Use of Remote Sensing Data for Drought Assessment: A Case Study for Bihar State of India during Kharif, 2013

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1. Introduction

Agricultural drought can be defined as the deficiency of soil moisture leading to crop stress at any stage of the crop. Impact of moisture deficiency is more felt during period just after germination, flowering and milking/fruit formation stages of the crop. Moisture stress during these phenological stages of the crop will result in yield reduction, both quantitatively and qualitatively.

Observation of vegetation from satellite platform provides a unique vantage view and an insight into the dynamics of the vegetation, both temporally and spatially (Kogan, 1997). There are two main optical domains characterizing the optical properties of plant, viz, the visible region and Near-Infrared Region (NIR). In the visible bands (0.4 to 0.7 μm), light absorption by leaf pigments dominate the reflectance spectrum of the leaf. The near-infrared spectral region between 0.7 to 3.0 μm has strong reflectance because of the spongy mesophyll cells, which mainly reflect light at cell/air space interface (Tucker and Sellers, 1986).

Taking the advantage of this differential reflectance nature from the vegetation, the Normalized Difference Vegetation Index (NDVI) has been derived as

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

where NIR is reflectance in the near-infrared region and Red that of red region. NDVI has become the primary tool for description of vegetation changes and interpretation of the impact of environmental phenomena (Kogan, 1990). NDVI is also effectively used for monitoring drought, estimating net primary production (NPP) of vegetation and crop yields, detecting weather impacts and other events important for agriculture, ecology and economics (Tucker et al., 1985; Hielkema et al., 1986; Kogan, 1987, 1990; Rasmussen, 1997).

However, NDVI as a vegetation index has limited success in estimating vegetation water content (VWC) (Chen et al., 2005). A potentially better way of estimating VWC is to use indices based on the longer wavelength reflective infrared range (1240–3000 nm) and in particular the shortwave infrared (SWIR) reflectance (1300–2500 nm) (Chen et al., 2005). The shortwave infrared is sensitive to vegetation cover, leaf moisture and soil moisture. The combination of NIR and SWIR bands has the potential of retrieving canopy water content (Ceccato et al., 2002). The combination of NIR and SWIR has different nomenclatures with different authors. Gao (1996) and Chen et al. (2005) defined NDWI (Normalized Difference Water Index) as:

$$\text{NDWI} = (\text{NIR} - \text{SWIR})/(\text{NIR} + \text{SWIR}) \tag{2}$$

where the NIR and SWIR are the reflectance values in near-infrared and shortwave infrared region.

The water indices using the 2130 nm appeared more useful in extracting the vegetation water status and in drought detection and water sustainability studies (Hojin et al., 2004). Hence, in this study, the NDWI using the 2130 nm is being used along with NDVI.

Vegetation Condition Index (VCI) provides information of how the current status of the vegetation compared with the historic maximum and minimum (Kogan, 1997). Under ideal conditions of good rainfall, adequate nutrients and management inputs, the crop in a region could grow to its maximum, producing maximum NDVI/NDWI for that year. On the contrary in a drought year with less rainfall and inadequate inputs results in very low NDVI. The maximum and minimum NDVI are the conceivable limits of the vegetation ecology over the several years considered. When the current year NDVI is related to the maximum and minimum values, it helps in getting a fair idea of the present status of vegetation compared to the historic maximum and minimum. In this study, 12 years historic database (2001-2012) of NDVI and NDWI was used to derive the VCI of 2013. The VCI of NDVI and NDWI are defined as

$$\text{VCI (NDVI)} = (\text{NDVI}_i - \text{NDVI}_{min})/(\text{NDVI}_{max} - \text{NDVI}_{min}) \times 100$$

$$\text{VCI (NDWI)} = (\text{NDWI}_i - \text{NDWI}_{min})/(\text{NDWI}_{max} - \text{NDWI}_{min}) \times 100$$

where NDVI_i is the NDVI at time *i* in current year, NDVI_{min} is the historic minimum and NDVI_{max} is the historic maximum NDVI during same period.

Mahalanobis National Crop Forecast Centre (MNCFC), in collaboration with National Remote Sensing Centre (NRSC), carries out district level drought assessment based on remote sensing, meteorological and agricultural data under NADAMS (National Agricultural Drought Assessment and Monitoring System) programme. The year 2013 had a normal monsoon over the whole country, except for states like Bihar, Jharkhand and North Eastern States. Till end of September 2013, Bihar had a deficit rainfall of 30 per cent, with some districts getting more than 60 per cent deficit rainfall. The meteorological drought resulted in agricultural drought in many parts of the state causing reduction in cropped area and delayed sowing time.

