NEAR REAL-TIME DETECTION OF OCCURRENCE OF DROUGHT STRESS IN NATURAL RUBBER PLANTATIONS USING MODIS TERRA SATELLITE DATA

B. Pradeep and James Jacob
Rubber Research Institute of India, Rubber Board (Ministry of Commerce & Industry, Govt. of India), Kottayam- 686 009, Kerala

We estimated Vegetation Temperature Condition Index (VTCI) of the traditional natural rubber regions of India (namely Kerala state and Kanyakumari district of Tamil Nadu state) for the months of September 2015 and September 2016 using MODIS 11 A2 LST and MODIS 13 A2 NDVI satellite products. Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) data from terra MODIS were used to calculate VTCI which is essentially a proxy indicator of drought stress occurring over large landscapes. Overlay analyses was carried out in GIS platform to generate VTCI of rubber growing regions using a rubber distribution map of the entire region that was earlier developed using satellite images from LISS III.

In September 2016, most parts of the study area, including the natural rubber plantations of Kerala state and Kanyakumari district of Tamil Nadu state experienced widespread drought compared to same time of the previous year. In September 2016, about 29% of the natural rubber holdings experienced drought whereas in September 2015 this was about 19%. During September 2016, severe drought was observed in natural rubber holdings of Kanykaumari and Trivandrum districts, followed by parts of Ernakulam, Idukki, Maplappuram and Northern districts of Kerala. In September 2015, severe drought was confined to natural rubber holdings in parts of Kottayam, Ernakulam and Pathanamthitta districts and Southern and Northern districts of Kerala were largely free from any drought unlike in September 2016. Compared to September 2016, natural rubber plantations in central Kerala (parts of Kottayam, Pathanamthitta and Ernakulam districts) showed significant level of drought in September 2015.

Comparing yield data from growers' fields for September 2015 and 2016, it was found that in those areas where drought was more severe in a year, there was more reduction in yield with respect to the other year that had less severe drought. September, a high rubber yielding time is a highly unlikely month for drought to occur in Kerala, because this month falls between the two monsoon seasons. Yet, in recent years it appears that even in September, significant drought stress occurs in

Kerala and this has been successfully monitored on a near real-time basis using MODIS terra satellite data.

Unseasonal and prolonged rains caused extensive incidences of Abnormal Leaf Fall disease in recent past which was also successfully monitored using satellite-based images. Identification of new locations where natural rubber can be cultivated without causing deforestation and conversion of food crops is another area of application of geospatial technology developed by us. We have developed GIS-based natural rubber distribution map of India with 96% accuracy and this gives us the ability to monitor future changes in the natural rubber landscape of the country. These applications of geospatial technology can be extended to natural rubber plantations in any part of the globe regardless of geographic boundaries.

Keywords: Drought, LST, MODIS, NDVI, natural rubber, remote sensing.
Correspondence: pradeep@rubberboard.org.in

INTRODUCTION

Droughts are considered to be one of the major natural hazards causing destructive impact on the environment as well as the economy of countries throughout the world. Drought is a deficiency in precipitation over an extended period, usually a season or more, resulting in a water shortage causing adverse impacts on vegetation, animals and or people (NOAA, 2008). Therefore monitoring drought especially in agriculture field is very vital for preparedness, early warning and management of different agricultural crops time to time.

Traditional methods of agricultural drought monitoring is purely based on climate data (rainfall) which had many limitations like network of meteorological stations, difficult to obtain data in near real time both spatially and temporally (Himanshu, *et al*., 2015). To overcome these difficulties satellite-based remote sensing technology has been revolutionary to greatly enhance the ability to monitor and manage the natural resources, including climate change and agricultural drought. Among many remote sensing techniques based drought monitoring, the normalized difference vegetation index (NDVI) and land surface temperature (LST) are two useful indices for monitoring the intensity, duration and impact of drought on regional or global level

