Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2015, Volume 4, Issue 1, pp. 1195-1203, Article ID Tech-440
ISSN 2320 - 0243

Review Article **Open Access**

Agricultural Drought Severity Assessment using Remotely Sensed Data: A Review

Sandeep V. Gaikwad[1], Karbhari V. Kale[1], Sonali B. Kulkarni[1], Amarsinh B. Varpe[2] and Ganesh N. Pathare[2]

Department of CS & IT, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, Maharashtra, India
Department of CS, Vinayakrao Patil Mahavidhyalay, Vaijapur, Aurangabad, Maharashtra, India

Publication Date: 28 August 2015

Article Link: http://technical.cloud-journals.com/index.php/IJARSG/article/view/Tech-440

Abstract Drought is natural hazard which is caused due to shortage of rainfall. Among the natural hazards, drought is hard to find out because it grows gradually and have huge impact on nature, human habitat and economy. Many satellite based drought indices have so far been suggested for regional and national levels. Meteorological and satellite based indices are used to detect different types of drought, including meteorological, agricultural and hydrological drought. NOAA-AVHRR, MODIS data are used in worldwide for vegetation analysis and drought monitoring and drought assessment. The several meteorological variables (indicators) such as precipitation, temperature, humidity and evapotranspiration are required to calculate drought severity level. The nature of drought indices shows different climate dryness, precipitation deficit or correspond to delayed hydrological impacts such as lowered water level in reservoir, lake, river streams, soil moisture level and agriculture crop health. The long term historical records of satellite imagery and climatic data are essential to calculate drought severity level and to determine drought risk prone area. The agriculture sector is vulnerable to the drought. Now day's satellite imagery has been used in agriculture drought assessment. The government agencies and district based municipal department can create drought mitigation plan based on drought monitoring model. This review paper has discussed the use of remotely sensed data for agriculture drought assessment.
Keywords *Drought; Meteorological Drought; Vegetation Indices; SPI; PDSI*

1. Introduction

Drought is an interval of time, generally of the order of month of the year in duration during which the actual moisture supply at a given place rather consistently fall short of the climatically expected or climatically appropriate moisture supply (Palmar, 1965). Drought occurs due to insufficient moisture level of crop production so that crop production highly affected due to the drought. Drought has a high impact on economy of the country, because it is very hard to balance between food demand and food supply. This issue has attracted the attention of scientific community, government planner and society.

Drought is a natural disaster which is hard to predict, and it is complex to study (Mishra and Desai, 2005). Scanty or irregular rainfall reduces soil moisture level (Bhuiyan, 2008). Various meteorological parameters like temperature, moisture, humidity, evaporation of water, rainfall are helpful for defining drought.

Drought is difficult to detect & monitor because of 3 reasons:

1) It developed slowly and the onset and end are indistinct;
2) It is precisely and universally defined and
3) Its impact is non-structural and often spreads over a very large area (Wilhite, 1993).

Drought can be assessed using meteorological based index and satellite based index. Several drought indices have been proposed based on vegetation indices, Normalized Difference Vegetation Indices (NDVI), Soil Adjusted Vegetation Index (SAVI), Land Surface Temperature (LST), Albedo, Temperature Condition Index (TCI), and Vegetation Condition Index (VCI) are also used for drought study.

2. Drought Characterization

Drought characterization is essential for drought management operations and preparedness of drought mitigation plan. Using drought indices is a realistic way to adapt large amounts of data into quantitative information that can be used in applications such as drought monitoring, mitigation planning and drought assessment (Wilhite, 2004). There are four types of the drought such as Meteorological, Agro-meteorological or agricultural, Hydrological, Socioeconomic drought (Dalezios, 2012).

