DROUGHT ASSESSMENT USING REMOTE SENSING AND GIS IN NORTH-WEST REGION OF BANGLADESH

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ABSTRACT

Drought is the most complex but least understood of all natural hazards in Bangladesh. Timely information about the onset of drought, extent, intensity, duration and impacts can limit drought related losses of life, human suffering and decrease damage to economy and environment. In this study an attempt has been made to apply RS and GIS techniques for drought detection in the north-west region which is the most drought prone area of of Bangladesh. Meteorological drought was determined based on Standardized Precipitation Index (SPI). SPI values were interpolated to determine the spatial pattern of meteorological drought and threshold value for different types of drought. Agricultural drought risk areas were identified based on Normalized Difference Vegetation Index (NDVI) by using surface reflectance with 250m resolution from MODIS satellite during 2000-2008. Anomaly of the NDVI from the mean values was classified to determine the agricultural drought risk. Meteorological and agricultural drought risk maps were prepared by integrating the various classes of drought. Finally, a resultant risk map was obtained by integrating agriculture and meteorological drought risk maps which indicate the areas facing a combined drought. The combined risk map shows that approximately 17% area has no risk, 23 % area face slight risk, 30 % area face moderate risk and 31 % area face severe to very severe risk within the study area. It was evident from the study that central, northern and southwestern districts of the north-west region of Bangladesh are more prone to agricultural and meteorological drought.

Keywords: *Agricultural drought, Meteorological drought, MODIS, NDVI, Standardized Precipitation Index.*

1. INTRODUCTION

Drought is an insidious natural hazard that results from a deficiency of precipitation from expected or "normal" such that when it is extended over a season or longer period of time, the amount of precipitation is insufficient to meet the demands of human activities and the environment (Wilhite, 2005). Drought is a regional phenomenon and its characteristics will vary from one climate regime to another (Iglesias et al., 2009). The severity of drought is also difficult to determine. Drought is often perceived as a creeping hazard as it develops slowly and has a prolonged duration (Smith, 2000). The climatic environment of uncertainty is one of the major threats in water resources management. Droughts are regional events and their occurrences are governed by regional climatic parameters like precipitation, evapotranspiration, temperature etc. So the characteristics and consequences of drought vary with respect to climatic regimes around the world. The National Water Management Plan (NWMP) considers occurrences of drought as a major water deficiency related issue in northwest region of Bangladesh (WARPO, 2001). Average occurrence of drought in Bangladesh is once in 2.5 years (Adnan, 1993; Hossain, 1990). Between 1960 and 1991, nineteen droughts have occurred in Bangladesh (Mirza and Paul. 1992). Inadequate water availability due to less rainfall than normal resulting reduced groundwater recharge, inferior ecosystem maintenance and subsequent low-grade cropping and household works is termed as drought in respect to Bangladesh. National Water Plan (NWP, 1991) describes that uneven and inadequate rainfall can greatly reduce crop production. Apart from loss to agriculture, droughts have significant effects on land degradation, livestock population, employment and health. Climate change issue also would bring Bangladesh at higher risk due to droughts (World Bank, 2000).

There are a number of indicators for drought monitoring and assessment. Every indicator has its successes and limitations in drought detection. Meteorological drought indicators assimilate information on rainfall, stored soil moisture or water supply but they do not express much local spatial detail. Also, drought indices calculated at one location is only valid for single location. Thus, a major drawback of climate based drought indicators is their lack of spatial detail as well as they are dependent on data collected at weather stations which sometimes are sparsely distributed affecting the reliability of the drought indices (Brown et al. 2002). On the other hand, satellite derived drought indicators calculated from satellite-derived surface parameters have been widely used to study droughts. Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI) are some of the extensively used vegetation indices. With the advancements in remote sensing technology, the historical drought indices were over powered by the newly developed indices from remote sensing data that are considered to be real time. Remote sensing and GIS technique is increasingly being regarded as a useful drought detection technique, as evidenced by its use across many parts of the world, e.g. Gujarat, India (Chopra, 2006), Western and Central Kansas, USA (Park, et. al., 2004), Batticaloa District, Srilanka (Partheepan and Dayawansa, 2008) and Borkhar District, Iran (Moktari, 2005).