(Singh *et al*., 2003). Wan, *et al*. (2004) and Parida (2006) reported the use of thermal radiation from the earth surface (in the infrared wavelength of the electromagnetic spectrum) for monitoring drought. Vegetation Temperature Condition Index (VTCI) is an indicator for drought, which combines information on the condition of vegetation (as assessed by NDVI) and land surface temperature, indirectly reflecting evapotranspiration from the landscape (Wang *et al*., 2001). Vegetation-LST relationships and the use of temperature-related drought indices were studied by Sun and Kafatos (2007). MODIS LST and NDVI products were used to generate the VTCI for monitoring drought (Wan *et al*., 2004 and Tian *et al*., 2016). Development of South Asia drought monitoring system by International Water Management Institute (IWMI), Colombo, Sri Lanka and National Agricultural Drought Assessment and Monitoring System (NADAMS) by National Remote Sensing Centre (NRSC), Indian Space Research Organization are typical examples of near real time drought monitoring at regional scale (IWMI, 2015 and NRSC, 2012).

The unlikely month of September of the current year experienced high temperature and drought stress in Kerala and Kanyakumari districts of Tamil Nadu, the traditional rubber growing region of India. This region experienced a reduction of annual monsoon by about 34% over the long term mean. Year 2016 is officially declared as drought affected year in Kerala by the state government. In the present study, using LST and NDVI data from MODIS terra satellite, we estimated VTCI. We monitored drought affected areas under natural rubber cultivation and estimated the extent of area of rubber plantations affected by drought stress in the traditional rubber growing regions of India for September 2016 and compared with September 2015.

STUDY AREA

The study area covered natural rubber growing regions of Kerala state and Kanyakumari district of Tamil Nadu state of India. This lies between 74^{o} 48' 33.10"E to 77^{o} 38' 35.43"E longitudes and 7^{o} 58' 56.27"N to 12^{o} 53' 19.11"N latitudes, covering a total geographic area of 40550.6 Sq. km. This area is characterized by highly undulating topography and elevation ranging up to 2692m above MSL. The annual rainfall ranges from 2000-5000 mm with an average of 3000 mm. Soils are mainly laterite and lateritic. Physiography of the study area is such that on eastern side covered with high land Western Ghats and on western side with coastal low land. The study area can be divided into lowland, midland and highland and rubber plantations are mainly cultivated in the midland and lower reaches of the highland regions. Study area map is given in Fig. 1.

METHODOLOGY

Geo-spatial mapping of rubber plantations

Administrative boundary was digitized from geo-referenced Survey of India toposheet of scale 1: 2,50,000 covering study area. Indian Remote Sensing (IRS) P6 LISS III scenes of the year 2012 and 2013 covering Kerala state and Kanyakumari district of Tamil Nadu were used for the delineation of NR area. Satellite acquisition dates were selected corresponding to complete re-foliation period of NR (February - March). Details of satellite data used for rubber plantation mapping are given in Table 1. Rubber trees being deciduous sheds leaf and re-foliate immediately, whereas other deciduous trees do not. Hence NR during this period shows distinct signature particularly in infrared band compared to other vegetation. Wherever district covers more than one satellite scenes then scenes were mosaic and clipped using district boundary. District satellite images were classified using K means clustering (minimum distance) algorithm in GIS environment. Four bands of IRS P6 LISS III and Normalized Difference Vegetation Index (NDVI) generated using band 2 and 3 were taken as inputs for image classification. Bitmap covering forests and low-lying areas was generated using toposheet and Google Earth and used as mask during classification. Using the ground knowledge, GPS readings of major vegetation classes and unique signature of NR and other vegetation, different spectral classes were aggregated into NR, mixed vegetation, paddy, water body and town/built up area. GPS readings (Garmin- Oregon 550) collected from dominant land use classes in each district were used as test point for accuracy assessment of classified image and generated accuracy assessment report for each district. Total 900 test points were taken for ground truth information from NR plantations and other land use land cover of the study area. Using raster to vector conversion tool, district-wise rubber area was extracted and further used for geo-spatial overlay analysis in GIS environment for estimating extent of rubber area under VTCI classes. Software used for image processing and analysis were ArcGIS v.10 and Rolta Geomatica v.10.3.1. Methodology of estimating VTCI is given below.