2.1. Meteorological or Climatological Drought

It is identifying based on precipitation data. If rainfall below the threshold then it causes to meteorological drought. Meteorologist makes distinction between absolute and partial drought. Absolute drought is said to be a period of 15 consecutive days to none of which is credited with 0.2mm or more of rainfall, whereas as partial is a period of at least 29 consecutive days of which its mean rainfall does not exceed 0.2mm (Ayoade, 2004).

2.2. Agro-meteorological or Agricultural Drought

It is described in terms of crop failure and exists when soil moisture is depleted so that crop yield is reduced considerably. The Agriculturalist perspective of drought is when moisture storage unavailable through rainfall or soil is insufficient to ensure optimal crop growth as in, (Ayoade, 2004). A precipitation deficit has impact on agricultural drought, meteorological and hydrological drought.

2.3. Hydrological Drought

It is occurred due to scarcity of the surface water or ground water for normal operation in a particular region. To hydrologist, drought is as a result of low flow in rivers below a critical threshold discharge. Hydrological drought has been defined in various studies done by many researchers and the scientific community as significant decrease in availability of water in all its forms, i.e. ground water, surface water, stream flow, lake reservoir levels and ground water level (Dalezios, 2012).

2.4. Socioeconomic

The impact of drought is defined in terms of loss from an average or expected return and can be measured by both social and economic indicators. The socio economic drought as observed in the case of Wilhite and Glantz (1985) is said to occur as a result of physical water shortage that ends up affecting people at individual scale. The greater demand on commodities than the supply of economic good can best describe this situation. The socio economic droughts reflects the elements meteorological, agricultural and hydrological is drought as it results from the low precipitation, less vegetation content reduction for forage, stream flow reduction.

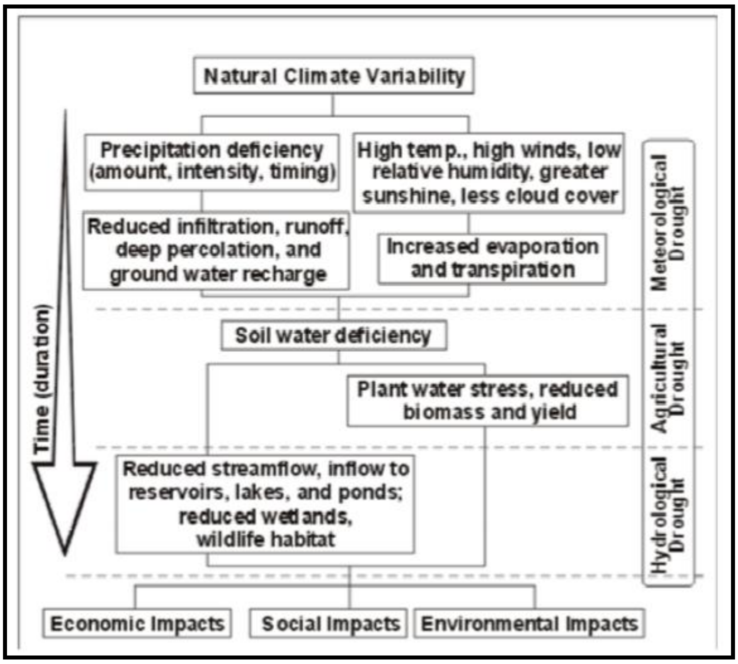

Figure 1: *Shows the Relationship between Meteorological, Agricultural, and Hydrological Drought Source (National Drought Mitigation Center)*

3. Meteorological Index

There are several drought indices which is based on meteorological data such as Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Reclamation Drought Index (RDI) etc.

3.1. Palmer Drought Severity Index

PDSI is sensitive to the weather condition, like dry, and wet (Palmer, 1965). PDSI is sensitive to the weather condition, like dry, and wet. The objective of the PDSI index was to identify the arid and semiarid region. PDSI use historical meteorological data for prediction of drought (McKee et al., 1995). But it cannot provide accurate result in various countries (Kogan, 1990). To solve this problem McKee et al developed the Standard Precipitation Index (SPI), which is based on long term record of precipitation.

