978-1-925488-52-4

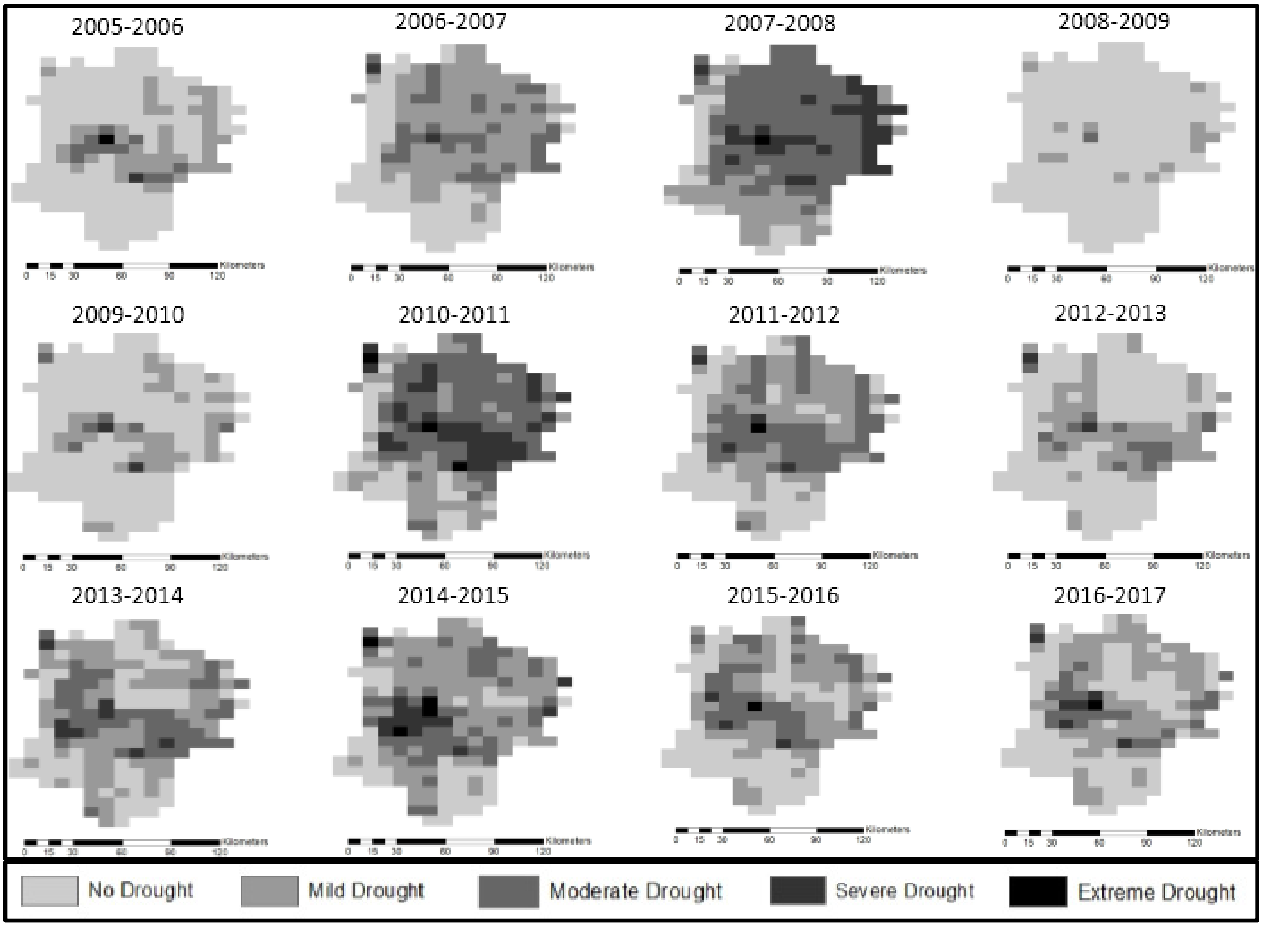

Figure 2: Drought Severity in Southern part of Barind Tract derived from TCI

The drought severity extracted from TCI seems to indicate that spatially, the center of the study area is more drought-prone than other location. One pixel, almost at the center seems to be thermally stressed throughout the years. The northeast side of the study area tends to have greater thermal vegetation stressbetween the years 2005-2008, wherethe drought had increment of stress, but the second jump within the three periods seems to be greater than the previous. From November 2012 to February 2014, the vegetation health seems to be quite unstressed. Suddenly the period 2010-2011 experienced a sudden rise in thermal vegetative stress. After that, there was no significant increase or decrease in the trend of TCI. Overall, 2010-2011 had the worst vegetation health due to thermal stress followed by 2007-2008. Whereas, 2005-2006, 2008-2009 and 2009-2010 had an insignificant amount of thermal vegetation stress (Figure 2).