Estimation of Vegetation Temperature Condition Index (VTCI)

The satellite data used for the calculation of VTCI is MODIS 11 A2 Land surface temperature (LST) and MODIS 13 A2 normalized difference vegetation index (NDVI) of corresponding time period for the month of September 2015 and 2016. Satellite image pre-processing such as conversion of file format, layer stacking, re-projection, multiplication with scale factor, sub-setting of study area were carried out prior to VTCI calculation. As the study area fell in two different tiles of MODIS data, these data were mosaicked and then re-projected to UTM WGS 1984. After re-projection, the MODIS LST and NDVI data were multiplied with a scale factor. VTCI is a near real time drought monitoring indicator derived from Terra MODIS NDVI and LST products. VTCI is defined as the ratio of LST differences among pixels with a specific NDVI value in a sufficiently large study area (Wang, et al., 2001).

$$VTCI = \frac{LST_{NDVImax} - LST_{NDVIi}}{LST_{NDVImax} - LST_{NDVImin}}$$

Where,

$LST_{NDVImax} = a + b\ NDVIi$

$LST_{NDVImin} = a' + b'\ NDVIi$

LST_{NDVIi} denotes LST of pixel whose NDVI value is NDVIi.

a, b, a' and b' are co-efficients derived from the regression equation

Here, $LST_{NDVImax}$ is the maximum LST and $LST_{NDVImin}$ is the minimum LST among pixels having the same NDVI value in the study area. The value of VTCI ranges from 0-1, the lower the value of VTCI, the higher the severity of drought and vice versa. VTCI approach was proposed for monitoring drought occurrence at a regional level (Wang et al. 2001). VTCI was calculated using regression equations of maximum and minimum LST value in each NDVI classes. Details of satellite data used for VTCI estimation is given in Table 2.

RESULTS AND DISCUSSION

LISS III satellite image based rubber plantation area mapping (age three years and above) of the study area as of the year 2012-2013 was 5, 58,599 ha. Spatial distribution of rubber growing areas of Kerala and Kanyakumari district of Tamil Nadu is given in Fig. 2. Analyses of rubber area under different VTCI classes were generated using overlay analyses. VTCI ranging from 0 to1 has been categorized into four different classes with an interval of 0 to 0.30, 0.31 to 0.50, 0.51 to 0.70 and 0.71 to 1. The smaller the VTCI, the more the drought stress and thus, the lowest class of 0 to 0.30 will be the region severely droughts and the class 0.71 to 1.0 will be low drought stress region. VTCI of Kerala and Kanyakumari district of Tamil Nadu for the years September 2015 and September 2016 are given in Fig. 3.

During September 2016, severe drought was observed in the natural rubber growing regions of Kanykaumari and Trivandrum districts, followed by some parts of Ernakulam, Idukki, Maplappuram and Northern districts of Kerala. In September 2015, severity of drought was confined to parts of Kottayam, Ernakulam and Pathanamthitta districts and southern and northern regions were free from any drought unlike in September 2016. Compared to September 2016 rubber growing regions of central Kerala (parts of Kottayam, Pathanamthitta and Ernakulam districts) showed significant level of drought in September 2015.

In September 2016, most parts of the study area, including the rubber growing regions of Kerala and Kanyakumari district of Tamil Nadu experienced widespread drought compared to September 2015. VTCI of rubber growing regions of the study area is given in Fig. 4. Study found that in September 2016, about 29% of rubber growing regions experienced drought whereas in September 2015 this was only about 19% (Fig. 5). VTCI classes of 0.31 to 0.5 and 0.51 to 0.7 for September 2016 and September 2015 were showed almost same per cent area of rubber under stress but per cent area of rubber under VTCI class 0.71 to 1 was highest in September 2016 than 2015 (Fig. 5). A report on drought monitoring of rubber growing areas of the study area for the year march 2010 found that 8.36 per cent of total rubber area of Kerala state and Kanyakumari district was under drought stress (Shebin *et al*., 2014).