In this context, this study attempts to analyse the agricultural situation during Kharif (rainy season) 2013, using remote sensing derived indices.

2. Materials and Method

2.1 Study Area

The area chosen for the study is the state of Bihar in India. The landform of Bihar is a vast stretch of fertile alluvial plain occupying the Gangetic Valley. Bihar is endowed richly with water resources, both the groundwater resource and the surfacewater resource. Not only by rainfall but it has considerable water supply from the rivers which flow within the territory of the state. Ganga is the main river which is joined by tributaries with their sources in the Himalayas. Around 61% of crop area is irrigated. Agriculture is the biggest industry in the state. The major crops grown in the state are paddy, wheat, lentils, sugarcane and jute.

2.2 Satellite Data

NOAA AVHRR satellite data starting from 1 June 2013 to 30 October was used for creating NDVI images. Satellite image was georeferenced and NDVI was created for every single day during the above mentioned period. Fortnightly and monthly NDVI composites were created for every month. The MODIS Terra 16-day 1 km Vegetation Index Product (http://LPDAAC.usgs.gov) starting from first fortnight of June to second fortnight of October for the year 2013 was used for generating NDWI. These products were computed from the atmospherically corrected bi-directional surface reflectance that have been masked for water and heavy aerosols (http://tbrs.arizona.edu/project/MODIS/userguide-doc.php). Using the equation (2) the NDWI was derived from near-infrared and shortwave infrared reflectance. Forest and other non-agricultural areas of the state were masked using Land Use Land Cover Layer generated by NRSC. Figure 1 shows the NDVI and NDWI images of the state of Bihar during Kharif 2013. Further VCI of NDVI and NDWI at district level was derived using the historic NDVI and NDWI data, respectively.

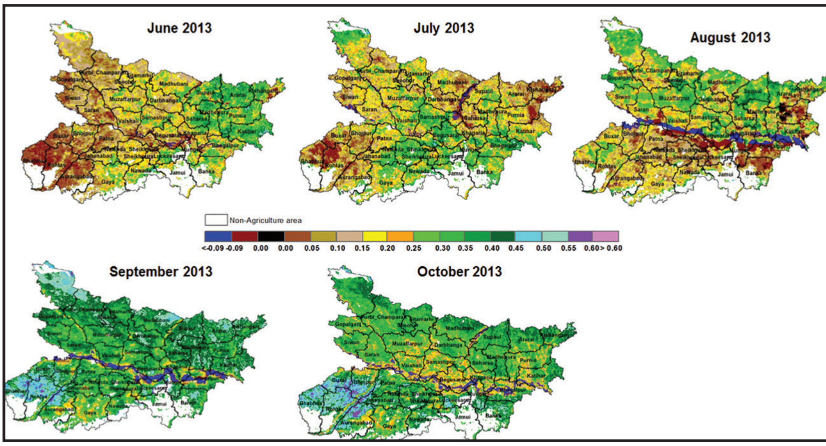

Fig. 1(a): NDVI images of Bihar state during kharif 2013.

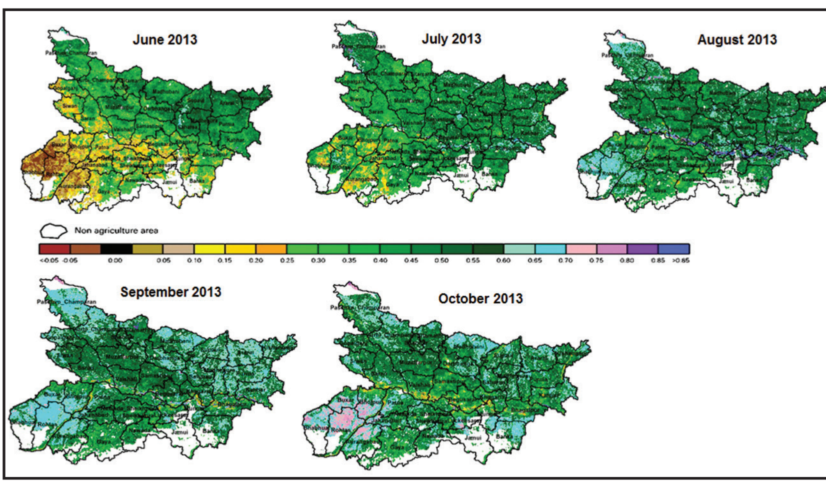

Fig. 1(b): NDWI images of Bihar state during kharif 2013.

2.3 Rainfall Data

Rainfall is the most important factor for drought related studies. This study used the weekly rainfall deviation data at district level. This data is available at IMD website. The data was downloaded in excel format and further weekly and monthly district rainfall deviation maps were prepared in GIS environment (Fig. 2).