The drought severity derived from VCI (Figure 3) seems to have a different situation in comparison to TCI. Moisture stress is pretty much non-existent from the November 2012 onwards. Overall, it seems that west and northwest side of the study area seems to experience mild to moderate form of drought, and rarely severe drought.

ISBN: 978-1-925488-52-4

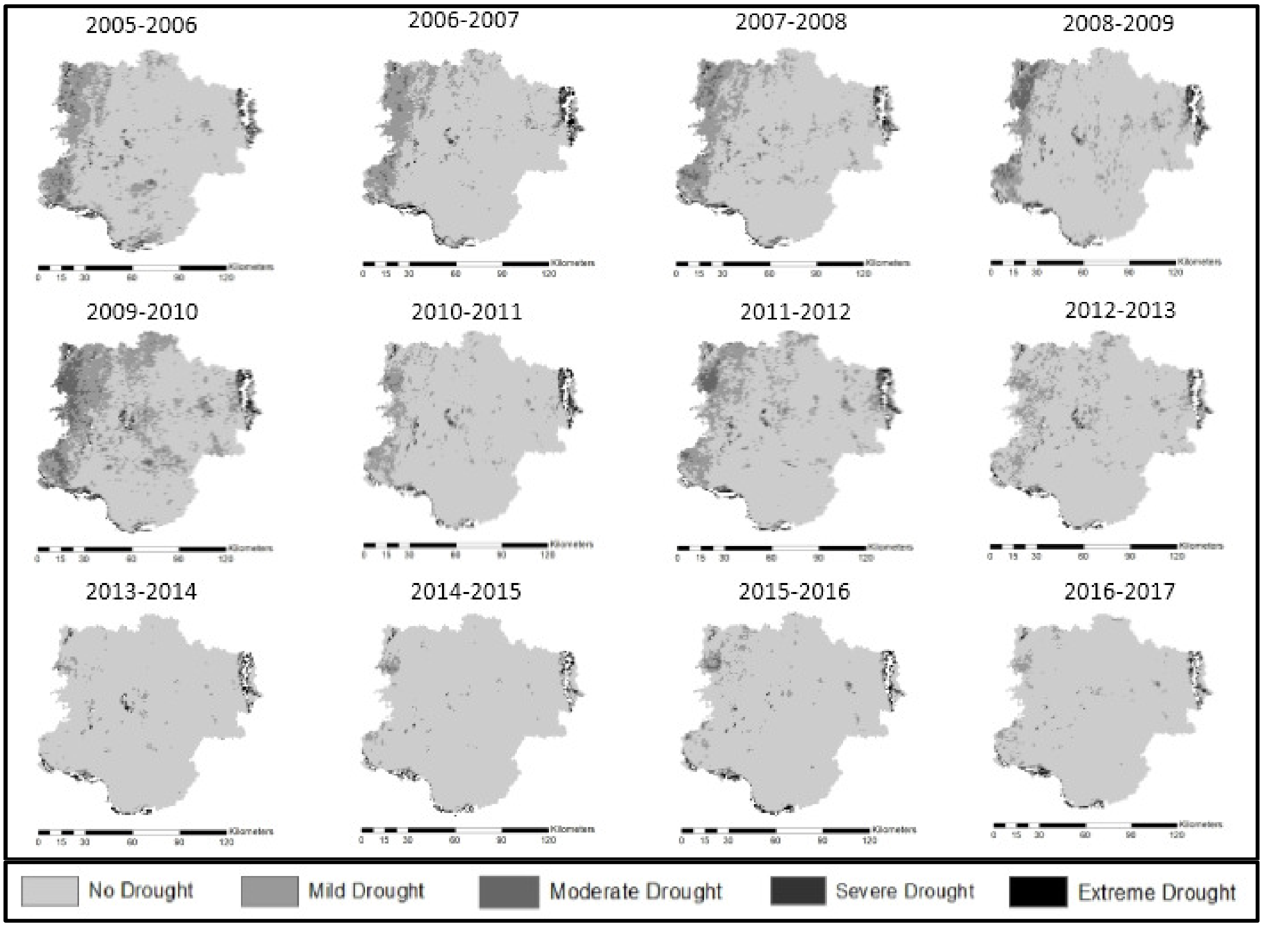

Figure 3: Drought Severity in South Barind derived from VCI

There also seems to be some drought on the east side of the region which is relatively constant throughout the temporal coverage. The period 2008-2009 and 2009-2010 seems to have at least some level of drought when compared the others. Prior to this time, there was some drought on the west side, but after 2010, drought due to moisture was not a big issue (Figure 3).

Spatially, the vegetation health is usually worse on the west and northwest side of the region. Even if there is adrought on the east side, it is usually mild or moderate drought. However, during the same time, the west and north-west side suffers from severe or extreme drought. The vegetation health was worst during the period 2009-2010 with severe and extreme drought occurring on the west and northwestern side of the study area. Mild drought was prevalent at many other locations. The periods prior to 2009-2010 still had a significant amount of bad vegetation health. From November 2010 to February 2013 the vegetation health improved and beyond that, there was no significant drought at all (Figure 4).