CONCLUSION

Study shows the utility of MODIS terra satellite data for near real time monitoring of drought in traditional rubber growing regions in India. Results clearly indicated that the intensity of drought in rubber plantation across Kerala state and Kanyakumari district of Tamil Nadu was high in 2016 compared to year 2015. Extent of area under rubber plantations that experienced different levels of drought can be monitored by analysing near real time LST and NDVI. The present study revealed an increase of drought affected rubber area by about 10 per cent from the year 2015 to 2016 during September. Comparing yield data from growers' fields for September 2015 and 2016, it was found that in those areas where drought was more severe in a year, there was more reduction in yield with respect to the other year with less severe drought. September is a highly unlikely month for drought to occur in Kerala, because this month falls between the two monsoon seasons. Yet, in recent years it appears that even in September, significant drought stress occurs in Kerala which is successfully monitored on a near-real time basis using MODIS terra satellite data.

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Table 1. Details of satellite data used for rubber plantation mapping

Satellite & Sensor	Resourcesat 1, LISS III *Resourcesat II, LISS III	Date of acquisition	Path-Row
		3^{rd} Mar. 2013 (*R II)	100 – 67
		25^{th} Mar. 2012	101 – 68
		25^{th} Feb. 2012	100 – 68
		20^{th} Feb. 2012	99 – 67
		20^{th} Feb. 2012	99 – 66
		20^{th} Feb. 2012	99 – 65
		5^{th} Mar. 2013	98 – 65
		5^{th} Mar. 2013	98 – 64
		29^{th} Mar.2013	98 – 63
		28^{th} Feb.2013	97 – 64
		24^{th} Mar. 2013	97 – 63
		2^{nd} Mar. 2011	100 – 67
		1^{st} Feb. 2011	99 – 67
		1^{st} Feb. 2011	99 – 66

Table 2. Details of satellite data used for VTCI estimation

MODIS Acquisition date	
11A2 LST	13A2 NDVI
29/ 09/2016	29/ 09/2016
22/ 09/2015	22/ 09/2015