2.4 Area Favourable for Crop Sowing (AFCS)

The Area Favourable for Crop Sowing (AFCS) was derived from (1) Shortwave Angle Slope Index (SASI) (Khanna et al., 2007) data integrated with ground data on cropping pattern, soil and irrigation availability and (2) Soil Moisture Index fromh spatial soil water balance model. AFCS reflects the agricultural area with significant surface wetness and hence favourable for crop sowing activity. The AFCS at district level has been derived and used with other indicators for drought assessment (Fig. 3).

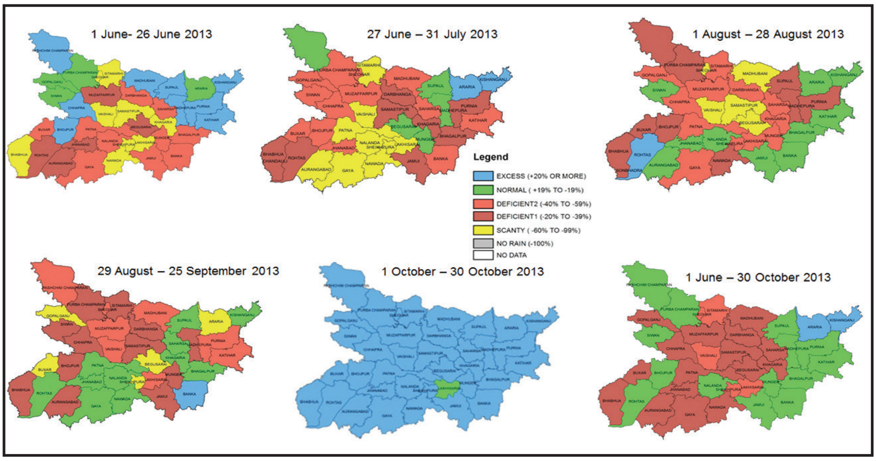

Fig. 2: Rainfall deviation maps of Bihar state during kharif 2013.

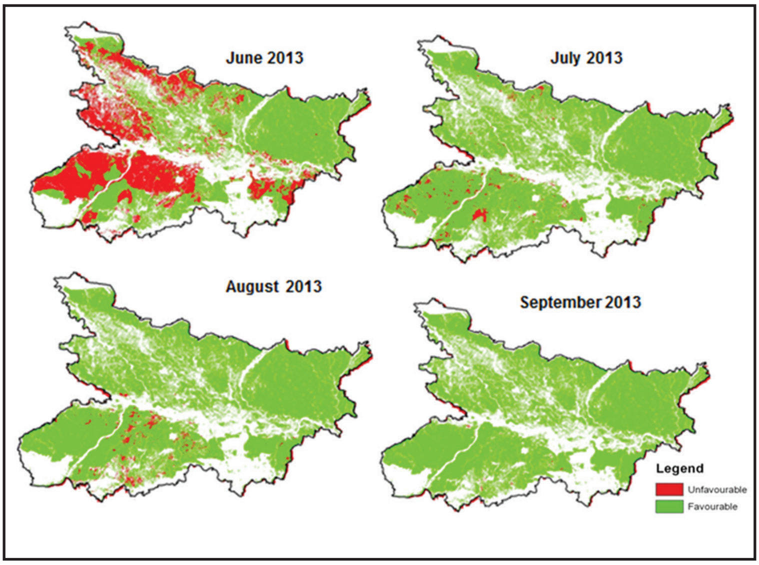

Fig. 3: Area Favourable for Crop Sowing for Bihar state of India during kharif 2013.

3. Results and Discussion

During June 2013, with early advance, the monsoon rainfall pattern covered the whole country by 16 June, compared to the normal date of 15 July. However, for Bihar state there was deficient rainfall during the kharif season of 2013. In the year 2013, till end of September, Bihar had a deficit rainfall of 30 per cent, with some districts getting more than 60 per cent deficit rainfall. Nine out of 37 districts had more than 50% deficit rainfall, while seven districts had normal or excess rainfall.

In kharif season (June to October) paddy was the major crop in Bihar. It can be observed in Fig. 1 that the peak NDVI was achieved during the month of September.

In kharif 2012 agricultural condition was more or less normal in Bihar state. Comparison of NDVI for year 2012 and 2013 over few districts of Bihar are depicted in Fig. 4. For the districts Kishanganj, Araria, Supaul and Paschim Champaran 2013 NDVI values closely followed the 2012 NDVI values showing the close-to-normal agricultural condition. But, in case of Vaishali, Nawada, Gaya and Muzzafarpur, 2013 NDVI values showed lower values in the months of August, September and October highlighting the poor crop condition in these districts. Similar patterns were also found for NDWI values.