3.2. Standard Precipitation Index

The Standard Precipitation Index is designed to quantify the precipitation anomaly for a specific time period (e.g., previous 1, 3, 5, or 12 months) based on the long-term rainfall record over that same time period (McKee et al., 1995). The SPI is computed by using the long-term precipitation records (minimum 30 years) over a specific time step to a probability distribution, which is then transformed to a gamma distribution function. Then, the mean SPI value for a specific location and time period is set to zero. The positive and negative SPI values represent more and less precipitation compared to historical mean precipitation, respectively (Edwards and McKee, 1997). The SPI was used as a measure of dryness in VegDRI and a single SPI interval was selected for each seasonal VegDRI model based on statistical testing of SPI intervals ranging from 1 to 52 weeks. Drought event occur any time the SPI is continuously negative and reaches intensity of -1.0 or less. The event ends when the SPI value becomes positive value. The following table shows SPI Values:

Table 1: *SPI Values*
(Source: National Drought Mitigation Center)

SPI Values	Assumptions
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-.99 to .99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

4. Remote Sensing for Drought Monitoring

Remote sensing is extremely useful for understanding the spatiotemporal land cover change in relation to the basic physical properties in terms of the surface radiance and emissivity data (Orhan, 2014). A major consideration for development of remote sensing for drought assessment and disaster reduction is the extended to which operational user can rely on a continued supply of data (Dalezios et al., 2012; Colwell, 1984). There are two types of remote sensing systems for drought assessment: meteorological and environmental (or resource) satellites. Meteorological satellites have also two types, namely geostationary such as METEOSAT and geosynchronous such as NOAA/AVHRR, and can contribute to operational monitoring and assessment of drought (Dalezios et al., 2012; Caccamo et al., 2011; Zhou et al., 2012). Similarly, environmental satellites such as LANDSAT series, SPOT, IKONOS, WORLD VIEW are used for study of land cover, disaster, vegetation etc., but it has low frequency of coverage, can contribute to land-use classification and qualitative features of drought and less to quantitative assessments (Peled et al., 2010). New sensors have higher spatial resolution, a current shortcoming in drought indices products (Niemeyer, 2008). Pre-processing of satellite image can be done by using geometric correction, haze removal algorithms and other atmosphere correction algorithm. NDVI has remained popular, other indices such as VegDRI, Vegetation Condition Index (VCI) (Kogan, 1990), Temperature Condition Index (TCI), and Vegetation Health Index (VHI) (Kogan, 1995) are currently operationally used (NDMC, 2011; NOAA, 2011). Other satellite image band near-infrared (NIR), red and short-wavelength infrared (SWIR) are used to compute drought index. The ratio of Land Surface Temperature (LST) and Normalized Difference Vegetation Index has been used to improve drought characterization accuracy (Cai et al., 2011; Lambin and Ehrlich, 1995; Rhee et al., 2010; Wan et al., 2004; Wang et al., 2001).

5. Literature Survey

Table 2: *Literature Survey of Study of Drought Indices*

No.	Author/Year	Country	Sensor	Study Period	Technique
1.	D. Nithya et al., 2014	Srivilliputhur Taluk Of Virudhunagar District, Tamil Nadu	Landsat ETM+, LISS III.	1990, 2000 and 2011	This paper is focused on SPI, NDVI and NDWI are very useful for early detection of agricultural vulnerability and hence should be a better methodology for remote sensing based vulnerability assessment studies.
2.	Sashikkumar et al., 2013	Chittar sub basin, Thamiravaruni, Tamilnadu		1982, 1986, 1989, 1999, and	Drought is assessed on the basis of Percentage Deviation of rainfall from long term annual mean precipitation. This method is useful to detect