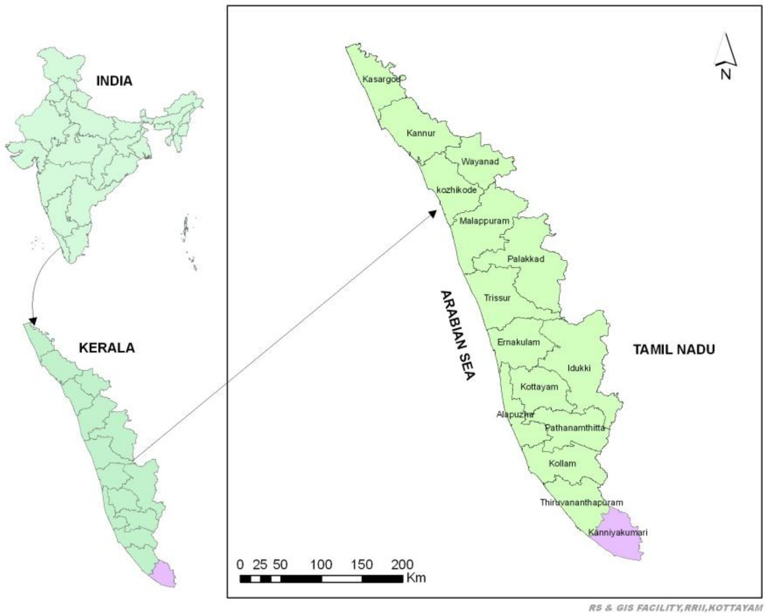

Fig. 1. Study area location

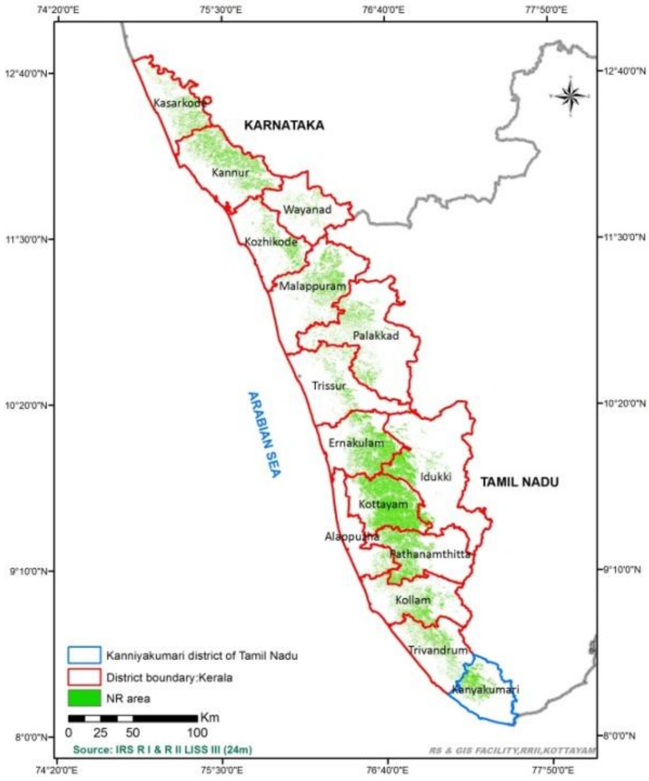

Fig. 2. Geo-spatial distribution of NR growing areas (age three years and above) in Kerala state and Kanyakumari district of Tamil Nadu state for the year 2012-2013

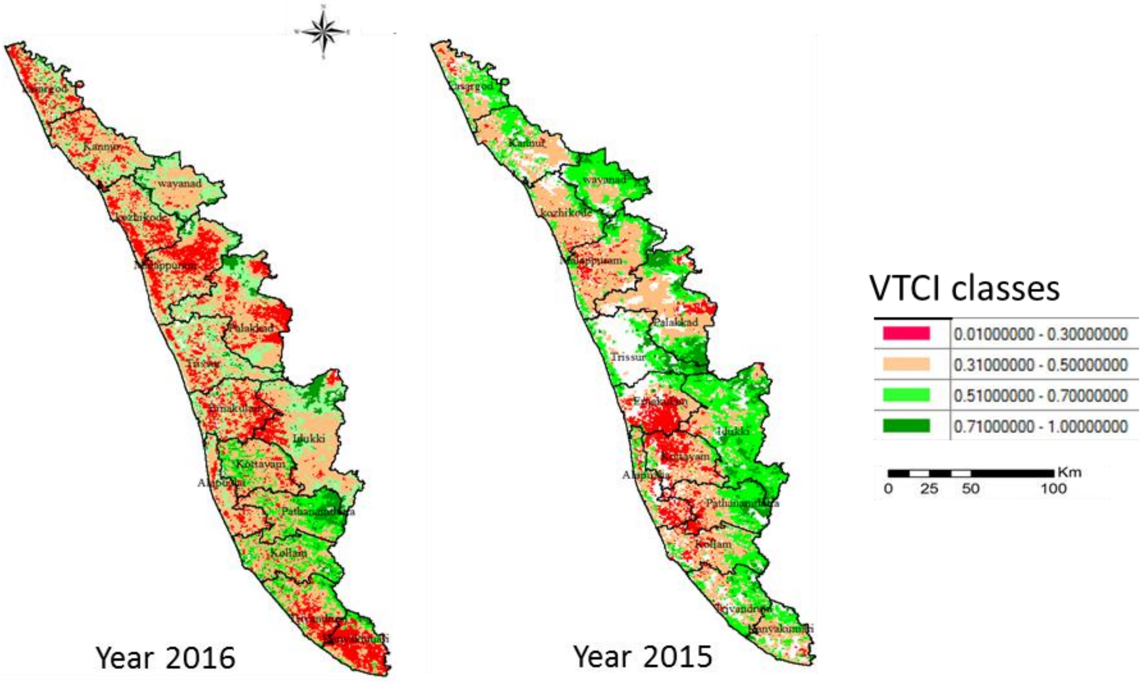

Fig. 3. VTCI of Kerala state and Kanyakumari district of Tamil Nadu state for September 2016 and September 2015

