Spatio-temporal analysis of the droughts of kharif 2009 and 2002

The performance of the southwest monsoon season was below normal in both 2009 and 2002, causing widespread drought in the country. Drought in 2002 had reduced the sown area to 112 m ha from a normal of 124 m ha, and foodgrain production to 174 mt from 212 mt (www.agricoop.nic.in). On the other hand, there was not much reduction in sown area during 2009–10 (121 m ha) compared to 2008–09 (123 m ha), but foodgrain production reduced to 218 mt (2009–10) from 234 mt (2008–09). Meteorological data on rainfall and the derivatives like aridity generated by India Meteorological Department (IMD) along with seasonal reports generated by the State Departments are most commonly used for drought monitoring and drought declaration. Over the last three decades, satellite data have been successfully utilized in monitoring and assessment of agricultural drought[1]. The National Agricultural Drought Assessment and Monitoring System project of the Indian Space Research Organisation[2] stands as an example for successful application of satellite remote sensing for operational drought assessment. Seasonal progression of satellite-derived Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) are used extensively to characterize the spatio-temporal pattern of drought[3].

The present study is a comparative analysis of two major drought events experienced in kharif 2002 and 2009 using 1 km 16 daily composite products (MOD13A2) of Moderate Resolution Imaging Spectroradiometer (MODIS) satellite. The 16-daily composite images of NDVI and NDWI from June to November for 2009, 2002 and for a normal year (2007/2008) were analysed and the mean values of NDVI and NDWI for each meteorological sub-division were extracted at fortnight and monthly intervals in each year. Selection of normal year for each sub-division was done on the basis of total seasonal rainfall and average yield of cereals, pulses and oilseeds.

The study covered 25 meteorological sub-divisions of IMD spread across 14 states. Kharif 2008 was identified as normal for Punjab (Punjab), Haryana, East Uttar Pradesh (East-UP), West Uttar Pradesh (West-UP), East Madhya Pradesh (East-MP) and West Madhya Pradesh (West-MP), and kharif 2007 was chosen as normal for Bihar, Jharkhand, Chhattisgarh, Orissa, East Rajasthan (East-Raj), West Rajasthan (West-Raj), Gujarat region Daman and DNH (Gujarat), Sourashtra Kutch and Diu (Sourashtra), Vidarbha, Marathwada, Madhya Maharashtra (Madhya-Mah.), Konkan and Goa (Konkan), North Interior Karnataka (NI-Kar), South Interior Karnataka (SI-Kar), Coastal Karnataka (Coastal-Kar), Telangana (Tel-AP), Rayalaseema (Rayal-AP), Coastal Andhra Pradesh (Coastal-AP), Tamil Nadu and Puducherry (TN). Spatio-temporal responses of NDVI/NDWI along with the rainfall pattern of both the years were compared. Similarities and differences in the occurrence and progression of agricultural drought between the two years and the overall seasonal performance were evaluated.

The SW monsoon of 2009 ended with a total rainfall deficiency of 23%, and has become one of the driest years in the recent past. The rainfall deviation in the four climatically homogeneous regions was –36% in Northwest India, –20% in Central India, –27% in East India and –4% in Peninsular India (www.imd.gov.in). The year 2002 was found to be one of the shortest monsoon years with rainfall deviation of –19% from normal at the all-India level. Rainfall deviations of –48% in Northwest India, –31% in Central India, +2% in East India and –27% in Peninsular India from the respective normal were recorded in 2002. Noticeable differences between 2002 and 2009 monsoon lie in the rainfall pattern and its spatial distribution. Very large rainfall deficit was found in June 2009 (–47%) compared to June 2002 (+4%). In July 2009, rainfall was less than normal by 4%, whereas that in 2002 was less by 51% of the normal. Since July is crucial for crop sowing in the entire country, the impact of the huge rainfall deficit in 2002 on crop sown area was high. Subsequently rainfall deficit of –4% and –10% was found in August and September 2002 respectively. Likewise –27% and –21% rainfall deficit was observed in August and September 2009 respectively. Based on the total seasonal rainfall and persistence of deficit/scanty rainfall during different fortnights, the meteorological dryness in 2009 and 2002 can be compared and summarized into three categories as under:

(i) Kharif 2009 was drier than kharif 2002 in 10 meteorological sub-divisions, viz. Jharkhand, Bihar, West-UP, East-UP, Gujarat, Marathwada, Vidarbha, Chhattisgarh, Tel-AP and Rayal-AP sub-divisions. Among these, in five sub-divisions, viz. Jharkhand, Bihar, Marathwada, Vidarbha and Chhattisgarh the rainfall of 2002 was more or less normal. Rest of the five sub-divisions were found to have deficit rainfall during both the years, and 2009 was drier than 2002.