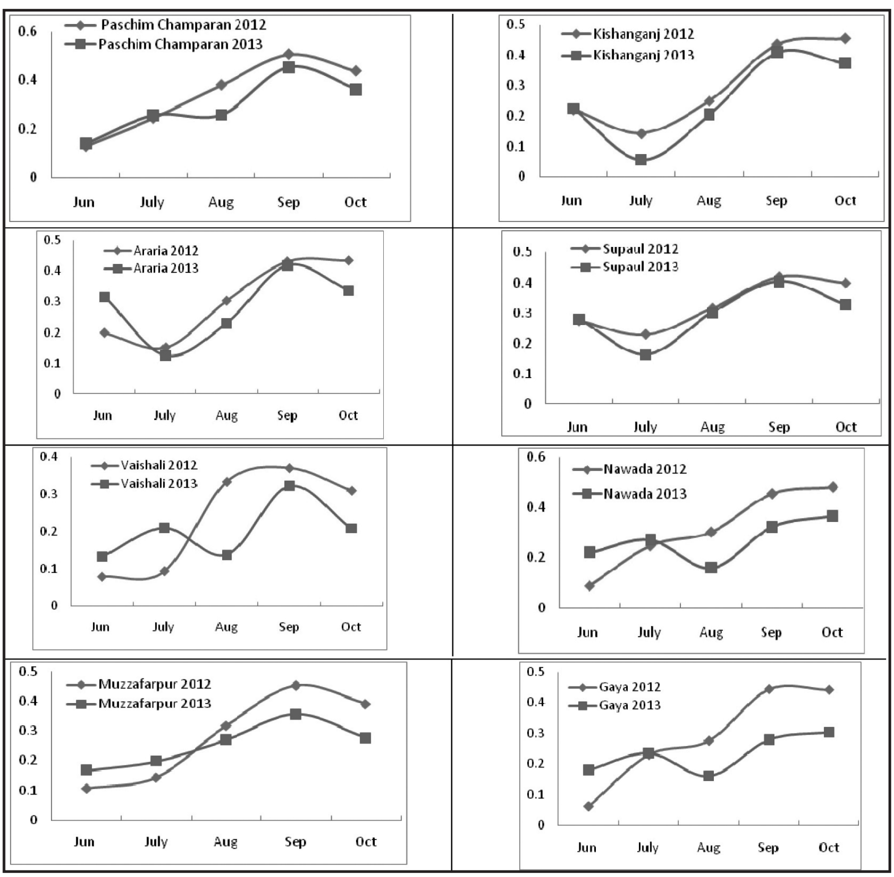

Fig. 4: NDVI profile of various districts showing comparison of agricultural condition in 2012 and 2013 kharif season.

Less than normal NDVI and NDWI, signifying delayed crop sowing/ reduced crop area/poor crop growth, are observed in central and southern districts of Bihar. More than 20 districts have received deficient rainfall up to 30 October 2013. Also, field visit has shown large number of fallow lands in Gaya and Nawada districts.

VCI of NDVI and NDWI at district level was derived using historic NDVI and NDWI values respectively. Other indicators such as rainfall deviation, area favourable for crop sowing and per cent irrigated area were integrated with VCI through a logical modelling approach to carry out the drought assessment for the kharif season 2013.

Under NADAMS programme, the districts are categorised as Normal, Watch and Alert for the months of June, July and August and for the months of September and October the districts are classified in Normal, Mild drought and Moderate drought category (Fig. 5). For the kharif 2013, considering all of the above mentioned factors five districts of Bihar (Gaya, Luckeesarai, Nawada, Sheikhpura, Vaishali) have been assessed under Moderate drought category, 12 districts (Begusarai, Darbhanga, Jahanabad, Katihar, Madhubani, Muzaffarpur, Patna, Saharsa, Samastipur, Saran, Sheohar, Sitamarhi) under Mild drought category and remaining 20 districts have been assessed under Normal category. This information has been regularly circulated to concerned national and state departments for necessary remedial action.

Fig. 5: Agricultural condition during various months of Kharif 2013.

4. Conclusion

Among the different types of the droughts, agricultural drought poses challenges in monitoring and assessment. This study shows that satellite based indices can be effectively used for monitoring and assessing the agricultural drought. The analysis of NDVI and NDWI and ground observations showed that in the 2013 kharif cropping season, many districts in Bihar were having comparatively poor agricultural condition, though no district had severe drought condition.

Acknowledgement

The authors wish to thank Dr. V.K. Dadhwal, Director, NRSC and Sh. Sanjeev Gupta, Joint Secretary, Government of India for their strong support for this work.

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