				2001	drought condition in the region.
3.	Sumanta Das, Malini Roy et al., 2013	Bankura District, West Bengal	Landsat ETM+ (2000), Landsat TM (2005), Landsat TM (2010).		It is found that the temporal variations of NDVI anomaly, VCI, TCI and MSI are closely linked with SPI and a strong linear relationship exists between them. Satellite derived drought-monitoring indices have also been correlated with precipitation index to see how vegetation stress condition and consequently agricultural production yield is changing with the variability of rainfall.
4.	Kipterer John Kapoi, et al., 2012	Nakuru, Rift Valley of Keniya	NOAA-AVHRR	2000, 2010, 2011	The use of temperature and vegetation index provides adequate means for mapping drought extended over agricultural field. LST, NDVI, WSVI. Precipitation data of 10 year used for area of study.
5.	Chaudhary, Garg et al., 2012	Bhopalgarh Tehsil, Jhodpur, India	Landsat-7 ETM+	2000-2001, 2001-2002, 2009-2010	This paper has presented drought indices like NDVI, VCI, SAVI, VCI, LST, and TCI. The analysis of Landsat Image Data of Pre and Post monsoon of Year 2000, 2002, 2010 was used to detect drought affected area.
6.	Dalezios, et al., 2012.	Thessaly, Greece	NOAA-AVHRR	1981-2001	Reconnaissance Drought Index (RDI) is used for the quantification of drought based on remote sensing technology. RDI is used for Hydrological drought estimation, which is only based on precipitation data.
7.	Kundu and Dutta, 2011	Churu, Thar Deseart, Rajasthan, India	NOAA AVHRR	1983-2003	This paper includes long term study of NOAA-AVHRR data, NDVI time trend + Long term rainfall data. According to this research spatial pattern changes due to change in vegetation conditions. The crop growth is entirely depending on rainfall. Desertification occurs because of deficit rainfall.
8.	Hasan Murad et al., 2011	North-West Region of Bangladesh	MODIS, TERRA Sensor.(MOD09 Product)	2000-2008	This paper has presented SPI, NDVI and NDVI-Anomaly indices For drought assessment study. The 30 year's rainfall data was used to calculate SPI index.
9.	Ebrahimi, et al., 2010	Shirkooh Basin, Iran.	Landsat-7 ETM+	1999-2002	In this research study, the Run-Test method was used to derive rainfall pattern over the study region. Meteorological Data was used to calculate PDI and MPDI indices. The satellite based indicators are SAVI2 and NDVI were used for drought area study.
10.	Renza, et al., 2010.	Madrid, Spain	Landsat-7 ETM+	2001-2009. (June Month)	This paper has studied the various indices like NDVI, NDDI, NDVIDev, NDWI and VCI. The NDDI index can be calculate by using composition of NDVI time series data. Landsat satellite provide high resolution image data, than MODIS, AVHRR sensor. This will be helpful to understand drought condition at small administrative area.
11.	Orhan, et al., 2014.	Salt Lake Basin, Turkey.	Landsat-5 TM	1984, 1989, 1998, 2003, 2007, 2011. (Aug Month)	This research paper has presented NDVI, VCI, TVX indices using spatiotemporal Landsat imagery. This research study has investigated the relationship between thermal infrared band of Landsat-5 TM and in-situ Infrared temperature data for agricultural drought.
12.	Rahman, et al.,	Bangladesh	NOAA-	1991-2005	Author has calculated vegetation indices like