This study was carried out to detect drought in the north-west region of Bangladesh which covers a total area of 32000 km^2 and is the most drought prone area of Bangladesh. The average seasonal rainfall of about 1000 mm during the five monsoon (June-October) months in the north-west is the lowest in the country and such rainfall is classified as low for a rainfed ecosystem (Garrity et. al., 1986). Drought is one of the important natural hazard events in this region. In this part of the country, seasonal drought occurs almost on a regular basis (SPARRSO, 2007). The major objectives of the study are to identify agricultural drought by remote sensing and GIS techniques application, to identify meteorological drought by SPI method and finally to assess drought of the study area by combining both agricultural and meteorological drought.

2. METHODOLOGY

2.1 Data

Surface Reflectance (SR) data of the MODIS (Moderate Resolution Imaging Spectra Radio-meter) Satellite with TERRA sensor used in this study. A product known as MOD09 consists of the best value of surface reflectance during eight days period was used. This data have a horizontal resolution of 250m and project on a sinusoidal grid. Data have been collected during the period from 2000 to 2008 by using web based Warehouse Inventory Search Tool (WIST). This data is atmospherically corrected and most representatives to the land surface conditions (Park, et. al., 2004). Rainfall data collected from Bangladesh Meteorological Department (BMD) which was used to derive Standardized Precipitation Index (SPI). Statistical data of the yield of rice (Aman) was collected form Bangladesh Bureau of Statistics to determine the impact of drought.

2.2 Tools and Techniques

MODIS Reprojection Tool (MRT) was used to reproject the raw satellite images with sinusoidal projected data into the regular geo-graphic coordinate system. Integrated Land and Water Information System (ILWIS) was used to process MODIS images and conduct spatial analysis. Pre-processing of satellite data includes many intermediate steps such as conversion of HDF format to tif format, reprojection, subset, multification factor, NDVI computed from model maker, inherited cloud problem with NDVI and Layer stacking etc.

Standardized Precipitation Index (SPI), a tool derived by Tom McKee (1993) et al., a measure of meteorological drought has been calculated from the available rainfall data collected by the Bangladesh Meteorological Department. Mathematically, SPI is calculated based on Eqn. 1.

$$SPI = \frac{(Xi - Xm)}{\sigma} \qquad (1)$$

where, Xi is monthly rainfall record of the station; Xm is rainfall mean; and σ is the standard deviation.

Monthly rainfall data of the 6 rainfall stations within the study area were used as an input to calculate SPI using a computer software which can be downloaded from web site at http://drought.unl.edu/monitor/spi/program/spi_program.htm#program. The classification of meteorological drought risks using SPI values are presented in the Table1.

Table 1: Meteorological drought risks classification using SPI values (McKee et al., 1993)

SPI Values	Class	Probability
2.0 and more	Extremely wet	0.977–1.000
1.5 to 1.99	Very wet	0.933–0.977
1.0 to 1.49	Moderately wet	0.841–0.933
-.99 to .99	Near normal	0.159–0.841
-1.0 to -1.49	Moderately dry	0.067–0.159
-1.5 to -1.99	Severely dry	0.023–0.067
-2 and less	Extremely dry	0.000–0.023

Agricultural drought has been calculated using MODIS Surface Reflectance data with 250m resolution. NDVI value was determined for each image using the following Equation (Eqn. 2) of the MODIS spectral bands.

$$NDVI = (band\ 2 - band\ 1) / (band\ 2 + band\ 1) \qquad (2)$$

The anomaly of NDVI has been calculated for a specific year using the mean, maximum value of the total durations e.g., 2000-2008 based on the following equation (Eqn. 3).

$$Anomaly\ NDVI\ i = (NDVI\ max\ i - mean\ NDVI\ max)/\ (mean\ NDVI\ max)*100 \qquad (3)$$

where, Anomaly NDVI i is NDVI anomaly in i^{th} year, NDVI max is maximum NDVI and mean NDVI max is the average of maximum NDVI during the period of study.

Time series of NDVI anomaly used to detect agricultural drought. The threshold values used in this study to classify agricultural drough risk using NDVI anomalies was presented in Table 2.

Table 2: Agricultural drought risk classification using NDVI anamolies

Percent of NDVI Anomalies	Class
0% to -10%	Slight drought
-10% to -20%	Moderately drought
-20% to -30%	Severe drought
above -30%	Very Severe drought

Finally, the agricultural drought and meteorological drought were integrated to find the combined drought for the study area. A schematic of the methodology has been presented in Figure 1.