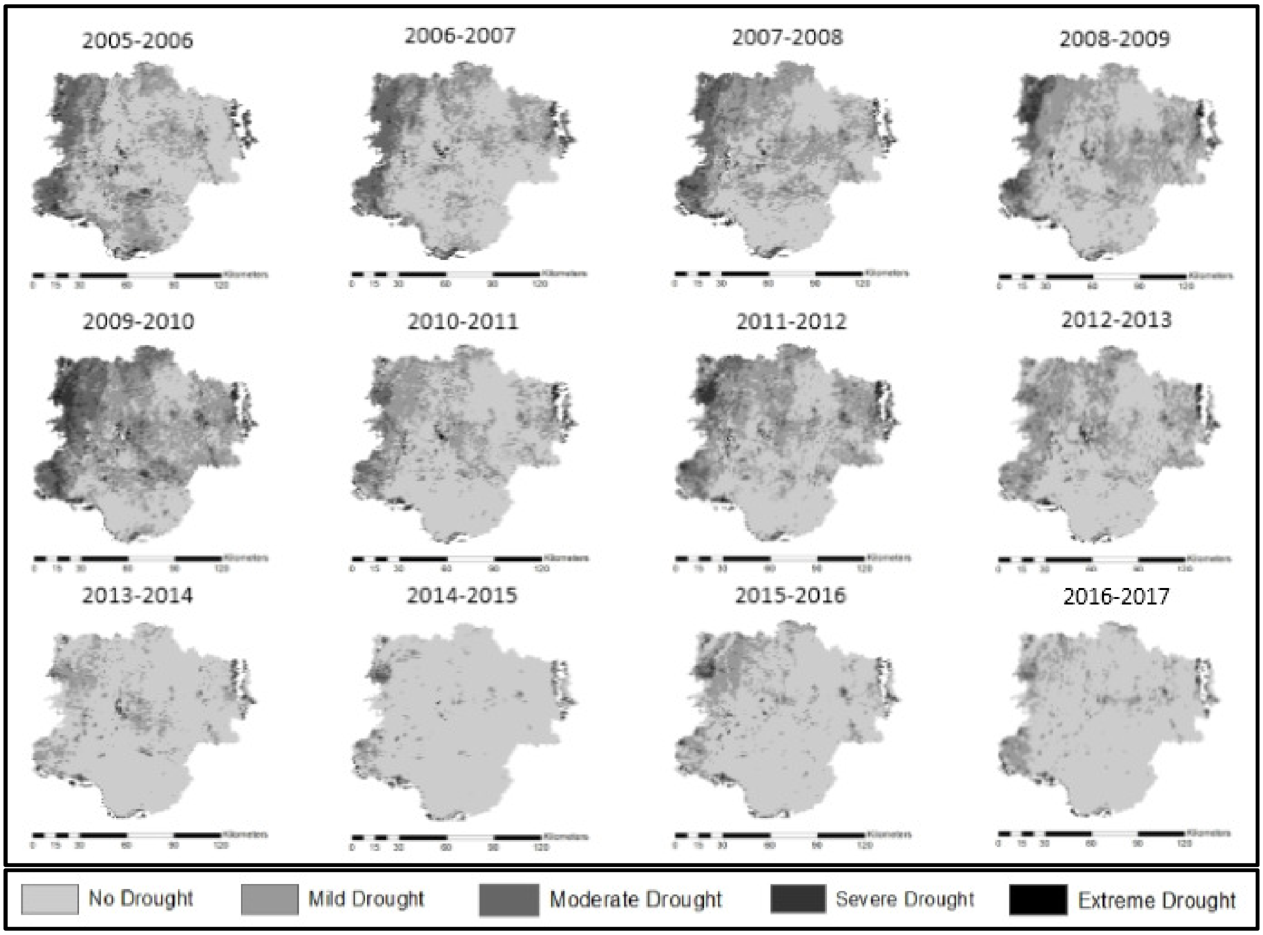

Figure 4: Drought Severity in South Barind derived from VHI

Overall, the TCI illustrated vegetation stress is greater towards the center of the study are, whereas VCI and VHI leaned more towards the west and northwestern side. The worst drought in terms of TCI was for the period 2010-2011 followed by the year 2007-2008. However, VCI and VHI displayed the period 2009-2010 to have the worst vegetation health.

5. Discussion

Although the VHI describes the overall vegetation health with regards to vegetation stress caused by temperature and moisture, it seems that the VHI is more sensitive to changes in the VCI, that the TCI. This may be due to the many values of VCI having much greater values than the TCI, which may upset the balance and give a much higher value than expected. Since the classification has lower percentages, much higher percentage can easily offset the value to more favorable conditions. Therefore, either the coefficients of TCI and VCI or the percentages for classification may be re-evaluated for this region. However, the indices are able to sufficiently measure the impact of the

ISBN: 978-1-925488-52-4

drought on vegetation, as it shows that the impact of drought within 2005 to 2010 is significant (Rahman &Lateh. 2016).

6. Conclusion

Remote sensing is widely used in drought related studies, especially with the introduction of NDVI, which is widely popular for vegetation response. It provides a platform to extract information about the surface of the earth, which is quick and easy and less data intensive. The information from satellite images can be combined in many ways to form indices that may act as a proxy to represent a phenomena which may be difficult to monitor. Drought and its impacts require such information that not only difficult to retrieve but also tough to analyze especially if it is a large region, which requires a tremendous amount of time and effort.