	2009		AVHRR		VH,VCI, and VHI, derived from Advanced Very High Resolution Radiometer (AVHRR) data covering a period of 15 years (1991– 2005). A strong correlation was found between Aus rice yield and VCI and VHI during the critical period of Aus rice development that occurs during March-April (weeks 8–13 of the year), several months in advance of the rice harvest.
13.	Liu, et al., 2008	China	MODIS	2005-2006	In this paper, author has derived RDRI, VCI, and LST indices from MODIS data which are used for drought severity study.
14.	C. Bhuiyan, 2008	Great Indian Desert contains extensive region of sandy landscape, and is located in the north-western part of India and eastern part of Pakistan	NOAA AVHRR	1984–2003	Spatial and temporal variations in rainfall, temperature, and vegetation indices in the Thar Desert have been analyzed and correlated for monsoon and non- monsoon seasons. The mean seasonal NDVI, the index representing greenness of vegetation was found to strongly correlate with seasonal rainfall. The time series of VCI and TCI shows that in certain years they correspond to each other. Dense vegetation is responsible to reduce the heat in area.
15.	C.S. Murthy, et al., 2007	Mahaboobnagar district, Andhra Pradesh, India	IRS 1C/1D WiFS (180 m) and IRS P6 AWiFS	2002, 2004, 2005	The use of moderate resolution satellite data like AWiFS/WiFS captures the spatial variability of drought impact on crops and it provides the information at disaggregated level within a district. Ground Truth point of the crop field, cropping pattern, and soil type was used to assess the drought situation. In this research paper author has used AWiFS dataset to investigate drought impact over the region.
16.	Bayarjargal, et al., 2006.	Mangolia	NOAA-AVHRR	1982-1999	The author has used NOAA- AVHRR sensor data to compute various vegetation indices like NDVI, Derived NDVI and VCI. It is found that, these indices have produced almost similar result.
17.	Thenkabail, et.al. 2004.	Afghanistan, Pakistan and western parts of India.	NOAA-AVHRR and MODIS-Terra-aqua	1982-2001	Author has used NOAA- AVHRR and MODIS data to investigate drought hazard. According to author, The DEVNDVI, and VCI are sensitive indicators of drought conditions.
18.	Steven M, et al., 2003.	Canada	Meteorological, temperature and precipitation.	1961–1999	In the research study, it is also found that Palmer's Z-index is the most appropriate index for measuring agricultural drought in the Canadian prairies. The evaluation model has indicated that, Z-index was the best suited for predicting crop yield when there is significant moisture stress. According to Steven M. et. al. 2003, there is a statistically significant relationship between the Z-index and Red Spring wheat yield in all crop districts, but the strength of the relationship varies significantly by crop district due to the influence of factors other than moisture availability (e.g. disease, pests, storm damage, and soil characteristics).
19.	Prathumchai, et al., 2001.	Thailand	JERS-1 OPS	1995, 1997	The research study has shown that, The NDVI can be used as indicators for Drought study. Author has derived NDVI composite from historical records of the satellite images.
20.	R.A. Seiler, et	Argentina, USA	NOAA-	1988, 1994,	The results paper investigates the relationship

	al., 2000.	AVHRR	1997.	between VCI and TCI index. Author has used NOAA-AVHRR data to derive VCI and TCI index.

Note*: TCI- Temperature Condition Index, VCI- Vegetation Condition Index, NDVI- Normalized Difference Vegetation Index, VHI- Vegetation Health Index, LST- Land Surface Temperature, RDRI- Remote Sensing Drought Risk Index, VH-* Vegetation Health, VHI- Vegetation Health Index, PDI- Perpendicular Drought Index, MPDI- Modified Perpendicular Drought Index, RDI- Reconnaissance Drought Index, WSVI- Water Supplying Vegetation Index.

According to the literature survey the satellite based drought indicators are most useful for drought monitoring and assessment purpose. Various satellite sensor data like Landsat, NOAA-AVHRR and MODIS satellite are used to monitor drought prone area. Meteorological parameters like precipitation, temperature are important to understand drought severity level.

6. Conclusion

The historical satellite imagery data and meteorological data are important to investigate drought phenomena. The cited paper has suggested that, the methods and techniques for continuous drought monitoring can be improved by linking historical AVHRR sensor data with MODIS sensor data. The advantage of Landsat imagery is that it provides high resolution data of 30m so that it is helpful to understand drought impact on small administrative area. This paper have studied various drought indices such as Normalized Difference Vegetation Index (NDVI), Drought Severity Index (DEVNDVI), Vegetation Condition Index (VCI), Temperature Condition Index (TCI), are useful to determine drought severity level.