(ii) The year 2009 was found to be better than 2002 in eight sub-divisions, viz. Orissa, West-Raj, East-Raj, TN, NI-Kar, SI-Kar, Coastal-Kar and Konkan. Among these, Konkan and Coastal-Kar are high-rainfall areas, with more than 2000 mm of rainfall even in 2002. Thus rainfall deficit did not have significant impact on agriculture. Normal rainfall was recorded during both the years over West-Raj and East-Raj, and 2009 had more rainfall compared to 2002. In the rest of the four sub-divisions rainfall was normal in 2009 and significantly less than normal in 2002.

(iii) More or less similar rainfall pattern in 2009 and 2002 was found in seven sub-divisions, viz. Punjab, Haryana, West-MP, East-MP, Sourashtra, Madhya-Mah and Coastal-AP. Rainfall was found to be normal during both the years over Madhya-Mah sub-division. Sourashtra received more than normal rainfall during both the years. Rainfall during both the years was significantly less than normal in the rest of the five sub-divisions.

Comparative analysis of MODIS-derived NDWI for 2002 and 2009 was carried out to detect changes in the sowing period surface dryness/wetness. Higher NDWI values during the sowing period reflect more favourable conditions for sowing and vice versa. Surface wetness as indicated by NDWI, was very low till the first fortnight of July during both the years causing hindrance to the progression of sowing. As a result, the crop sown area was significantly less than normal up to the first fortnight of July in both the years. During the second fortnight of July 2009, the NDWI values increased by a significant proportion, although they continued to be less than normal in all the sub-divisions. Such an increase in 2002 was less pronounced compared to 2009, indicating continued dry conditions in 2002. The sub-division-wise NDWI profiles during the sowing period (second fortnight of June to first fortnight of August) for 2009, 2002 and a normal year revealed three distinct patterns: (i) Lower NDWI in both 2009 and 2002 indicating reduced surface wetness and equally unfavourable conditions for sowing in both the years (Tel-AP, Rayal-AP and Coastal-AP sub-divisions); (ii) NDWI values of 2009 were marginally higher than those of 2002, but less than normal, signifying slightly better sowing period agricultural situation in 2009 compared to 2002 (Orissa, Sourashtra, East-MP, West-MP, East-UP, Coastal-Kar, Konkan sub-divisions); (iii) NDWI values of 2009 were significantly higher than those of 2002, but less than normal (East-Raj, West-Raj, Haryana, West-UP, Jharkhand, Gujarat, Chhattisgarh, Marathwada, Madhya-Mah, TN and Vidarbha sub-divisions). In Bihar, NDWI values of 2009 were found to be less than those of 2002. As rainfall in Bihar during 2002 was normal, it needs to be inferred that the sowing period agricultural situation was less than normal in 2009.

NDVI integrated over the second fortnight of July and first fortnight of August represents the greenness of agricultural vegetation at the end of the sowing period. Timely completion of sowing and normal crop progression immediately after sowing results in higher values of integrated NDVI. End-of-sowing-period greenness of 2009, 2002 and a normal year were compared. NDVI anomalies from normal were computed for 2009 and 2002 (Figure 1). Sowing-period NDVI anomalies of 2002 were found to be much higher compared to those of 2009 in most of the sub-divisions. This indicates that the sowing-period agricultural drought intensity in kharif 2002 was more, leading to further delayed sowing or reduction in crop sown area compared to that of kharif 2009. In Gujarat, Sourashtra, East-Raj, West-Raj, Haryana, Punjab, East-MP, West-MP, Vidarbha and Madhya-Mah sub-divisions, the anomalies were higher reflecting more intense agricultural drought conditions in 2002. This was due to faster recovery of soil wetness conditions in 2009 caused by significant rainfall during the second fortnight of July. Equally intensive sowing-period drought conditions in both the years were found in Rayal-AP, Coastal-AP and Tel-AP sub-divisions. No significant anomalies were evident in both the years over TN, Jharkhand, Bihar, Orissa and Coastal-Kar sub-divisions.