The water scarcity in the north-west region and in particular the Barind tracts has been a long-term issue in Bangladesh. Being able to monitor near real-time is of benefit, as the TCI, VCI and VHI are such tools that can help predict an oncoming drought, the yield of various crops or the loss or gain to the economy. If used properly these indices may be used as an integral part of water resource management.

References

1. Bhuiyan, C., Singh, R. P., &Kogan, F. N. (2006). Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data. *International Journal of Applied Earth Observation and Geoinformation*, *8*(4), 289-302.
2. Brammer, H. (1987). Drought in Bangladesh: lessons for planners and administrators. *Disasters*, *11*(1), 21-29.
3. Didan. K., (2015). MOD13A3 MODIS/Terra Vegetation Indices Monthly L3 Global 1km SIN Grid V006. NASA EOSDIS Land Processes DAAC. https://doi.org/10.5067/modis/mod13a3.006
4. Jahangir Alam, A. T. M., Saadat, A. H. M., Sayedur Rahman, M., & Rahman, S. (2014). Spatio-temporal variation of agricultural drought in the barind region of Bangladesh: an application of a Markov chain model. *Irrigation and Drainage*, *63*(3), 383-393.
5. Kogan, F. N. (1990). Remote sensing of weather impacts on vegetation in non-homogeneous areas. *International Journal of Remote Sensing*, *11*(8), 1405-1419.
6. Kogan, F. N. (1995). Application of vegetation index and brightness temperature for drought detection. *Advances in Space Research*, *15*(11), 91-100.
7. Kogan, F. N. (2001). Operational space technology for global vegetation assessment. *Bulletin of the American Meteorological Society*, *82*(9), 1949-1964.
8. Kogan, F. (2002). World droughts in the new millennium from AVHRR-based vegetation health indices. *Eos, Transactions American Geophysical Union*, *83*(48), 557-563.