Several meteorological variables such as precipitation, temperature, humidity and evapotranspiration are useful to understand drought and its impact on land cover. The deficit rainfall is responsible for desertification process. The long-term historical data of rainfall is used to calculate SPI index. The integration of geospatial technology in drought monitoring and decision support system can deliver better result of drought assessment in agricultural sector.

Acknowledgement

Authors would like to acknowledge and thanks to University Grants Commission (UGC), India for granting UGC SAP (II) DRS Phase-I & Phase-II F. No. 3-42/2009 & 4-15/2015/DRS-II for Laboratory facility to Department of Computer Science and Information Technology, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, Maharashtra, India and financial assistance under UGC -BSR Fellowship for this work.

References

Ayoade, J., 2004: *Introduction to Climatology for Tropics*, (Eds.) first published by John Wiley in 1983: Reprinted by Sam Adex Printers Felele Rab, Ibadan.

Colwell, N.R., 1984: *Remote Sensing Research for Agricultural Applications (USA)*. California University, Berkeley, Space Sciences Laboratory.

Dalezios, N.R., Bampzelis D., and Domenikiotis, C. *An Integrated Methodological Procedure for Alternative Drought Mitigation in Greece*, European Water. 2009. 27/28; 53-73.

Dash, P., 2005: *Land Surface Temperature and Emissivity Retrieval from Satellite Measurements*. A PhD Dissertation Submitted to Institute of Meteorology and Climate Research Forschungszentrum, Karlsruhe, University of Karlsruhe, Germany.

Ebrahimi, M., Matkan, A.A., Darvishzadeh, R. *Remote Sensing for Drought Assessment in Arid Regions- A Case Study of Central Part of Iran, "Shirkooh-yazd"*. Wagner W., Székely, B. (eds.): ISPRS TC VII Symposium – 100 Years ISPRS, Vienna, Austria. IAPRS. 2010. XXXVIII; 7B.

Edwards, D.C. and McKee, T.B., 1997: *Characteristics of 20th Century Drought in the United States at Multiple Time Scales*. Climatology Report Number 97-2, Colorado State University, Fort Collins, Colorado.

Ghulam, A., Qin, Q. and Zhan, Z. *Designing of the Perpendicular Drought Index.* Environmental Geology. 2007. 52 (6) 1045-1052.

Kanellou, E., Spyropoulos, N. and Dalezios, N.R. *Geoinformatic Intelligence Methodologies for Drought Spatiotemporal Variability in Greece.* Water Resource. Manage. 2011. 26; 1089-1106.

Kogan, F.N. *Application of Vegetation Index and Brightness Temperature for Drought Detection.* Advances in Space Research. 1995. 11; 91-100.

Kogan, F.N. *Global Drought Watch from Space*. Bulletin of the American Meteorological Society. 1997. 78; 621-636.

Kogan, F.N. *Remote Sensing of Weather Impacts on Vegetation in Non-Homogeneous Areas.* International Journal of Remote Sensing. 1990. 11 (8) 1405-1419.

Lambin, E. and Ehrlich, D. *Combining Vegetation Indices and Surface Temperature for Land-Cover Mapping at Broad Spatial Scales*. Intentional Journal Remote Sensing. 1995. 16 (3) 573-579.

Liu, L., Xiang, D., Zhou, Z., and Dong, X. *Analyses the Modification Functions of the Drought Monitoring Model Based on the Cloud Parameters Method*. In: 2008 Congress on Image and Signal Processing, IEEE. 687-691.

Mishra, A.K. and Desai, V.R. *Spatial and Temporal Drought Analysis in Kansabati River Basin India.* International River Basin Management. 2005. 3 (1) 31-41.