Growing period crop condition was assessed using NDVI integrated over active crop growing period, i.e. during August and September. Integrated NDVI images for 2002, 2009 and a normal year were generated and analysed. Difference image of integrated NDVI (2009 minus 2002) is shown in Figure 2. The difference image indicates that in most of the sub-divisions, the integrated NDVI of 2009 was higher than that of 2002, signifying better agricultural situation in kharif 2009. The low integrated NDVI values and negative differences signify either equally intensive or more intensive agricultural drought conditions in large contiguous areas of all three sub-divi-

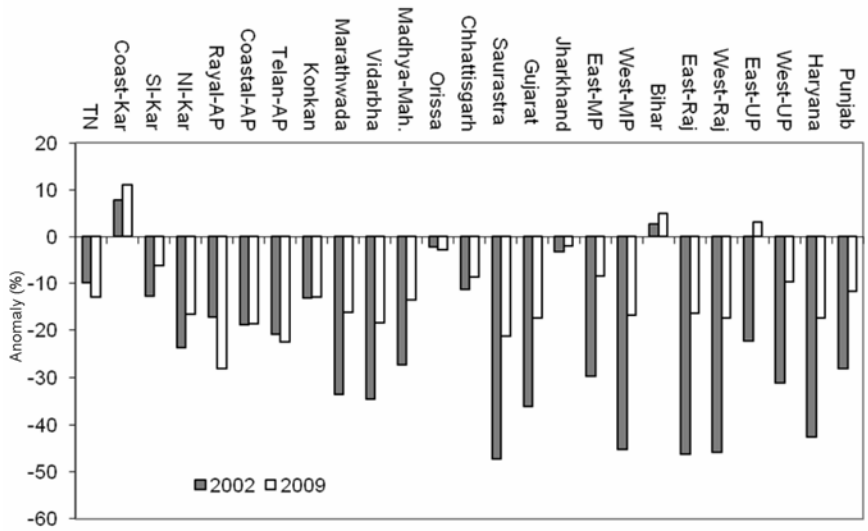

Figure 1. Sowing-period of NDVI anomaly from normal, 2002 versus 2009.

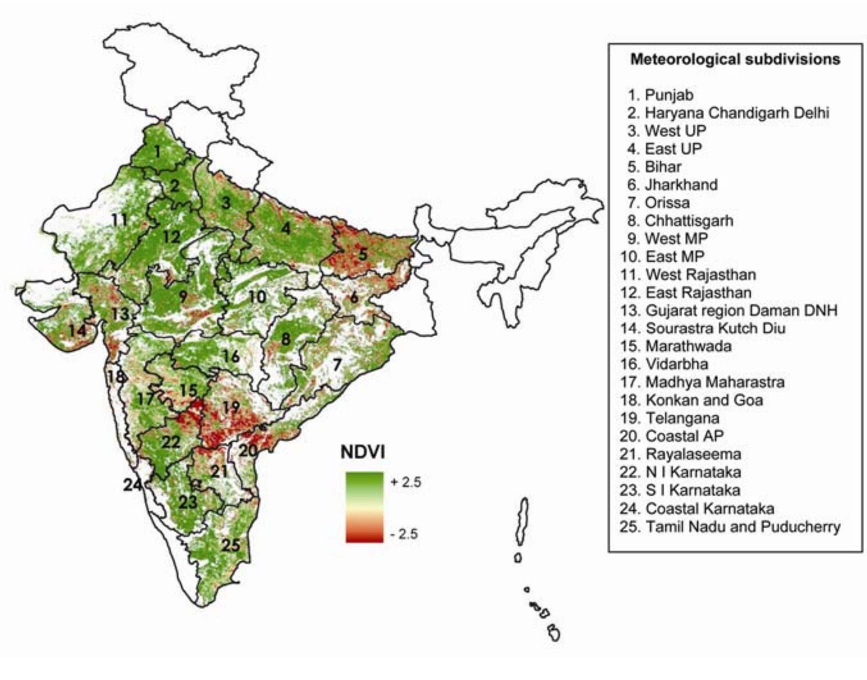

Figure 2. Difference image (2009–2002) of integrated (cumulative) NDVI during crop-growing period (August–September).

sions of Andhra Pradesh and in isolated parts of Gujarat, Sourashtra, NI-Kar, East-UP, West-UP, East-Raj, West-Raj and Jharkhand sub-divisions. Negative values of difference image over Bihar sub-division need to be interpreted differently, since 2002 was a near-normal year in this sub-division. The negative values of difference image in the NI-Kar were caused due to residual cloud cover in the satellite images.