9. Kogan, F., Gitelson, A., Zakarin, E., Spivak, L., & Lebed, L. (2003). AVHRR-based spectral vegetation index for quantitative assessment of vegetation state and productivity. *Photogrammetric Engineering & Remote Sensing*, *69*(8), 899-906.
10. Liu, W. T., &Kogan, F. (2002). Monitoring Brazilian soybean production using NOAA/AVHRR based vegetation condition indices. *International Journal of Remote Sensing*, *23*(6), 1161-1179.
11. McKee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In *Proceedings of the 8th Conference on Applied Climatology* (Vol. 17, No. 22, pp. 179-183). Boston, MA: American Meteorological Society.
12. McKee, T. B., Doesken, N. J., & Kleist, J. (1995). Drought monitoring with multiple time scales. In *Proceedings of the 9th Conference on Applied Climatology* (pp. 233-236). Dallas, Boston, MA: American Meteorological Society.
13. Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of hydrology*, *391*(1), 202-216.
14. Murad, H., & Islam, A. S. (2011). Drought assessment using remote sensing and GIS in north-west region of Bangladesh. In *3rd International Conference on Water and Flood Management* (pp. 2-797).
15. Palmer, W. C. (1965). *Meteorological drought* (Vol. 30). Washington, DC: US Department of Commerce, Weather Bureau.
16. Prasad, A. K., Chai, L., Singh, R. P., &Kafatos, M. (2006). Crop yield estimation model for Iowa using remote sensing and surface parameters. *International Journal of Applied Earth Observation and Geoinformation*, *8*(1), 26-33.
17. Rahman, A., Roytman, L., Krakauer, N. Y., Nizamuddin, M., & Goldberg, M. (2009). Use of vegetation health data for estimation of Aus rice yield in Bangladesh. *Sensors*, *9*(4), 2968-2975.
18. Rahman, A. S., Jahan, C. S., Mazumder, Q. H., Kamruzzaman, M., &Hosono, T. (2017). Drought analysis and its implication in sustainable water resource management in Barind area, Bangladesh. *Journal of the Geological Society of India*, *89*(1), 47-56.
19. Rahman, M. R., &Lateh, H. (2016). Meteorological drought in Bangladesh: assessing, analysing and hazard mapping using SPI, GIS and monthly rainfall data. *Environmental Earth Sciences*, *75*(12), 1-20.
20. Rhee, J., Im, J., & Carbone, G. J. (2010). Monitoring agricultural drought for arid and humid regions using multi-sensor remote sensing data. *Remote Sensing of Environment*, *114*(12), 2875-2887.
21. Riebsame, W. E., ChangnonJr, S. A., & Karl, T. R. (1991). *Drought and natural resources management in the United States. Impacts and implications of the 1987-89 drought*. Westview Press Inc.
22. Rojas, O., Vrieling, A., &Rembold, F. (2011). Assessing drought probability for agricultural areas in Africa with coarse resolution remote sensing imagery. *Remote sensing of Environment*, *115*(2), 343-352.
23. Singh, R. P., Roy, S., &Kogan, F. (2003). Vegetation and temperature condition indices from NOAA AVHRR data for drought monitoring over India. *International Journal of Remote Sensing*, *24*(22), 4393-4402.

24. Tarpley, J. D., Schneider, S. R., & Money, R. L. (1984). Global vegetation indices from the NOAA-7 meteorological satellite. *Journal of Climate and Applied Meteorology*, *23*(3), 491-494.
25. Tucker, C. J., & Choudhury, B. J. (1987). Satellite remote sensing of drought conditions. *Remote sensing of Environment*, *23*(2), 243-251.
26. Unganai, L. S., &Kogan, F. N. (1998). Drought monitoring and corn yield estimation in Southern Africa from AVHRR data. *Remote Sensing of Environment*, *63*(3), 219-232.
27. 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. *International Journal of Remote Sensing*, *25*(1), 61-72.
28. Wan Z., S. H. (2015). MOD11B3 MODIS/Terra Land Surface Temperature/Emissivity Monthly L3 Global 6km SIN Grid V006. NASA EOSDIS Land Processes DAAC. https://doi.org/10.5067/modis/mod11b3.006