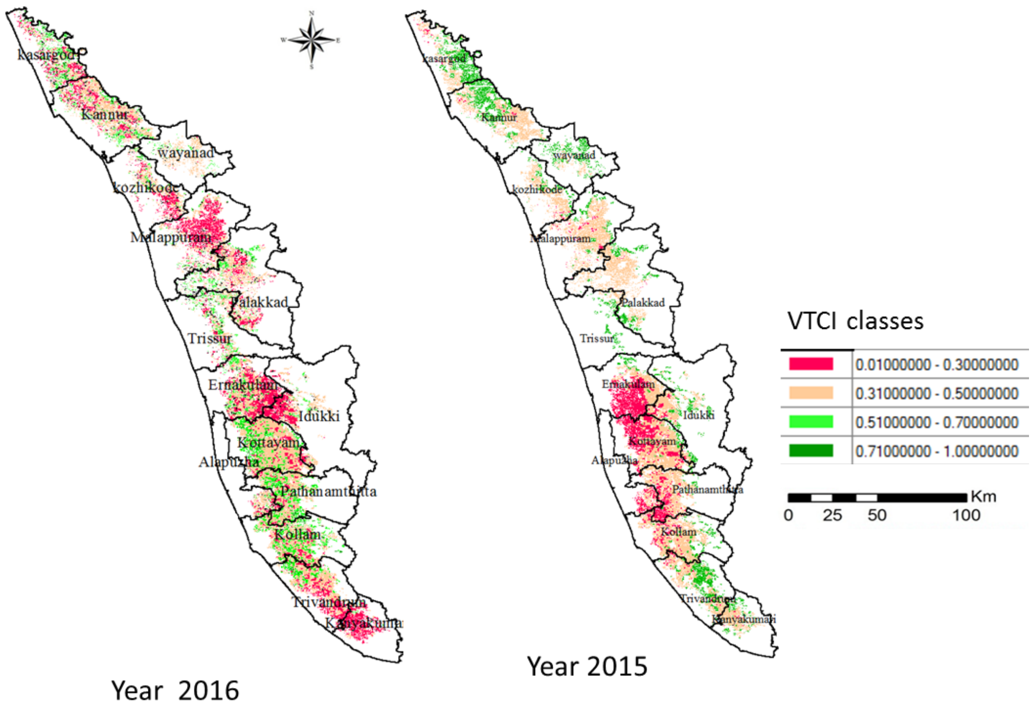

Fig. 4. VTCI of rubber growing regions of Kerala state and Kanyakumari district of Tamil Nadu state for September 2016 and September 2015

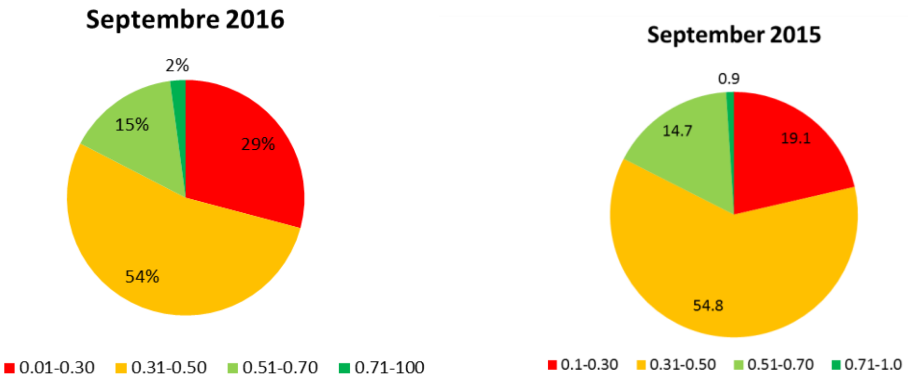

Fig. 5. Per cent NR area under different VTCI classes for Kerala state and Kanyakumari district of Tamil Nadu state for the year September 2016 and September 2015