McKee, T.B., Doesken, N.J. and Kleist, J., 1995, January 15-20: *Drought Monitoring with Multiple Time Scales*. Preprints, 9th Conference on Applied Climatology, Dallas, Texas. 233-236.

Niemeyer, S. *New Drought Indices*. Options Méditerranéennes. Série A: Séminaires Méditerranéens. 2008. 80; 267-274.

NDMC, 2011: *Vegetation Drought Response Index.* National Climatic Data Center, http://drought.unl.edu/MonitoringTools/VegDRI.aspx. Accessed on 6th May 2015.

NOAA. *STAR- Global Vegetation Health Products*. National Oceanic and Atmospheric Administration (NOAA), 2011. http://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh_browse.php. Accessed on 7th May 2015.

Orhan Osman, Semih Enkercin, and Fikiz Dadaser-Celik. *Use if Landsat Surface Temperature and vegetation Indices for Monitoring Drought in the Salt Lake Basin Area, Turkey*. The Scientific World Journal. 2014. Article ID 1429. 11.

Peled, E., Dutra, E., Viterbo, P. and Angert, A. *Technical Note: Comparing and Ranking Soil Drought Indices Performance over Europe, through Remote-Sensing of Vegetation*. Hydrology Earth System. Science. 2010. 14; 271-277.

Palmer, W.C. *Meteorological Drought,* Research, Paper No. 45, U.S. Department of Commerce Weather Bureau, Washington, D.C. 1965. 58.

Rhee, J., Im, J. and Carbone, G.J. *Monitoring Agricultural Drought for Arid and Humid Regions Using Multi-Sensor Remote Sensing Data*. Remote Sensing. Environment. 2010. 114 (12) 2875-2887.

Surendra Singh Chaudhary, Garg, P.K. and Ghosh S.K. *Mapping of Agriculture Drought Using Remote Sensing and GIS.* International Journal of Scientific Engineering and Technology. 2012. 1 (4) 149-157.

Sumanta Das, Malini Roy Choudhury and Sachikanta Nanda. *Geospatial Assessment of Agricultural Drought - A Case Study of Bankura District, West Bengal*. International Journal of Agricultural Science and Research (IJASR). 2013. 3 (1) 1-28.

Thenkabail, P.S., Gamage, M.S.D.N., Smakhtin, V.U*. The Use of Remote Sensing Data for Drought Assessment and Monitoring in South West Asia. Colombo, Sri Lanka.* International Water Management Institute. 2004. 1-23.

Tsegaye, T*. Improving Drought Management and Planning Through Better Monitoring in Africa.* Drought Network News (1994–2001), 1998. 81. http://digitalcommons.unl.edu/droughtnetnews/81.

Wilhite, D. and Glantz, M. *Understanding the Drought Phenomenon: The Role of Definitions*. Water International. 1985. 10 (3) 111-120.

Wilhite, D.A., 2004: *Drought as a Natural Hazard.* In: International Perspectives on Natural Disasters: Occurrence, Mitigation, and Consequences, edited by Stoltman, J.P., Lidstone, J. and Dechano, L.M. Kluwer Academic Publishers, Dordrecht, Netherlands. 147-162.

Wilhite, D.A., 1993: *The Enigma of Drought. Drought Assessment, Management and Planning: Theory and Case Studies.* Kluwer Academic Publishers, Boston, Ma. 3-15.

Wang, P., Li, X., Gong, J. and Song, C. *Vegetation Temperature Condition Index and Its Application for Drought Monitoring*. In: Geoscience and Remote Sensing Symposium. IGARSS'01. IEEE 2001 International, Institute of Electrical and Electronics Engineers (IEEE). 2001. 141-143.

Wang, L. and Qu, J.J. *NMDI: A Normalized Multi-Band Drought Index for Monitoring Soil and Vegetation Moisture with Satellite Remote Sensing*. Geophysics. Res. Letter. 2007. 34 (20) L20405.