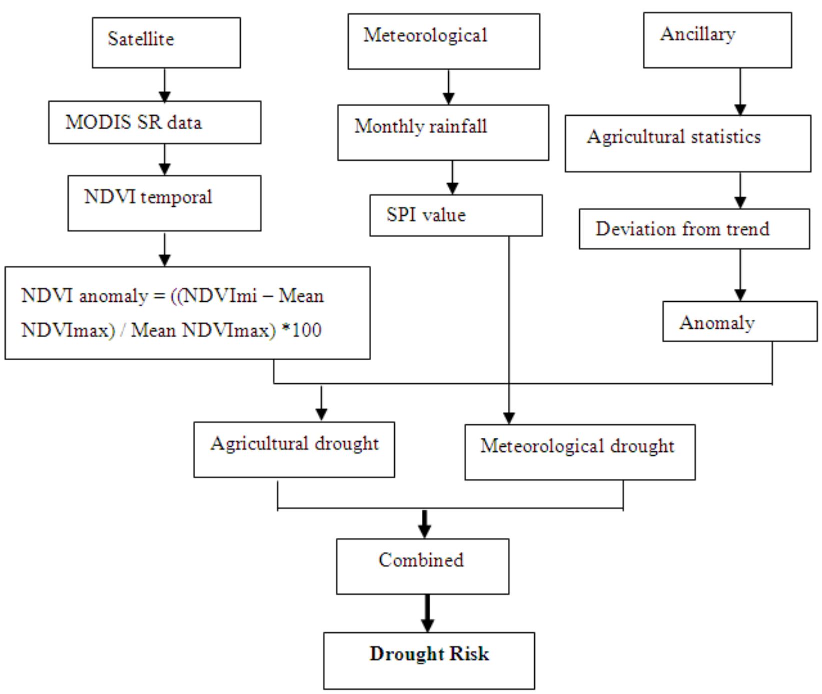

Figure 1: Schematic presentation of the methodology

2.3 Drought Risk Maps

Agricultural drought risk has been calculated for the study area and presented in Figure 2(a). It has been revealed from this figure that Gaibanda, Thakurgaon and Panchagarh face high agricultural drought risk covering 15.68 % of the total area, while 5 districts Bogra, Dinajpur, Nilphamari, Joypurhat and Sirajgong face moderate drought risk covering 33.15 % of the total area. Kurigram, Lalmonirhat, Nawabgong, Pabna, Rajshahi and Rangpur have slight agricultural drought risk covering highest 35.70 % of the total area, whereas Naogaon and Natore covering 15.47 % area is free from agricultural drought risk.

Meteorological risk map of the study area were generated for the study area and presented in Figure 2(b). This figure releaved the presence of very severe metereologcial drought risk in Dinajpur, Thakiurgaon and Gaibanda district, whereas the slight metereologcial drought risks exist in Naogaon and Sirajgong districts.