Objective comparisons with geospatial indicators, performed in this study indicate intense agricultural drought situation in the sowing period (up to the first fortnight of July) in both 2009 and 2002 kharif seasons. From the second fortnight of July, the recovery in the situation was faster in 2009, facilitating more crop-sowing in contrast to 2002. End-of-sowing-period crop growth anomalies confirmed more delay/reduction in crop sown area and poor crop growth in 2002 compared to 2009. Active crop-growing period integrated crop condition (NDVI) also revealed more intense agricultural drought conditions in 2002 kharif season compared to kharif 2009. Normal or slightly less than normal agricultural performance in 2009 could be inferred in the sub-divisions of Orissa, Uttar Pradesh, Madhya Pradesh, Punjab, Haryana, Maharashtra, Karnataka and Chhattisgarh, and better than 2002 and less than normal agricultural performance over the sub-divisions of Rajasthan and Gujarat. Equally intensive agricultural drought situation in both the years in all the three sub-divisions of Andhra Pradesh was evident. Agricultural performance of Bihar during kharif 2009 could be slightly less than normal. In Jharkhand, the coarse-resolution geospatial indicators did not show sensitivity because the crop area is isolated and constitutes a small proportion of the geographic area.

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C. S. MURTHY*
ABHISHEK CHAKRABORTY
M. V. R. SESHA SAI
P. S. ROY

National Remote Sensing Centre,
Indian Space Research Organisation,
Hyderabad 500 625, India
**For correspondence.*
e-mail: murthy_cs@nrsc.gov.in

Occurrence of non-protoplasmic mineral deposition in seed coat of *Biota orientalis* Endl. (Cupressaceae)

Biomineralization of calcium crystals is of common occurrence in all photosynthetic organisms from small algae to angiosperms and giant gymnosperms[1]. Calcium oxalate crystals occur in plants in two principal forms, monohydrate ($CaC_2O_4 \cdot H_2O$) and dihydrate ($CaC_2O_4 \cdot 2H_2O$). Each of these has a different crystal structure. The monohydrate form known as whewellite belongs to the monoclinic system of crystallization, and the dihydrate form known as weddellite, belongs to the tetragonal system[2]. The crystals have specific shapes and sizes, and are usually found in the form of prisms, druses, styloids, raphides and crystal sand[3]. Their occurrence and abundance in specific tissues of various plants are so constant that they are often used as a taxonomic tool[4].

Calcium oxalate crystals are found in various plant parts and occur in the cell wall or vacuole within specialized cells called idioblasts. The crystals in the vacuole are formed within the intravacuolar membrane chambers (crystal chambers) that differentiate and proliferate exclusively in the vacuoles of crystal cells[5,6].

In gymnosperms crystals are widely distributed generally in the wood of *Abies magnifica*[7], the bark of *Abies nordmanniana*[8] and *Larix decidua*[8,9], *Picea excelsa*[8,9] , leaves of *Tsuga canadensis*[10], *Ginkgo biloba*[11] and rarely in the seed coat and the nucellus of *Picea abies*[12].

In the present paper occurrence of non-protoplasmic crystal inclusions in the form of solitary crystals, druses and crystal sands in the seed-coat cell layers of *Biota orientalis* Endl., a monotypic genus of Cupressaceae, has been reported and described, and its chemical nature determined. The solitary crystals are of prismatic or styloid type, polyhedral in shape. Druses are mainly found in star or rosette form. All forms of crystals are monohydric calcium oxalate in nature, confirmed by X-ray diffraction (XRD) pattern and energy dispersive X-ray (EDX) analysis.

Fresh, mature seeds of *B. orientalis* Endl. were collected from Nainital (29°N, 79°28′E) and Ranikhet (34°N, 81°02′E), Uttaranchal, North India during the end of November 2008. Cones attached to branches were collected and seeds isolated. Fresh seeds (Figure 1 *a*) were taken for anatomical study and the remainder preserved for maceration and mineralogical observation. The seeds were soaked overnight for softening, and transverse sections of seed coats were made. Maceration of the dry seed coats was done by overnight treatment with conc. nitric acid, washed thoroughly several times to make it acid-free and centrifugation to recover the crystals. Both the thin sections and scattered isolated crystals were observed, studied and photographed under SEM (Leica S440).

EDX analysis (INCA, Oxford Instruments, UK) was done for elemental analysis of the crystals present in the seed coat, following the usual technique. The accelerating voltage used during the analysis was 15 kV. XRD scans for all the samples were taken using the X'pert Pro XRD machine, which is a fully computerized instrument with CuKα radiation. The XRD pattern of each sample was matched with the standard ICDD database installed in the machine. After suitable matching with the standard data,