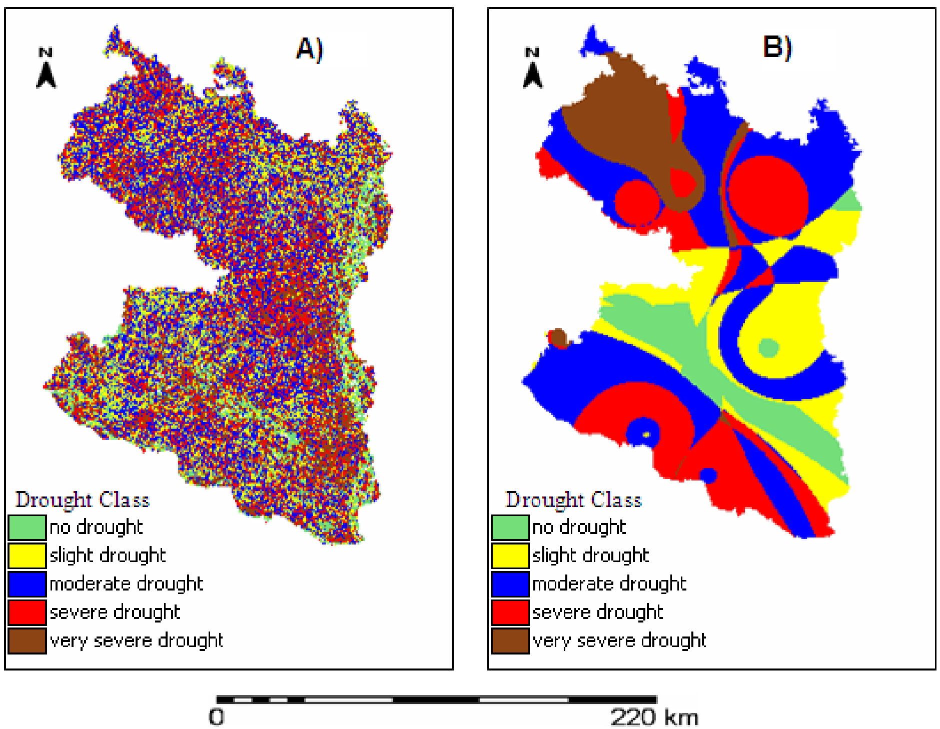

Figure 2: a) Agricultural drought risk and b) meteorological drought risk areas

The percentage of areas in each district of the north-wesdst region facing combined drought risk was presented in Table 3. Sirajgong and Naogaon are two districts free from drought risk. Slight and moderate risk areas encompass 22.71% and 29.72% of total geographical area. Severe and very severe risk prevails in nearly 21.29% and 9.42% of the area which comprises of districts that are major producers of food grains as well as different vegetable. Therefore a stress has to be given more on these districts while drought management plans are prepared.

Final drought risk map, which has been obtained by integrating the risk maps generated from agriculture and meteorological drought. Figure 3 shows the percentage area affected by the combined risk.

Table 3: Area facing both agricultural and meteorological drought risks

Sl. No.	Drought Risk	No. of Districts	Name of Districts	Area (km²)	% of Area
1	No risk	2	Sirajgong, Naogaon	5437.34	16.86
2	Slight risk	4	Kurigram, Nawabgong, Bogra, Joypurhat	7322.45	22.71
3	Moderate risk	5	Rangpur, Rajshahi, Pabna, Natore, Lalmonirhat	9581.58	29.72
4	Severe risk	3	Dinajpur, Nilphamari, Gaibanda	6867.32	21.29
5	Very Severe risk	2	Panchagarh, Thakurgaon	3036.31	9.42
Total		16		32245	100%

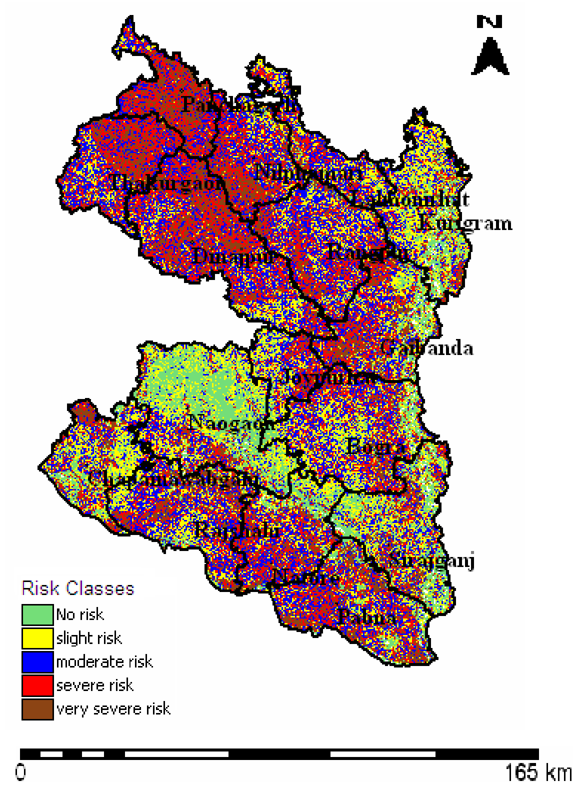

Figure 3: Combined drought risk areas

3. CONCLUSIONS

In this study, the agricultural and meteorological drought prone areas in the north-west region were identified by using Remote Sensing and GIS technology and drought risk areas were to delineate by integration of satellite images, meteorological information and crop yield data. The role of satellite derived index for drought detection has been exemplified by integrating meteorological derived index called Standardized Precipitation Index. It is found that the temporal variations of NDVI anomaly are closely linked with SPI and a strong linear relationship exists between NDVI and SPI. Highest correlation was found in Natore district with a R^2 value of 0.81. 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. Results show that 13 out of 16 districts in the north-west region show significant correlation between NDVI anomaly and SPI during the Kharif season. Moreover, a significant correlation has been observed between NDVI anomaly and crop yield anomaly for most of the districts in the north-west region of Bangladesh. The seasonal pattern of rainfall and NDVI, suggest that the northern and south-western part of the north-west region is a low rainfall area, where SPI value is low and the corresponding NDVI values is also low. Thus it can be said that NDVI index and precipitation index shares a strong correlation where water is a major limiting factor for plant growth.

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